AN ANALYSIS OF LATE PROTEROZOIC - EARLY CAMBRIAN MICROFOSSILS AND BIOSTRATIGRAPHY IN CHINA AND AUSTRALIA

by

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This thesis is my own work except where specifically acknowledged.

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Abstract

It is well known that Late Proterozoic and Early Cambrian microfossils probably lived in aqueous or semi-aqueous environments. Analogy with modern aqueous phytomicroorganisms suggests that water depth, temperature, distance from the shore, prevailing currents, salinity and other factors influenced their abundance and diversity. Consequently microfossil assemblages are of significance in interpreting depositional environments, as well as for evolutionary study and biostratigraphic correlation.

The samples in this research are collected from the Upper Proterozoic to Cambrian sequences in northern Anhui and Jiangsu Provinces, central eastern China; the South China Platform; and the Amadeus Basin, central Australia. Each region has been described in separate chapters.

The Upper Proterozoic and Lower Cambrian sequences in the northern Anhui and Jiangsu Provinces, central eastern China are named the Huainan and Huaibei Groups. Palaeoenvironmental investigations combine the data from outcrops, rock thin sections, stable isotope analyses and microbiota. Seven lithofacies have been described. They are flat-bedded limestone, stromatolitic limestone, clastic limestone, interbedded clastic dolomites and shales, interbedded shales, limestones and sandstones, lower flat and cross-bedded sandstones, and ferruginous conglomerate.

There is considerable interest in the Liulaobei Formation of the Huainan Group, because it contains possible metazoan fossils. It is considered to have been deposited in a shallow marine shelf environment. The shales and siltstones from the lower part are dominantly flat bedded; these grade regressively to the upper cross-bedded silty limestones and sandstones. The greatest abundance and diversity of microfossils occurs in the lower part of the formation which is interpreted as having been deposited in a relatively deeper water environment. The *Chuaria - Tawuia* assemblage which occurs in the Liulaobei Formation has been considered biostratigraphically useful. However, the assemblage seems to range from the Middle Proterozoic to Early Cambrian and the value for biostratigraphic correlation is limited.

The Liulaobei Formation has been considered by various workers to be pre-Sinian, Sinian and Early Cambrian. The microfossil study suggests the formation is most likely to be late Sinian (Ediacarian). The Gouhou Formation was previously considered as the late Sinian, but here is considered to be Early Cambrian.

The diversity of the microfossils in the Early Cambrian on the South China Platform is remarkable. The assemblage is dominated by abundant spinose acritarchs of the genera *Skiagia, Baltisphaeridium, Goniosphaeridium, Liepaina, Comasphaeridium* and others. This assemblage has a cosmopolitan distribution.

Microfossil investigation in the Amadeus Basin of central Australia has allowed the recognition of three assemblages from the Late Proterozoic to the Cambrian. The assemblage from the early Late Proterozoic Gillen Member (Bitter Springs Fromation) is dominated by spheroidal acritarchs and contains many spinose forms, such as *Skiagia, Comosphaeridium, Trachyhystrichosphaera* and *Micrhystridium.* The Ediacarian Pertatataka Formation is a turbiditic deposit from a submarine fan. The pelagic assemblage from the turbidite consists mainly of morphologically complex, very large acritarchs, and a gradual increase in the diversity of the spinose acritarchs from the lower part to the upper part of the formation has been observed. The assemblage from the Middle Cambrian Tempe Formation varies in different samples in relation to local depositional emergence of the shallow water environment.

The studied microfossils can be related to four depositional environments. The assemblage from the open coastal and nearshore shelf environment increases its diversity and abundance from inshore to offshore; spinose plankters occur more frequently with increasing distance from the shore; and acritarchs are morphologically more complex in offshore conditions. Spheroidal microfossils seem to be distributed from inshore to offshore environments. Cyanobacterial filaments are widely distributed on tidal flats, and decrease in abundance with increasing distance from the shore. The assemblage from the offshore or pelagic turbidite deposits consists of the most abundant large, diverse and morphologically complex plankters. The assemblage from the hypersaline lagoons is of low diversity, usually dominated by one or a few taxa, and filamentous cyanobacteria are common. The assemblage from non-marine saline lakes and ponds is dominated by benthic microorganisms.

Occurrences of megascopic algal fossils in China and elsewhere indicate that a few species occurred at several localities in the Middle Proterozoic and that diversity increased at the end of the Middle Proterozoic or early in the Late Proterozoic. They decreased in diversity at the time of the Late Proterozoic glaciations. Diverse assemblages occurred again in the late Ediacarian; most taxa are vendotaenides. The Early Cambrian mega-algal fossils are similar to those of the Ediacarian.

Three plankton radiations have been recorded from the Late Proterozoic to the Early

Cambrian. Initial radiation in the early Late Proterozoic is followed by a decrease in diversity at the time of the widespread Late Proterozoic glaciations; a gradual increase in diversity has been observed in the early Ediacarian sequences, and this radiation is succeeded by the another decrease across the Proterozoic - Cambrian transition. The Early Cambrian radiation rises from the trilobite *Eoredlichia - Wutingaspis* Zone or *Holmia* Zone. These evolutionary events may related to global geochemical events such as rising oxygen levels and prevailing deposition of phosphate minerals.

Seventy-six genera have been described, sixteen of which are new and one is emended, including one hundred and sixty species, sixty-seven of which are new and seven are emended.

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Chapter 1

INTRODUCTION

The Acritarcha (Evitt, 1963A; Downie, et al., 1963) is a group of microfossils of unknown affinities, and probably represents the reproductive stages of cyanobacterial and algal cysts or spores. They are organic-walled, empty or deformed sheaths and can be observed in acid-resistant residues on slides or in rock thin sections.

Though their taxonomic affinities are uncertain, we still have good reason to study these microfossils. They may represent the first organisms and provide man with knowledge of the origin and early history of life. The study has extended mankind's knowledge of procaryotic microorganisms to 3500 Ma (million years) ago (Awramik et al., 1983). Because of environmental restriction on the microorganisms preserved in cherts, the microfossils in detrital rocks may be a better assemblage among which to search for evidence of Proterozoic evolutionary innovations (Knoll et al, 1981). The microfossils preserved in shales have provided some of the least debatable evidence for early eucaryotes (Schopf and Oehler, 1976), and have prompted speculation about gigantism among cyanobacteria (Peat et al., 1978). Acritarchs in Proterozoic detrital rocks can be at least as useful biostratigraphically and environmentally (Timofeev, 1959, 1966, 1969, 1973; Timofeev et al., 1976; Vidal, 1976, 1981; Vidal and Knoll, 1982, 1983; Sin et al., 1973; Volkova, 1969; Volkova et al., 1979; Downie, 1982; Vidal and Ford, 1985) as stromatolites in the calcareous facies.

During the last thirty years, microfossil investigation has succeeded in filling several basic gaps in our knowledge of the early history of microorganisms in the Proterozoic. These important results were attained in spite of the fact that the application of micropalaeontological methods in Proterozoic or Archaean rocks encounters considerably greater difficulties than in Palaeozoic rocks. It is to the mid-1950's that the spectacular developments in Proterozoic micropalaeontology can be traced. Timofeev

(1959) published his paper on the microphytological investigation of the Proterozoic and Early Palaeozoic sequences in the Soviet Union. He considered that some microfossils had a tetrahedral scar, but he corrected this misunderstanding in his later papers. Since then many contributions have been published in search for the evidence of acritarchs, in which were named many new genera and species. Vidal (1976) set an excellent example for the study of the microfossils from the Visingsö Beds in Sweden. Volkova et al. (1979) summarized information on the Cambrian acritarchs on the East European Platform. Lindgren (1981, 1982) undertook a detailed study of *Leiosphaeridia* Eisenack, 1958. He considered that *Leiosphaeridia* is a form-taxon of heterogenous composition, without indication of possible relationship to modern algae, and thus must be classified in an artificial taxonomic system. Vidal and Knoll, after studying acritarchs from the Soviet Union, Sweden, China, the United States, and other localities, proposed several microfossil assemblages from the Upper Riphean to Early Cambrian for biostratigraphic correlation (Vidal, 1981; Vidal and Knoll, 1982, 1983).

The palaeobotanical school, in comparison with the above mentioned school studying microfossils for biostratigraphic correlation, has successfully investigated microfossils preserved in cherts from many units, including the Gunflint (Barghoorn and Tyler, 1965) and Bitter Springs Formations (Schopf, 1968; Schopf and Blacic, 1971). Scientists in this school emphasize biological interpretation of microfossils and employ taxonomic systems erected for modern microorganisms (Knoll, 1984). Diver and Peat (1979) considered the division between the two schools is not absolute and an improved picture of Proterozoic microorganisms needs them to be combined. Knoll (1984) reported an assemblage of plankton from the chert facies of the Upper Riphean Hunning Formation, Svalbard. Most of the morphologically complex acritarchs in the Sinian Doushantuo Formation, the Yangtze Gorges are found in the chert or phosphorite thin sections (Yin Leiming and Li Zaiping, 1978; Zhang Zhongying, 1984; Yin Leiming, 1985; Awramik et al., 1985; Chen Meng'e et al., 1986). The project in this thesis is mainly restricted to the investigation of acritarchs from maceration.

1.1. Review of Investigation on the Proterozoic Acritarchs in China and Australia

The first paper on Proterozoic acritarchs in China was published in 1973 when Sin and Liu undertook a systematic investigation of Proterozoic sequences in the Yenliao region, northern China. They considered that the microfossil assemblage from the Chuanlinggou Formation could be correlated with that of the lower and middle parts of the Riphean System in the southern Urals and the Diabaig Formation of the Torridonian series in Scotland; and the assemblage from the Xiamaling (Hsiamaling) Formation with that of the Valdai Series on the Russian Platform.

Ouyang Shu et al. (1974) described Sinian and Cambrian microfossils from southwestern China and started the micropalaeontological investigation of the Sinian System (800-600 Ma). Following this, Xing Yusheng and Liu (1978), Yin Leiming and Li (1978), Zhao Ziqiang et al. (1980), Wang Fuxing et al. (1982, 1983, 1987), Wang Fuxing (1985), Yin Leiming (1986a, 1986b, 1987) and others published work on more than one hundred microfossil forms. Yin Leiming and Li Zaiping (1978) described 26 genera, 71 species, and 11 confer species, of them, 22 are new, including some large spinose acritarchs from chert thin sections of the Sinian Doushantuo Formation in southern China. Many other acritarchs have been reported from the chert and phosphorite sections in the Doushantuo Formation recently (Zhang Zhongying, 1982, 1984, 1986; Awramik et al., 1985; Chen Meng'e and Liu Kuiwu, 1986; Zhang Yun, 1987).

The Upper Proterozoic sequences in northern Anhui and Jiangsu Provinces of the central-east China are well investigated micropalaeontologically. Yang Qinghe et al. (1980) used microfossil assemblages to correlate and subdivide the Proterozoic sequences in this region. Yan Yongkui (1982) studied microfossil assemblages from the Liulaobei Formation and considered the assemblage represented a transitional micropalaeoflora from the Qingbeikouan (800-1000 Ma) to the Sinian Systems. Similar results have been reached by Yin Chongyu (1985) and Yan Yongkui (1984). Yin Leiming (1983) investigated the microfossils from the Diaoyutai Formation in Liaoning, northern China, and the Liulaobei Formation in Anhui, and he found the assemblages from the two formations could be correlated and indicated an age of about 750-850 Ma. The microfossils in cherts from this region contain filamentous and spheroidal forms (Zhang Zhongying and Yang Yongkui, 1984).

Proterozoic sequences in the Jixian region of northern China contain productive shales and cherts. Chen Jinbiao et al. (1980) reported 34 genera including 97 species from the sequences. Yan Yuzhong (1982) described fusiform acritarch *Schizofusa sinica* from the Chuanlinggou Formation (1800 Ma?) and he (1985) reported many more forms again from the same formation, including 23 genera and 71 species. Yin Leiming (1985) described an assemblage from the Dahongyu Formation (1678 Ma?). Microfossils from cherts in the sequences have been extensively investigated (Zhang Yun, 1981, 1985, 1988; Zhu Shixing, 1982b; Liu Chili, 1982).

Xing Yusheng and Liu Kuizhi (1982) concluded that the microfossils from the Changcheng System (1800-1400 Ma) were mainly simple, small procaryotes; in the Jixian System (1000-1400 Ma) appeared eucaryotic microfossils; and the Qingbeikouan and Sinian Systems are characterized by large forms (50-100*um* in diameter) and occurrence of some morphologically complex forms such as *Micrhystridium.*

Proterozoic microfossil investigations in Australia are mainly from chert facies (e.g. Schopf, 1968; Schopf and Blacic, 1971; Oehler, J., 1977; Oehler, D., 1978). Only a few papers concern the microfossils from shale facies. Peat et al. (1978) reported a microfossil assemblage from the Middle Proterozoic Roper Group (approximate age: 1500 Ma), and the assemblage from the McMinn Formation of that group includes algal cells and filaments, large acritarchs and giant filaments of uncertain affinity. They considered that the assemblage was very advanced for its geological age and some specimens with a probable life cycle and a example of endospory might be indicative of eucaryotic affinities.

Damassa and Knoll (1986) investigated the microfossils from the Ediacarian Arcoona Quartzite Member of the Tent Hill Formation, Stuart Shelf, South Australia. The microfossils consist of leiosphaerid acritarchs and cyanobacterial filaments, which they considered may provide biostratigraphic characterization of sequences containing the earliest invertebrate biota, because they found the microfossil assemblage differed from phytoplankton assemblages of both Late Riphean and Cambrian age distributed in many other parts of the world.

Upper Proterozoic and Lower Cambrian sequences in China and Australia are widely distributed and not metamorphosed. The sequences from three main regions in the two countries were sampled for microfossil investigation in this study. They are northern Anhui and Jiangsu Provinces in central-eastern China, the South China Platform (or the Yangtze Block or Platform), and the Amadeus Basin in central Australia. More than five hundred samples have been collected and processed, and more than five thousand negatives have been taken for prints. The data used in the thesis are housed in the Commonwealth Palaeontological Collections of the Bureau of Mineral Resources, Canberra ACT, Australia.

1.2. Discussion of Maceration Methods

Maceration methods have been discussed by many investigators. Vidal (1976) described them in detail. Usually, a sample is dissolved with HCL, HF, and HNO_3, then sieved or floated in heavy liquids, and mounted on slides for microscopic examination.

Samples must be prepared carefully without contamination. At the first step we need to crush rocks to small pieces (shales 30--80g., siltstones 90--150g). Because some of the microfossils are relatively large, some spheroids with diameters more than 500-600*u*m or larger and filaments thousands of microns in length, rock samples not smaller than 1mm would be suitable for processing.

Recently, filters have been widely used in the laboratory to sieve samples, since disadvantages exist in using heavy liquids to float organic matter and many organic fragments are left in samples, making photographic work difficult. It should be noted what mesh diameter sieve was used. Vidal (1976) used a sieve with 20*u*m mesh diameter, but many microfossils in the Proterozoic have a diameter less than 20*u*m. More than two thousand nine hundred specimens were counted from the Late Proterozoic Liulaobei Formation from northern Anhui, China (samples were not sieved), and nearly thirty precent of them are smaller than 20*u*m. Some species, such as *Micrhystridium* spp., *Pyritosphaera barbaria* (=*Bavlinella faveolata* (Shepeleva) Vidal, 1976), *Ambiguaspora parvula* Volkova, 1976, *Lophosphaeridium tuberosum* etc., are usually small, but they play an important role in eucaryotic evolution and biostratigraphic correlation. This indicates that a sieve with smaller diameter should be used. In this research a 10*u*m-diameter sieve sometimes has been used.

This thesis has been written as a series of separate chapters. As a result some data are repeated several times so that each chapter can be considered as a coherent piece of work.

Chapter 2

LATE PROTEROZOIC AND EARLY CAMBRIAN MICROFOSSILS FROM NORTHERN ANHUI AND JIANGSU, CENTRAL EASTERN CHINA

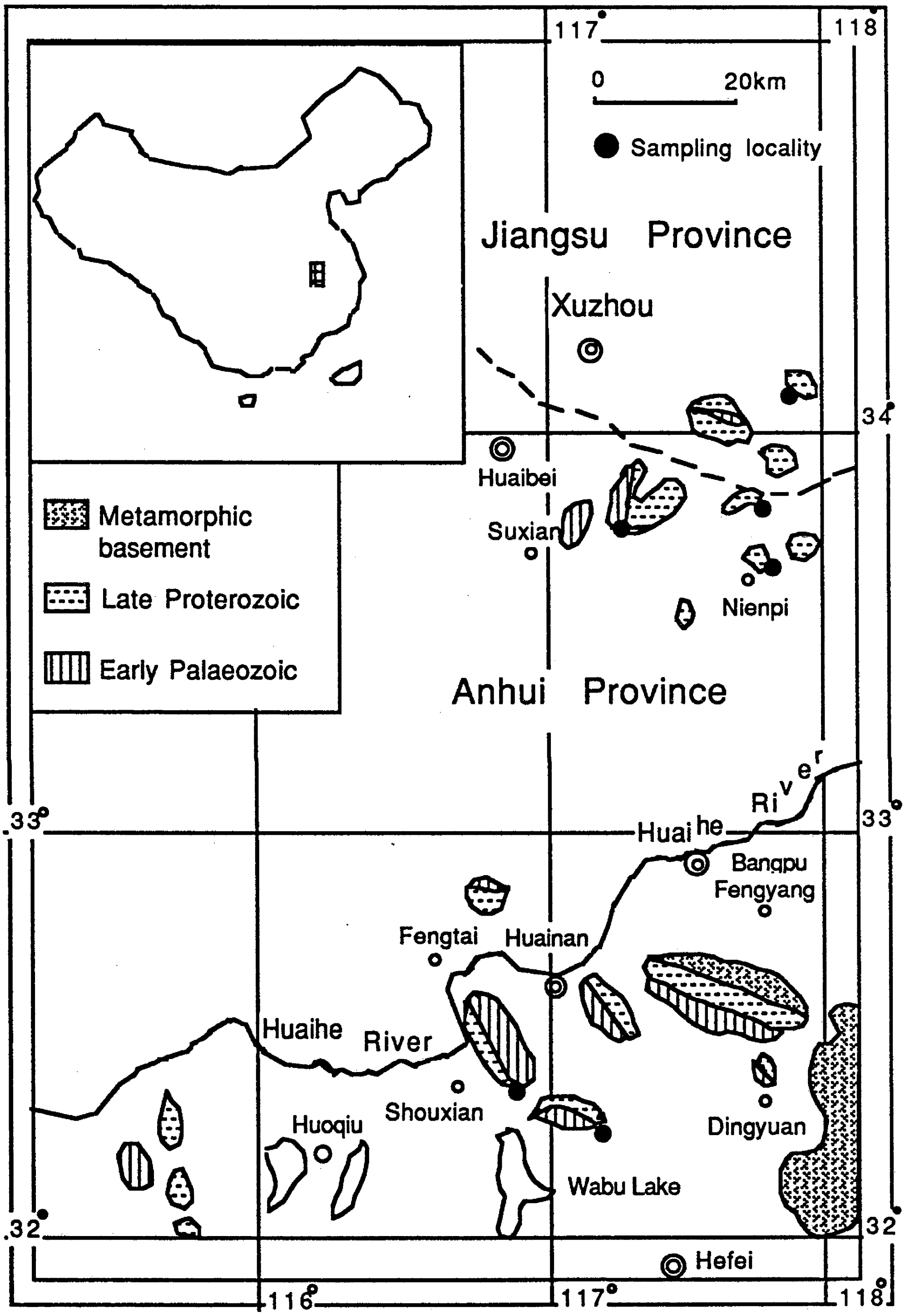
2.1. INTRODUCTION

The Chinese platform is divided into northern and southern tectonic regions. On the North China Platform (or Sino-Korea Block) (Zhang Wentang, 1980), the Proterozoic includes the Qingbeikouan (800-1000 Ma), Jixianian (1000-1400 Ma) and Changchengian (1400-1800 Ma), unconformably on a metamorphic basement older than 2000 Ma. The type section of these units is located at Jixian, Hebei Province. No tillites occur in the type section. On the South China Platform (or Yangtze Block), the Proterozoic consists of the Sinian (600-800 Ma), which lies on a metamorphic or granitic basement. The Sinian contains tillites. Correlation of these regions is one of the problems addressed in this research.

The Upper Proterozoic in northern Anhui and Jiangsu Provinces, central-east China, is tectonically in the transitional belt along the southern margin of the North China Platform. It consists of the Huainan Group on the south, and Huaibei Group on the north of the Huaihe River (Text-figure II-1). The Huainan Group underlies the diamictite of the Fengtai Formation. Both groups yield abundant microfossils, mega-algal fossils, stromatolites and soft-bodied metazoans. Recently many Chinese geologists have investigated this region, expecting to provide the evidence needed to correlate the northern with the southern sequences.

The investigation of the Late Proterozoic in northern Anhui started nearly five decades ago when Lee (1939) correlated the sequence with the Sinian. Subsequently Xie (1947), Xu (1958), Yang Zhijian (1960) and Zhu Zhaoling et al. (1964) agreed with this interpretation.

A team of geologists from Anhui and Jiangsu Provinces investigated this region in completing the 1:200,000 and 1:50,000 geological maps from 1976 to 1978, and used the name Fengyang Group for the lower metamorphosed rocks and Huainan and Huaibei Groups for the covering sequences. Zheng Wenwu (1979, 1980) reported the worm-like metazoan fossil *Sinosabellidites huainanensis* Zheng, the megascopic fossils *Chuaria circularis* Walcott, *Tawuia dalensis* Hofmann, and other mega-algal fossils from the Liulaobei Formation, Huainan Group. From these identifications he considered the biota (or "Huainan Biota") ranged in age from 650-950 Ma, and suggested that the Huainan Group might be correlated with the Sinian. Yan Yongkui (1982), Yin Leiming (1983), and Yin Chongyu (1985) studied microfossils from the Liulaobei Formation. They found that these assemblages could be compared with those of the upper Qingbeikouan and the lower Sinian, and suggested that the Liulaobei Formation might represent the absent strata between the Qingbeikouan and Sinian. This suggestion has been supported by Wang Guixiang (1982) because an isotopic age of 840 Ma was produced by the whole-rock Rb-Sr method for shales from the Liulaobei Formation.



Text-fig. II-1. Index map and regional geology of northern Anhui and Jiangsu Provinces, central eastern China. Sample localities are indicated by black spots.

2.2. LITHOFACIES AND PALAEOENVIRONMENT

The Upper Proterozoic and Lower Cambrian sequences distributed in the Huaihe River region of northern Anhui and Jiangsu Provinces, central eastern China, are exposed at more than ten localities. The sequences include shales, sandstones, limestones, dolomites and conglomerates. They have been divided into the Huainan and Huaibei Groups (discussed later in this Chapter), and both groups unconformably overlie pre-Late Proterozoic metamorphosed basement.

Previous interpretations of depositional environments of the Upper Proterozoic sequences in this region range from continental to marine (Zhang Shien et al., 1984), but most interpretations are based on outcrop observations only. This study will attempt to combine data from outcrops, thin sections, isotopic $\delta^{13}C$ values and the microbiota; X-ray diffractometer measurements have helped to get major rock compositions. Seven lithofacies have been recognised and are described below.

2.2.1. Lithofacies 1 - Flat-bedded Limestone

Lithofacies 1 consists of grey, flat-bedded, very fine-grained limestone; sometimes there is interbedded silty limestone and shale. The Guanjiaying Formation (Yin, Ch., 1985) in the Huainan region belongs to this facies. The formation is 107-254m thick. The limestones of the formation are well-bedded, some are laminated, and no stromatolites, cross-bedding or other sedimentary structures have been observed. The calcite crystals are very fine, 10-50*u*m in diameter and they are regarded as primary sediment. The limestone contains mainly calcium carbonate and some quartz, and chlorite is occasionally detected.

The limestone of lithofacies 1 has been considered as marine (Li Shangxiang et al., 1984). Four limestone samples have been processed for $\delta^{13}C$ values, and they range from +1.9 to +2.7 per mil. The values generally suggest a marine origin (Schwarcz, 1969).

The flat-bedded limestone has been interpreted as a sublittoral deposit. The well-bedded, especially laminated limestones, suggest probably that deposition was formed well below the littoral zone; the small calcium carbonate crystals are closely arranged and almost equivalent size may suggest they were not influenced by ground water, possibly far away from shore. Such a carbonate deposits have been observed in the modern offshore sublittoral embayment plain (deeper than 4m) of Hamelin Pool in Shark Bay, Western Australia, and in other similar locations.

The lower part of the Wangshan Formation in the Huaibei region may also belong to lithofacies 1. Its limestones and dolomites are well bedded, contain no cross-bedding, nor stromatolites, and possibly indicate a sublittoral environment. The upper part of the Wangshan Formation contains large ripple marks and stromatolites, and belongs to lithofacies 2.

2.2.2. Lithofacies 2 - Stromatolitic Carbonates

Stromatolites occur abundantly in carbonate sediments of the Huainan and Huaibei Groups. Lithofacies 2 consists of grey to red stromatolitic carbonates more than 2000m thick, including the Jiuliqiao, Sidingshan, Zhaowei, Jiudingshan, Weiji, Zhangqu, upper Wangshan and Jingshanzhai Formations.

Stromatolites are biosedimentary structures produced by some combination of sediment trapping, binding and precipitation as a result of the growth and metabolic activity of microorganisms, mainly cyanobacteria (blue-green algae), and their forms are dominated by the effects of water currents and reaction to light (Walter, 1977).

Stromatolitic carbonates occur variously in the Upper Proterozoic sequences in this region. In the Jiuliqiao Formation stromatolites include *Baicalia*, *Jurusania*, *Minjaria*, and *Inzeria*; their host rocks of dolomitic limestone or limestone are cross-bedded. Some beds display lower flat-bedded layers. Abundant mega-algal fossils including *Chuaria circularis* Walcott and *Tawuia dalensis* Hofmann, and soft-bodied worm fossils such as *Pararenicola huaiyuanensis* Wang and *Protorenicola baiguashanensis* Wang have been found in these layers. The sedimentary structures in these flat-bedded layers suggest a lower energy water environment (sublittoral to lower interlittoral).

The Sidingshan Formation consists mainly of dolomites (>98%) and includes stromatolites *Tungussia, Eleonora, Baicalia, Conophyton, Mirabila, Jurusania* and other groups. The dolomite contains intraclast structures and some cross-bedding in oolitic sediments. The term 'intraclasts' was introduced by Folk (1959) to describe fragments of penecontemporaneous, usually weakly consolidated carbonate sediment that have been eroded from adjoining parts of the water bottom and redeposited to form a new sediment. These reworked deposits may be formed on rock exposure where there is wave attack. In the Sidingshan Formation intraclasts are sometimes present with oolites, which are considered to be deposited in warm, shallow water, and a turbulent environment.

The limestones of the Zhaowei Formation contain the stromatolites *Jurusania, Conophyton* and *Tungussia.* The stromatolites in the lower part of the formation occur in association with small ripple marks and fenestrae (birdseye structures). The term 'fenestrae' is applied to primary or penecontemporaneous gaps in carbonate rocks larger than grain-supported interstices (Tebbutt et al., 1965). These may be open spaces in the rock, or partially or completely filled by secondarily introduced sediment or sparry cement or both. Shinn (1968) considered that the more nearly spherical openings, "birdseyes", were caused by trapped gas bubbles and that the less regular planar forms were caused by shrinkage, and these features were considered to have been formed in a supralittoral environment, sometimes in an interlittoral environment and never in sublittoral environments. However, fenestrae do occur in subtidal environments in the stromatolites of Shark Bay, Western Australia. Xue Yaosong et al. (1984) summed up six types of birdseye structures, and considered they could be formed in various models and in various environments, probably from subtidal zones to supratidal marsh. In the upper part of the formation, the stromatolites occur with intraclast structures, cross-bedding, ripple marks and desiccation cracks, and some stratiform stromatolites have been observed. The stromatolitic limestone of the Zhaowei Formation probably was deposited in high energy water conditions and arid environments.

Stromatolites only occur in the upper part of the Zhangqu Formation and include *Conophyton* and *Minjaria*. The lower part of the formation outcrops as light reddish or grey-pink limestone. Parallel layers dominate the limestone and occasionally intraclast structures have been observed.

The Jingshanzhai Formation is about 22m thick and consists of stromatolitic limestone and dolomite interbedded with grey and dark shales. At the base of the formation is a bed of conglomerate (20-70cm thick) with quartzite pebbles and calcareous cement, and this is overlain by a reddish dolomite with small stromatolites. The upper part of the formation consists of grey limestone with stromatolite bioherms, including *Boxonia, Acaciella* and other groups. The shales contain *Chuaria circularis* Walcott and *Tawuia dalensis* Hofmann and microfossils which are dominated by cyanobacterial filaments *Eomycetopsis robusta* (Schopf).

Each unit mentioned above may have been formed in a slightly different environment. At Hamelin Pool in Shark Bay, Western Australia, stromatolites are mainly distributed in intertidal to shallow subtidal environments. In the intertidal zone, stromatolites are growing with lower relief (10-50cm), in association with ooid and intraclast sand; some desiccation cracks and small ripples have been found. In the subtidal zone, stromatolites with high relief and columnar forms are found with ooid and intraclast sands and large ripples. Lithofacies 2 probably contains some sublittoral stromatolitic carbonates in the Jiuliqiao and Zhangqu Formations, which contain thick flat-bedded carbonates; and some interlittoral carbonates, such as the Zhaowei Formation, which contains ripple marks and desiccation cracks. Generally occurrences of the stromatolites indicate interlittoral to shallow sublittoral depositional environments.

Some carbonates were processed for $\delta^{13}C$ values (4 from the Jiuliqiao Formation, 8 from the Sidingshan Formation, 2 from the Zhaowei Formation). The all values range +0.5 to 3.9 per mil and possibly indicate a marine environment.

2.2.3. Lithofacies 3 - Clastic Limestone

Lithofacies 3 consists of grey limestone or silty limestone with rare occurrence of stromatolites. The limestone is exposed at the Qingtongshan section, northern Anhui, and Zhaowei section, northern Jiangsu. It is referred to the Jiayuan Formation. Sedimentary structures in the formation include intraclasts, oolites, desiccation cracks, cross-bedding, stratiform stromatolites, fenestrae, synaeresis cracks, and teepee structures.

Oolites are characteristically most abundant in waters less than 10m (often less than 2m) deep (Choquette, 1978). They generally occur in the turbulent part of shoals, such as on the Bahama Banks, the bodies of oolite sand have complex cross-bedding (Imbrie and Buchanan, 1965). The cross-bedded oolites in the formation may suggest a similar environment.

Bedding varies from indistinct massive to thin lamination, and teepee structures have been observed in the limestones. These structures are produced at sites of groundwater seepage. The extensional boundaries are distinguished from desiccation cracks in that they are lined and capped by the deposits from the upward-flowing water (Ferguson et al., 1982). In Hamelin Pool, Shark Bay, teepee structures have commonly been observed in the upper intertidal and supratidal environments.

Synaeresis cracks are shrinkage crack systems attributed to a spontaneous dehydration of gel-like materials, even in an aqueous environment. This is caused by the contraction of the internal units of gel and probably results from the formation of additional bonds between different parts of the colloidal structure (Dean, 1948). Synaeresis occurs upon aging and is an indication that gels are thermodynamically unstable. Dehydration and associated shrinkage may occur through evaporation without the release of liquid from the gel (Neal, 1980). Thus the formation of synaeresis cracks is different from that of desiccation cracks even though they are similar in form. "A major factor controlling the geometry is that desiccation cracks generally form on essentially flat or slightly inclined surfaces exposed to the air, whereas synaeresis cracks in natural gel may form in completely confined spaces, at depth, and without reference to the earth's gravity field. Consequently, synaeresis cracks are much less regular in form" (Neal, 1980, p.791), and thus they are not an environmental indicator.

Desiccation cracks are generally considered as indicative of an arid environment. In Hamelin Pool, stratiform stromatolites have not been found below the upper part of intertidal zone and are commonly formed by cyanobacterial filaments; they depend on occasional tidal and ground water to remain moist and sometimes occur with desiccation cracks. The occurrence of stratiform stromatolites and desiccation cracks (plate II, fig.E) may indicate an upper interlittoral and supralittoral environment.

In the Jiayuan Formation, microfossils were only collected from the lower flat-bedded silty limestone. Leiosphaerids, such as *Leiosphaeridia, Kildinosphaera, Trachysphaeridium, Protoleiosphaeridium* and *Stictosphaeridium* are dominant. Filamentous specimens of *Eomycetopsis robusta* have been found. Few micrhystrids are present. The microfossils suggest that assemblage is indicative of a nearshore environment.

The limestones of lithofacies 3 are probably marine carbonates ($\delta^{13}C$ values are +3.1 to +4.0 per mil), and they may have been deposited in the upper intertidal and supratidal, arid environment, occasionally in the lower intertidal or subtidal.

2.2.4. Lithofacies 4 - Interbedded Clastic Dolomites and Shales

Lithofacies 4 consists of interbedded beds of grey dolomite and variously coloured shales from the Gouhou Formation. The dolomites contain quartz, a small amount of chlorite and rare calcium carbonate; sedimentary structures in the dolomite include desiccation cracks, stratiform stromatolites, intraclasts and cross-bedding. The shales consist mainly of quartz, mica and a small amount of calcium carbonate; the beds in the lower part of the formation contain abundant organic matter, including the fossils *Chuaria circularis* and *Tawuia dalensis*. The shales are varied in colour, from grey or green to brown. Halite pseudomorphs are present (Zhang Shien, et al., 1984). The sedimentary structures probably indicate an arid littoral or supralittoral environment.

The study of microfossils from the Gouhou Formation leads to a similar conclusion.

The microfossil assemblage is dominated by filamentous mats, including abundant cyanobacteria *Eomycetopsis robusta* and *Siphonophycus* sp.. Cyanobacterial mats are photosynthetic and consequently are restricted in the photic zone. The cyanobacterial mats in Hamelin Pool, Shark Bay, Western Australia are widely distributed on the intertidal flats and shallow subtidal platform.

Li Shangxiang et al. (1984) considered the Gouhou Formation had been deposited in an arid lagoonal environment.

2.2.5. Lithofacies 5 - Interbedded Shales, Limestones and Sandstones

Lithofacies 5 consists of grey, yellow or brown shales interbedded with silty limestones and fine sandstones. It includes the Liulaobei Formation in the Huainan region and the Shijia Formation in the Huaibei region.

The Liulaobei Formation contains a series of yellow-grey shales, interbedded silty limestones and silty sandstones. Parallel beds dominate the lower part of the formation, and some rocks, especially the shales, are finely laminated. No cross-bedding or other sedimentary structures have been observed. These features may indicate a low energy environment. Dou Shouchu and Zheng Wenwu (1979) interpreted the environment as bathyal, but it is unlikely to have been this deep, because the rocks contain abundant microfossils, particularly filamentous mats which are usually indicative of shallow water conditions. In my view, the rocks have probably been deposited in a sublittoral shelf environment. The upper part of the formation contains more silty limestones and sandstones. Abundant tabular cross-bedding and slump structures have been observed in silty limestones. Slump structures are considered to result from downslope motion. The structures are asymmetrical and overturned in the direction of lateral movement, indicating a penecontemporaneous deformation or disturbance of bedding due to subaqueous flat-bedded movement of sediment, without loss of cohesion (Bouma, 1978). They occur with cross-bedding, possibly indicating turbulent water, perhaps a shallow sublittoral environment.

The silty limestones of the Liulaobei Formation are mainly composed of calcium carbonate, some quartz and a small amount of mica and chlorite. Nine limestone samples (five of them repeated) have been processed for $\delta^{13}C$ values and all data range within +0.8 to +2.3 per mil. The values possibly indicate a marine environment.

The shales in the lower part of the formation are composed of quartz, mica, calcium carbonate and chlorite, but in the upper part only quartz, mica and calcium carbonate, lacking chlorite. The absence of chlorite possibly suggests the depositional environment was slightly changed.

The shales of the Liulaobei Formation contain mega-algal fossils, soft-bodied worm-like fossils and microfossils. Fossils are most abundant in the lower part of the formation. The fossil assemblages probably indicate a shallow water condition. The relation between the microfossil distribution and depositional environment in the Liulaobei Formation will be discussed later in this chapter (Text-figure II-5, 6).

The Shijia Formation is exposed separately in two localities. The rocks in the lower part of the formation have been intruded by granite dykes, and are metamorphosed and folded. Parallel layers are present in the limestones and sandstones, and no cross-bedding has been found. In the upper part a few beds of carbonate concretions are observed. The concretions are ellipsoidal, with concentric layers. They show growth outward from a nucleus and irregular shapes are formed because two or more concretions united during growth. Many concretions are early diagenetic.

Distribution of microfossils in the Shijia Formation is varied. Some samples are dominated by spheroidal acritarchs and others contain abundant filaments. No spinose specimens have been found. The microfossil assemblage probably indicates a nearshore environment.

It is concluded that lithofacies 5 probably ranges from sublittoral to interlittoral environments. The main sedimentary evidence is preserved in interbedded limestones and sandstones. The microfossil assemblages from shales suggest nearshore, shallow water conditions.

2.2.6. Lithofacies 6 - Lower Flat and Cross-bedded Sandstones

Lithofacies 6 consists of light brown to reddish, well-sorted, fine to coarse-grained feldspathic and quartzite sandstones with a calcite or siliceous cement. Examples include the sandstones of the Bagongshan and Shouxian Formations.

The sandstone of the Shouxian Formation overlies the Liulaobei Formation (lithofacies 5) and contains several rhythmical sedimentary sequences. Each sequence starts with relatively coarse sandstone, grades upward and ends with parallel-bedded silty sandstone. Cross-bedding and ripple marks have been found. Some hummocky structures, which indicate storm attack, have been observed (Li Shangxiang et al., 1984). The sandstone is probably a shoreface, foreshore and beach deposit. Parallel-bedded sandstone of a moderately high energy environment has been found in the middle part of the sequences. Li Shangxiang et al. (1984) considered that the sandstone of the Shouxian Formation was a marine deposit.

The Bagongshan Formation varies in thickness (2-192m). It grades from underlying conglomerate and decreases in thickness from the north-east to the south-west. The upper part of the formation contains chlorite, but chlorite has rarely been detected from the lower part. Beds with cross-bedding and ripple marks have been observed interbedded with the parallel layers. Similar to the sandstone of the Shouxian Formation, it probably indicates a beach to foreshore environment. In the Huainan region part of the Bagongshan Formation has been considered to have been deposited in an estuarine environment (Li Shangxiang et al., 1984).

2.2.7. Lithofacies 7 - Ferruginous Conglomerate

Lithofacies 7 consists of ferruginous conglomerate of the Caodian Formation. The conglomerates lies unconformably on metamorphosed basement. It has a restricted distribution and varies in thickness up to 21m. Its clasts are mainly quartzites and metamorphics, angular or sub-rounded in shape, several centimeters to more than 0.5m in diameter. The matrix is silty or sandy, and often ferruginous. It has been considered to be a continental deposit in the front of an ancient source platform (Li Shangxiang et al., 1984).

2.3. HUAINAN GROUP

2.3.1. Definition and Age

The Huainan Group (sensu stricto) consists of a sequence of Upper Proterozoic unmetamorphosed carbonate and clastic rocks distributed in the Huainan-Fengyang-Huoqiu regions. It disconformably overlies the metamorphosed rocks of the Fengyang Group and underlies the diamictite of the Fengtai Formation and the Lower Cambrian Houjiashan Formation which contains skeletonized fossils *Megapalaeonlenus fengyangensis* Chu, *Hsuaspis* sp., *Obolella* sp., *Hyolithellus* sp., and other Lower Cambrian fossils. The Huainan Group occurs mainly at several localities in an east-west belt more than 200 km long. The sequences are well exposed in the Fengyang and Huainan regions, and are more than 1000m thick. The group consists of seven formations as shown in Text-figure II-2. The diamictite of the Fengtai Formation has been considered to be of glacial origin (Zheng Wenwu and Dou, 1980; Ren Runsheng, 1982).

The Huainan Group has been described differently by different authors, and sometimes even by the same author (as shown in Text-figure II-3). These differences arise from the fact that some authors have not correctly applied stratigraphic nomenclature, and may have misinterpreted the regional basin structure. The group has been considered as Sinian (Zheng Wenwu, 1980), Qingbeikouan (Yang Qinghe et al., 1980), or the lower part of the sequence as Qingbeikouan and the upper as Sinian (Yan Yongkui, 1982; Yin Chongyu, 1985; Zhang Shien et al., 1984; Sun Weiguo et al., 1986), and even the Lower Cambrian (Vidal and Moczydlowska, 1987). The present microfossil investigation suggests the Huainan Group probably belongs to the Sinian, most likely the upper Sinian.

Dou et Zheng, 1979			Zheng Wenwu,1980			Yang et al., 1980			Yao et Zhang, 1983			Zhang et al., 1984		Sun et al., 1986		
												Sinian	Wugangji Fm.			
			Cambrian		Houjiashan Fm.											
					Fengtai Fm.								Fengtai Fm.	Sinian		Fengtai Fm.
Sinian		Luoquan Fm.														
Qingbeikouan	Huainan Group	Lailaimiao Fm.	Sinian	Huainan Group	Lailaimiao Fm.											
		Sidingshan Fm.			Sidingshan Fm.	Qingbeikouan	Xuhuai Group	Sidingshan Fm.	Sinian	Xuhuai Group	Sidingshan Fm.		Sidingshan Fm.		Feishui Group	Sidingshan Fm.
		Jiuliqiao Fm.			Jiuliqiao Fm.		Huainan Group	Jiuliqiao Fm.			Jiuliqiao Fm.		Jiuliqiao Fm.			Jiuliqiao Fm.
										Bagongshan Group	Sishilichangshan Fm.					
		Shouxian Fm.			Shouxian Fm.			Shouxian Fm.					Shouxian Fm.			Shouxian Fm.
		Liulaobei Fm.			Liulaobei Fm.			Liulaobei Fm.			Liulaobei Fm.	Qingbeikouan	Liulaobei Fm.	Qingbeikouan	Huainan Group	Liulaobei Fm.
											Wushan Fm.					
		Bagongshan Fm.			Bagongshan Fm.			Bagongshan Fm.					Bagongshan Fm.			Bagongshan Fm.
								Caodian Fm.		?	Caodian Fm.		Caodian Fm.			

Text-fig. II-2. Subdivision schemes of the Upper Proterozoic sequence in the Huainan region, northern Anhui, central eastern China.

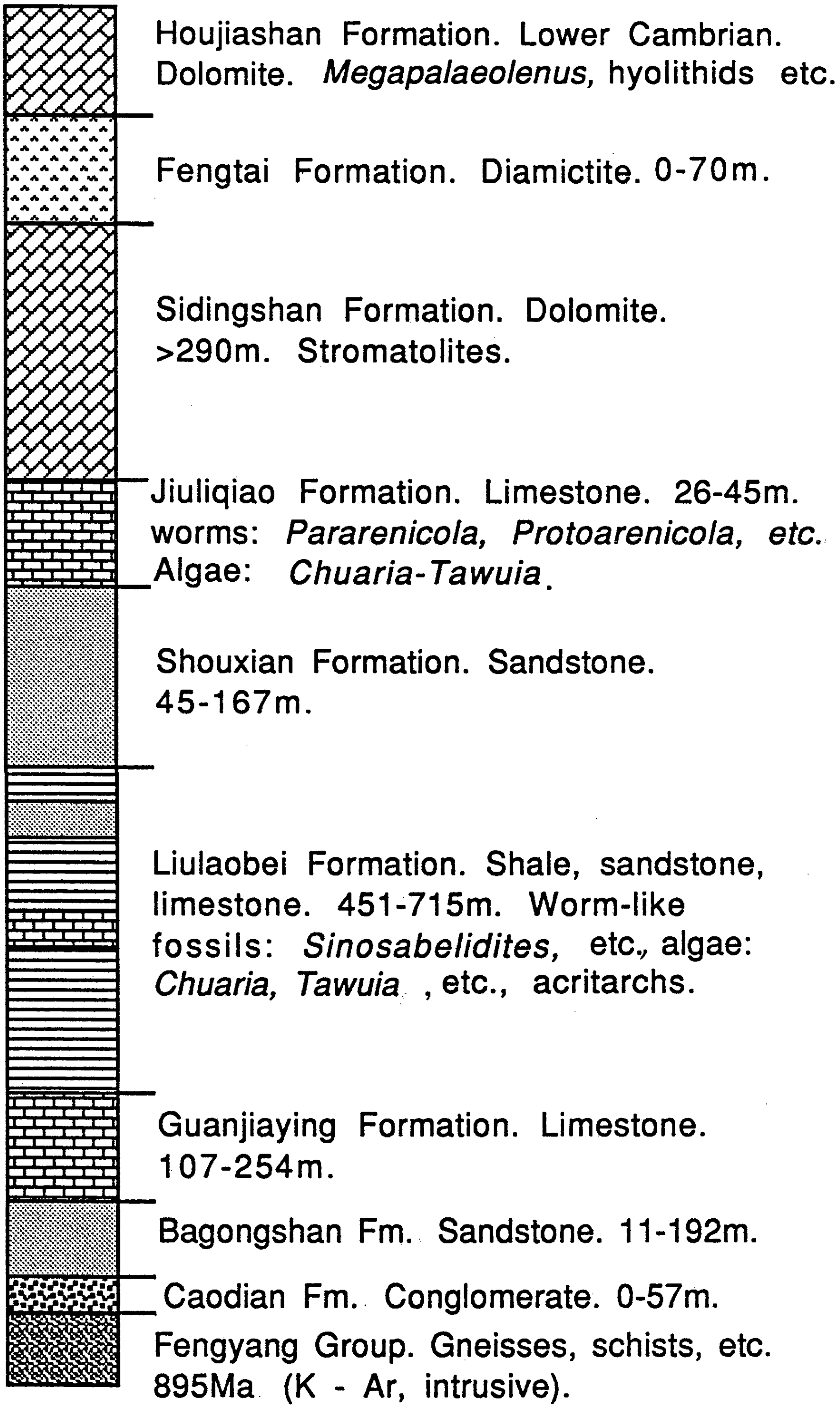
2.3.2. Stratigraphy

The Huainan Group unconformably overlies metamorphic basement. In the Fengyang section, northern Anhui, it unconformably overlies the Fengyang Group, which has been dated at 895 Ma (K-Ar, intrusive) and 1650 Ma (K-Ar, metamorphic) (Yang Qinghe et al., 1980), and 1878 Ma (K-Ar, metamorphic) (Zhang Shien et al., 1984). In the Huainan region it is in contact with possibly Archaean or Early Proterozoic gneisses.

The Huainan Group has been divided into two transgressive - regressive cycles (Sun Weiguo et al., 1986). The Caodian Formation, the lowest conglomerate belonging to the lithofacies 7, lies unconformably on the metamorphosed basement. It has a restricted distribution, varies in thickness and is probably a continental deposit. The conglomerates are upward disconformably into coarse quartz sandstones of the Bagongshan Formation of the lithofacies 6, which is considered as transitional marine sediment.

The Guanjiaying Formation consists of grey limestones interbedded with silty limestones and shales, and probably is deposited in a sublittoral environment (lithofacies 1). The limestones were considered previously to be the lowest member of the Liulaobei Formation, but the formation is now distinguished by the presence of thick, grey limestones (Yin Chongyu, 1985), and the interbedded sandy shales which contain less abundant organic matter. The Guanjiaying Formation conformably overlies the Bagongshan Formation.

The Liulaobei Formation, 250 - 590m thick, contains a series of yellow-grey shales, interbedded silty limestones and silty sandstones (Lithofacies 5). Parallel beds dominate the lower part of the formation, and some rocks, especially the shales, are finely laminated; the limestones in the upper part contain cross-bedding and slump structures. The sequence in the Liulaobei Formation probably is regressive, from a relatively deeper to a shallower water condition. The shales in the lower part of the formation yield abundant organic matter. Isotopic data (K-Ar) of the formation display big discrepancies (840 Ma, Wang Guixiang, 1982; 716.4 Ma, cf. Yin Chongyu, 1985). Thirty-four shaly samples have been collected from the formation for microfossil investigation (Text-figure II-4). The rocks pass upward conformably into feldspathic and quartzitic sandstones of



Text-fig. II-3. Generalized sequence of the Huainan Group in the Huainan region, northern Anhui,central eastern China.

the Shouxian Formation, which contains some large-scale tabular cross-bedding and ripple marks (lithofacies 6). These have been interpreted to be deposited in turbulent water, probably in a littoral environment. Isotopic ages for the sandstone are 749 Ma and 738 Ma (Yang Qinghe et al., 1980; Zhang Shien et al., 1984).

The Jiuliqiao Formation conformably overlies the Shouxian sandstones, and consists of dolomitic and silty limestones. The limestone is 26-45m thick and has been described as part of lithofacies 2. The lower part of the formation is dominated by parallel-bedded silty limestones. Several layers are laminated. Some laminae contain worm-like soft-bodied and mega-algal fossils. Microfossils are poorly preserved, mainly fragmented, and can not be identified. The limestone is conformably overlain by the stromatolitic dolomites of the Sidingshan Formation (lithofacies 2), which contains intraclasts and oolitic cross-bedded sediments. The sedimentary structures suggest the formation was deposited in a shallow, turbulent environment.

The dolomites of the Sidingshan Formation, which form the top of the Huainan Group, underlie the diamictite of the Fengtai Formation which has a restricted distribution. In the Huainan region, the Sidingshan Formation unconformably underlies the Lower Cambrian Houjiashan Formation; and the Fengtai Formation is absent. At Shanjiacun, Fengtai County, 25km west of Huainan City, the Sidingshan dolomite disconformably underlies the Fengtai Formation. The diamictite is about 75m thick and is disconformably overlain by the Houjiashan Formation. Compared with the Lower Cambrian sequence on the South China Platform, the basal Cambrian sequence (the Qiongzhusi Formation and the uppermost part of the Dengying Formation) may be absent in northern Anhui. The location of the Proterozoic - Cambrian boundary in this region, therefore, is unclear.

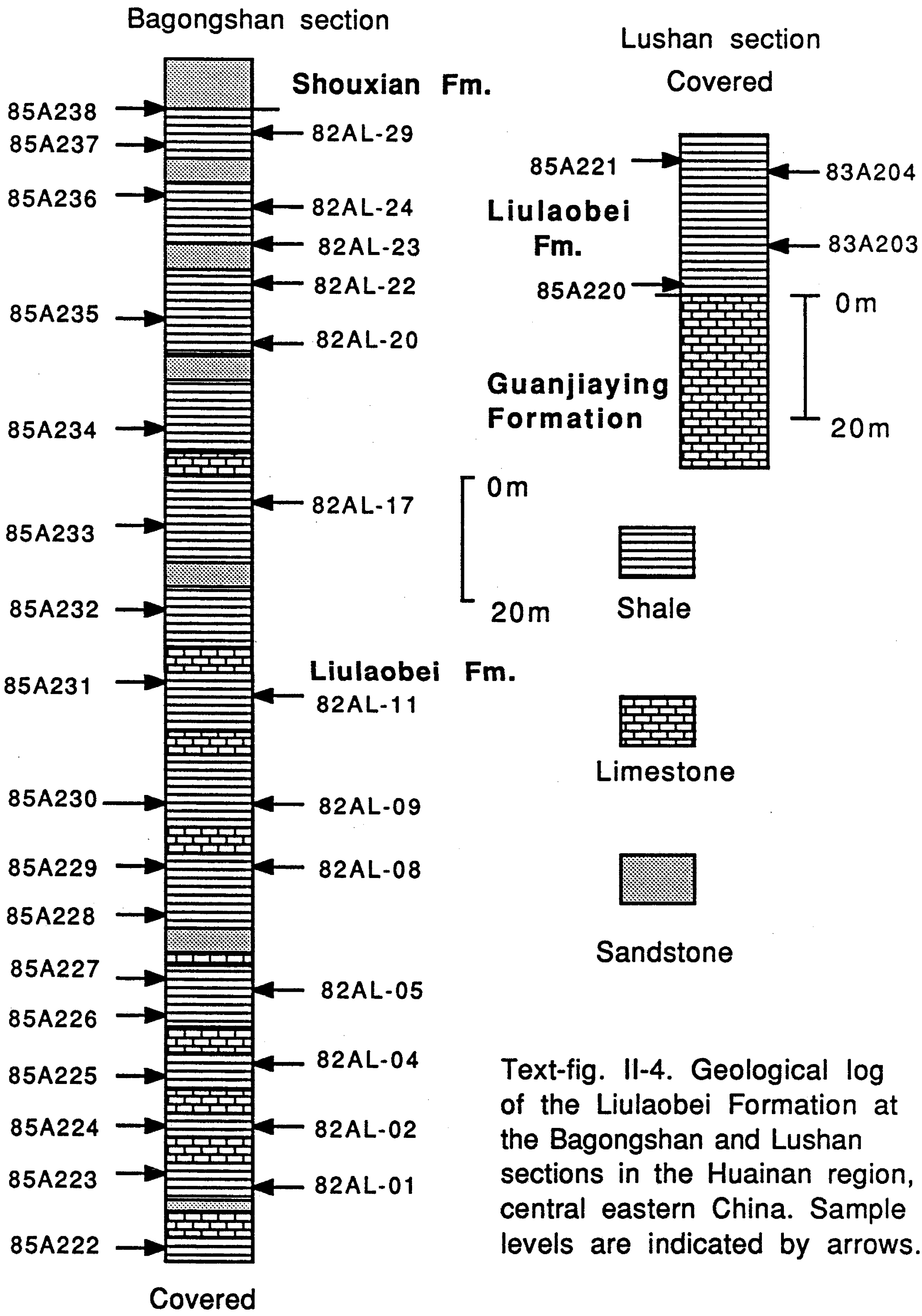
The Huainan Group in the Huainan - Fengyang region is well exposed over a small area, and the basement and younger rocks are well known. The Liulaobei and Jiuliqiao Formations produce abundant soft-bodied worm-like fossils, stromatolites, mega-algal fossils and microfossils. The group has been considered as an important sequence to study the biostratigraphic relationship between the North and South China Platforms. The microfossils studied in this group are mainly collected from the Liulaobei Formation.

2.3.3. Lithology and Preservation

The rocks of the Liulaobei Formation are unmetamorphosed and locally well exposed. The microfossils from the formation are well preserved, and commonly yellowish in colour. The preservation of the chitinozoan-like microfossils and worm-like soft-bodied fossils, in addition to microfossil colour index analysis (Staplin, 1977), suggests the rocks probably have not been subjected to a temperature more than 100°C (Laufeld, 1974).

Most rocks micropalaeontologically investigated are green or yellow-green in colour, and some shales are dark grey. The dark layers always contain some pyrite grains and probably were deposited a reducing environment, at least during diagenesis, and fossils are usually well preserved in these layers. Generally, the microfossils from the Liulaobei Formation are abundant in dark-grey or yellow-grey shales, infrequent in yellow shales and silty limestones and rare in sandstones. Diversity is highest in the shales. The individual laminae in the shales are often yellow-green, yellow-grey, grey, or light yellow; the darker laminae commonly contain abundant organic matter. Statistical analysis of the microfossil abundance and diversity in the Liulaobei Formation was restricted to the shales.

The microfossils from the silty limestones of the Jiuliqiao Formation are very poorly preserved; most of them are too fragmentary to be identified. The silty limestones are very fine grained, and contain some worm-like metazoan fossils. The limestones of the Liulaobei Formation are similar to those of the Jiuliqiao Formation, but no metazoan fossils have been found. The limestones of the Zhaowei and Jiayuan Formations (Huaibei Group) are argillaceous, and yield well-preserved microfossils. More argillaceous composition of carbonate seems to be an important factor for microfossil preservation.



Text-fig. II-4. Geological log of the Liulaobei Formation at the Bagongshan and Lushan sections in the Huainan region, central eastern China. Sample levels are indicated by arrows.

2.3.4. Distribution of the Microfossil Assemblages

Many attempts have been made to relate the distribution of microfossils to depositional environments (Staplin, 1961; Wall, 1965; Williams and Sarjeant, 1966; Smith and Saunders, 1970; Laufeld, 1974; Vidal, 1976, 1979, 1981a; Vidal and Knoll, 1983; Jacobson, 1979; Knoll, 1984). As the Proterozoic and Early Cambrian microfossils are exclusively restricted to aqueous and semi-aqueous environments, depth, distance from shore, prevailing currents and salinity probably influence their abundance and diversity.

Smith and Saunders (1970) concluded that the acritarchs from the Silurian of east-central Pennsylvania indicated that 'the degree of preservation reflects the depositional environment - forms from deeper open marine sediments are generally well preserved, while those in near shore and transitional facies are usually fragmentary and abraded'. Wall (1965) reached similar conclusions when he investigated the microplankton, pollen and spores from Liassic strata (Lower Jurassic) in Britain. He stated 'major stratigraphic changes are coincident with the Plienebachian transgression and or marked facies changes', and reduction in diversity of species was related to accumulation in an inshore, basinal environment. These statements have been accepted in the acritarch investigations of Proterozoic sediments (Vidal and Knoll, 1983).

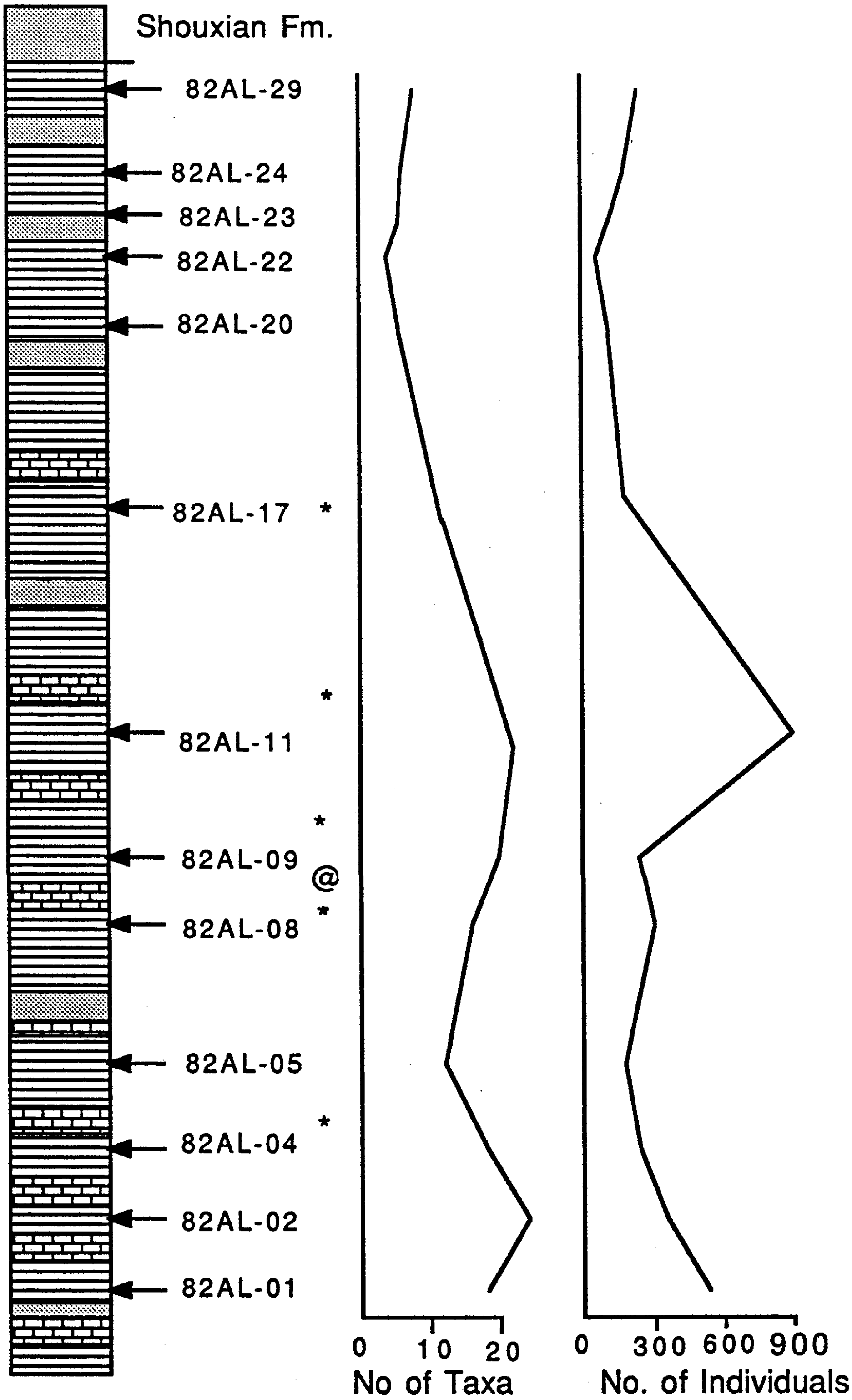
The sedimentary characters of the Liulaobei Formation indicate a regressive depositional environment. A decrease in the abundance and diversity of the acritarchs have been observed from the lower, deeper-water part of the formation to the upper, shallower part. Thirty-nine species and 2910 specimens of spheroidal acritarchs (specimens were collected only by heavy liquid) vary in distribution as shown in Text-figure II-5, 6 (3 or 4 slides counted for each sample).

The species with spines, *Micrhystridium oligum* Jankauskas, *M. spinosum*, *M. circulapertum* sp. nov., *M. quadratapertum* sp. nov. and other unnamed species of *Micrhystridium*, and with tubercles, *Lophosphaeridium tuberosum* sp. nov., have only been observed in samples of the lower part of the formation, 83A204, 82AL01 to 82AL09. These occurrences seem to support the view that acritarchs with processes lived in offshore open marine environments (Jacobson, 1979).

The leiosphaerid acritarchs appear to be independent of environment in the Liulaobei Formation. The specimens of *Leiosphaeridia asperata* (Naumova) Lindgren, 1982, *Sinianella uniplicata* (Yin, L.) , *S. scabrata* sp. nov., *Kildinosphaera chagrinata* Vidal, *K. granulata* Vidal, *Protoleiosphaeridium densum* (Timofeev) comb. correct., *P. flexuosum* (Timofeev), *P. laccatum* (Timofeev), *Trachysphaeridium* cf. *laminaritum* (Tim.) Vidal, *Stictosphaeridium* sp. and other spheroidal specimens occur in almost every sample, but an increase in abundance in the deeper water deposits has been observed.

It should be noted that fragments of the filamentous fossils, *Eomycetopsis*, *Oscillatoriopsis*, *Siphonophycus*, *Archaeotrichion* and other unidentified filaments, occur in most samples. In modern water environments benthic cyanobacterial filaments similar to these generally live in the upper part of the photic zone. Their abundance in the Liulaobei Formation therefore suggests that the host rock was probably deposited in a shallow water environment.

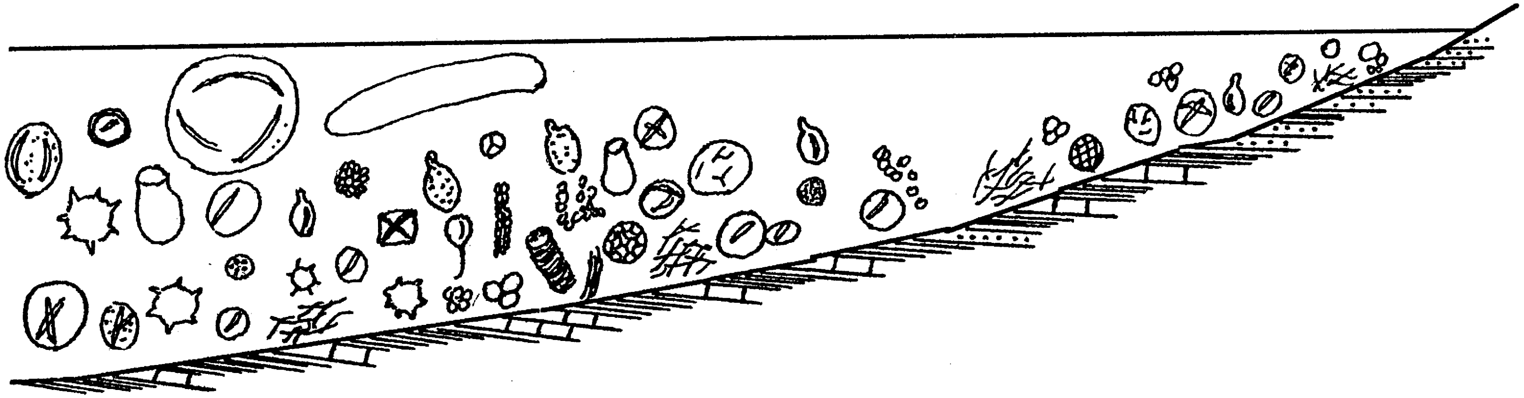
Also relevant to this discussion of palaeoenvironment is an interpretation of the chitinozoans (Eisenack, 1931), which form a group of extinct microscopic organisms whose systematic position is not known (Jansonius and Jenkins, 1978). The taxonomic position of chitinozoan-like specimens found in the Proterozoic have been questioned (Knoll and Vidal, 1980; Summons et al., 1987), and they have been referred to as "vase-shaped microfossils". Only one formal genus of this type, *Melanocyrillium* Bloeser, 1985, has been named (from the Kwagunt Formation, Chuar Group, Grand Canyon, Arizona). The vase-shaped specimens recorded from the Liulaobei Formation are abundant and diverse. Some are similar to the chitinozoans from the Late Palaeozoic, and one specimen probably has an operculum structure (pl.XVI, Fig.B). Under the scanning electron microscope, some specimens, differing from *Melanocyrillium*, display a double-walled structure pl.XVI, fig.C. Thus I tentatively use "chitinozoan-like microfossils" for these specimens. The distribution of these fossils is similar to that of acritarchs, and they became less abundant from deeper to shallow water, or from offshore to nearshore sediments. Jacobson (1979) got almost the same result when he compared the distribution of acritarchs to that of chitinozoans in Ordovician rocks. The increase in abundance in a



Text-fig. II-5. Abundance and diversity change of the acritarchs from the Liulaobei Formation at the Bagongshan section in the Huainan region, northern Anhui. Symbol @ indicates the occurrence of worm-like fossils and symbol * indicates the occurrences of *Chuaria - Tawuia* assemblage.

seaward direction is considered to be due to better living conditions for the chitinozoans (Laufeld, 1974).

Microfossil distribution is sometimes used as an indication of depositional environments. However, interpretation is subject to several sources of error. Unlike pollen and spores, they are independent living organisms and vary in type and abundance with minor chemical changes in water conditions; they also may be transported easily by currents. Consequently it is not surprising to find abrupt changes in the type, abundance and diversity of the taxa within small stratigraphical intervals. Sampling, therefore, becomes a very important matter in studies of the microfossils. This can be demonstrated from the work of the Liulaobei Formation; for example, samples tens of meters apart are dominated by planktonic and benthic assemblages, and these may be repeated; on the micro-scale, single hand specimen samples has produced different taxonomic ratios because layers within the samples have been differently represented during the processing. Thus environmental analyses based on microfossil distribution are tentative, especially in the Late Proterozoic where sampling is very poorly controlled. However we note that leiosphaerids dominate most assemblages and their distribution is apparently independent of environment.



Text-fig. II-6. Diagrammatic sketch of distribution of microfossils from deep to shallow water in the Liulaobei Formation, Huainan Group .

2.3.5. *Chuaria* -- *Tawuia* Assemblage

The shales of the Liulaobei Formation yield abundant specimens of the mega-algal fossils *Chuaria circularis* and *Tawuia dalensis*. Generally these two genera occur together in the formation. Zheng Wenwu (1978, 1980) reported this assemblage and he suggested that it ranged from 650 to 950 Ma in age. Hofmann (1985b) documented the world-wide occurrences of *Chuaria* and *Tawuia* and suggested a time range of 700-1100 Ma, whereas Sun Weiguo et al. (1986) and Sun Weiguo (1987), having studied the structure of *Chuaria* and the distribution of the two genera, considered their range to be 700-900 Ma.

The affinities of these carbonaceous megafossils have been matters for contention. The disc-like *Chuaria* was reported in Proterozoic rocks about one century ago when Walcott investigated the Chuar and Unkar Group of Powell's Grand Canyon Series (Walcott, 1883). He considered them to be hyolithids, but with a further study he described them as discinoid brachiopods (Walcott, 1899). Consequently the genus was referred to the gastropods (Wentz, 1938; Knight et al., 1960), problematica (Neave, 1939), inorganic matter (Schindewolf, 1956; Hantzschel, 1962), unrecognized genus (Hantzschel, 1975), foraminifera (Loeblick and Tappan, 1964), and algae (White, 1928; Glaessner, 1966; Cloud, 1968). Ford and Breed (1972, 1973), after a detailed study, suggested that it was an alga of unknown affinities, namely, an acritarch. Hofmann (1977) considered that *Chuaria* was not a single genus but consisted of a variety of biological groups, some possibly being small animals. Duan Chenghua (1982) described it in the Family Chuariaceae, which he interpreted as probably planktonic multicellular algae. Vidal and Ford (1985), using acid-resistant specimens from the Chuar Group, emended its diagnosis, and Sun Weiguo (1986) considered that it is related to *Nostoc*, a cyanobacterium.

Currently *Chuaria* is considered by most students to be a planktonic alga. Its structure is not clear because during diagenesis the internal organic material is carbonised. Jux (1977) studied the wall structure of *Chuaria*, and suggested that it was similar to that of *Leiosphaeridia* and *Tasmanites*. In transverse section (cf. Food and Breed, 1973, pl.62, fig.5-6), it appears likely to be an empty spheroid of the kind formed by species of *Nostoc* (Sun Weiguo, 1987), *Volvox* (Suresh and Raju, 1983) and other organisms, unicellular or multicellular, if they have similar morphology.

The occurrence of *Chuaria* is complex. In the Chuar Group, it was reported as a massive occurrence (Ford and Breed 1973). Similarly other Late Proterozoic occurrences have been recorded from the Hector Formation, Banff National Park, Alberta, Canada (Gussow, 1973); the Bhima Basin, southern India (Suresh and Raju, 1983); the Volta Basin, western Africa (Amard and Affaton, 1984); the Visingsö Beds, Sweden (Brotzen, 1941; Vidal, 1976); the Chapoghlu Shale, northern Iran (Stocklin et al., 1964); the Vindhyan Kaimur Group, India (Chapman, 1935). In China it has been reported from the Qingbeikouan Jingeryu Formation at the Jingeryu Village, Jixian County, Tianjin; the Nanfen Formation, Qinggouzi of Hunjiang, Jilin Province and Guanjiatun of Fuxian County, Liaoning Province (Duan Chenghua, 1982). In Hebei, China, *Chuaria* is associated with *Longfengshania*, a genus with a tail-like stem (Du Rulin and Tian, 1985). In northern Anhui, it has been reported to occur in association with *Tawuia* in six formations (Zheng Wenwu et al., 1984). In the Little Dal Group, Canada, it occurs with both *Tawuia* and *Longfengshania* (Hofmann and Aitken, 1979; Hofmann, 1985a). All these disk-like specimens are named *Chuaria circularis*, but we can not be sure they are same; the species is probably heterogeneric.

Chuaria and *Tawuia* show variation in outline from circular to elongate. Based on the ratio of length to width, several genera have been named: *Fengyangella* Zheng, *Sicyusa* Zheng, *Langania* Yang, *Ovidiscina* Zheng, *Conicina* Zheng, *Cylindraceusa* Yan, *Linguiformia* Zheng, *Nephroformia* Zheng, *Ephippiodeusa* Yan, *Pumilibaxa*, *Arciformia* Yan, *Shouhsienia* Sin and others (Wang Guixiang, ed., 1984). Most of them were considered by Hofmann (1985a) to be synonyms of *Chuaria* or *Tawuia*. Many specimens cannot even be placed in one or other of these genera because the ratio between width and length displays continuous variation.

If we consider specimens from a single locality, disk-shaped forms normally referred to *Chuaria circularis* are often on, or even apparently within, elongate individuals that would be referred to *Tawuia* (pl.IV, fig.F). They are obviously related. This conclusion is supported by recent observations of the green alga *Ulta lacluca* v. *rigida*, which in its reproductive stage can produce specimens with an outline like both *Chuaria* and *Tawuia* (pl.III, fig.G). These two genera would therefore seem to be best regarded as "form genera".

This view is supported by the fact that a variety of modern algae such as *Volvox* and cyanobacteria like *Nostoc* can be made to produce *Chuaria*-like shapes by crushing in the laboratory. Presumably the whole range of *Chuaria* - *Tawuia* shapes could be produced by crushing specimens of *Ulta lacluca* v. *rigida*. As a result we cannot be sure that *Chuaria* and *Tawuia* represent different taxa, and therefore their value for correlation purposes must be limited.

Chuaria and *Tawuia* assemblages have been considered to range from 700 to 900 Ma (Sun Weiguo et al., 1986), but the occurrences of the assemblage in the late Sinian Shijia Formation and probably Lower Cambrian Gouhou Formation suggests a younger age. *Tawuia* has been collected recently from the Dengying Formation (upper Sinian) in Jiucheng County of eastern Yunnan (Chapter III in this thesis). The two mega-algal genera, therefore, probably range over a long geological period. They were abundant in the Late Proterozoic but declined as animals increased in the Early Cambrian.

2.3.6. Spheroidal Acritarchs

Spheroidal acritarchs usually dominate Late Proterozoic microfossil assemblages. In northern Anhui, *Leiosphaeridia*, *Kildinosphaera*, *Protoleiosphaeridium*, *Trachysphaeridium*, *Stictosphaeridium* and other spheroidal form-taxa are the most abundant taxa in rocks of that age. These genera are widely distributed in the Late Proterozoic of the Soviet Union, (Volkova, 1969; Timofeev, 1966, 1969), Sweden (Vidal, 1976), England (Zhang Zhongying, 1982), Greenland (Vidal, 1982) and China (Sin et Liu, 1973; Yin Chongyu, 1985).

After studying the acritarchs in northeastern Poland, Volkova (1969) considered *Leiosphaeridia*-domination of the microfossil assemblage to be a characteristic feature of the Valdaian Series. This view point is supported by Damassa and Knoll (1986) because they found a similar assemblage from the Ediacarian Arcoona Quartzite Member of the Tent Hill Formation, Stuart Shelf, South Australia.

Leiosphaerid acritarchs for instance *Leiosphaeridia*, consist of a group of microfossils with smooth surface texture. Their size, according to Lindgren (1982), varies from 8*u*m to 440*u*m, and their internal structures are unclear. Surface characters do not show with certainty if they are unicellular or multicellular structures. Many modern spheroidal algae, such as Chlorophyta, Rhodophyta and cyanobacteria are known to produce forms of this type. Leiosphaerids are therefore probably of heterogeneric origin.

Because the wall of leiosphaerids is flexible, various folds should be formed by compression during diagenesis. The folds were used as characteristic features by some authors and several taxa have been named, for example, *Macroptycha*, *Scaphita*, *Pseudozonosphaeridium*, *Leiopsophosphaera*, *Trachytriletes*, and *Kildinella*. Lindgren (1981, 1982) reached the conclusion that they were congeneric with *Leiosphaeridia*. Observation of the reproductive stages of a green alga, *Ulva lacluca* v. *rigida*, shows that its individual spheroids are multicellular. When they die, some of them leave a spheroidal excystment. After mounting on slides, their surface displays various folding patterns, very similar to those of the Late Proterozoic species *Leiosphaeridia asperata* (Naumova) Lindgren, 1982. Folds are not a reliable feature for identification.

Leiospheroids are generally abundant in the Upper Proterozoic. They dominate microfossil assemblages of the Vendian in the Soviet Union (Volkova, 1969) and some parts of the Ediacarian in Australia (Damassa and Knoll, 1986). In northern Anhui, they occurred in almost every sample throughout the Liulaobei Formation, and they also are abundant in the microfossil assemblages from the Lower Cambrian Gouhou Formation in northern Anhui and the Shipai Formation in Yangtze Gorges (Zang, in this thesis, Chapter III). In the Amadeus Basin, central Australia, leiosphaerids are found abundantly in the microfossil assemblage of the pre-Ediacarian Bitter Springs Formation (by maceration), some occur in the Ediacarian Pertatataka Formation, and some have been found in the Middle Cambrian Tempe Formation (Zang, in this thesis, Chapter IV). Abundant leiosphaerids, therefore, are important feature in some regions in the Vendian, but they have few distinctive features, and cannot be usefully divided into confidently recognisable taxa. Their stratigraphic use is therefore limited.

Kildinosphaera is morphologically similar to *Leiosphaeridia* in over-all shape and colony form, but differs in its surface textures. Specimens of *K. chagrinata*, *K. granulata*, and *K. verrucata* have been found from the Sinian to the Lower Cambrian in northern Anhui. The other known species of this genus, *K. lophostriata*, is characterized by its surface striate texture. The species is considered to be characteristic of the early Late Proterozoic (Upper Riphean) in Europe and North America (Vidal and Siedlecka, 1983). Unfortunately the species has not been recorded from China and Australia.

Spheroids such as *Protoleiosphaeridium*, *Trachysphaeridium* and *Stictosphaeridium* have a reputation for long stratigraphic ranges. Because they lack distinctive structures they probably are heterogeneric taxa, and possibly have no significance for biostratigraphic correlation.

2.3.7. Biostratigraphic Significance of the Liulaobei Assemblage

Recently the age of the Liulaobei Formation has been questioned (Cloud, 1986). A microfossil investigation indicated the formation was of the Early Cambrian *Holmia* age because scattered specimens of *Skiagia* have been observed (Vidal and Moczydlowska, 1987). This study tries to use the microfossils and other available information to interpret the stratigraphic position of the Liulaobei Formation. (The occurrence of *Skiagia* and its significance will be discussed in Chapter III of this thesis).

The Liulaobei Formation is probably of Late Proterozoic age. The Huainan Group is overlapped by the Lower Cambrian Houjiashan Formation. In the Huoqiu and Huainan regions the Houjiashan Formation has two levels yielding abundant trilobites: the upper level contains *Megapalaeolenus fengyangensis* Chu and *Redlichia*, and the lower has abundant *Hsuaspis* (Zhou Benhe et al., 1984). The trilobites suggest that the Houjiashan Formation should be correlated with the Lower Cambrian Canglangpu Formation (Zhang <=Chang> Wentang et al., 1979) in eastern Yunnan on the South China Platform. The Meishucun section in eastern Yunnan has been proposed as the international reference section for the Proterozoic - Cambrian boundary. Zhou Benhe et al. (1984) recorded a bed of 0-25m thick phosphorites below the Houjiashan Formation. This bed contains the brachiopod *Obolella* in its upper part. *Obolella* has a long geological range, and also occurs in the Qiongzhusi Formation. It has been suggested that the phosphorite bed should be correlated with the upper or even the middle part of the Qiongzhusi Formation (Zhou Benhe et al., 1984). Rocks corresponding with the middle and lower Qiongzhusi Formation and the top of the Dengying Formation (the Xiaowaitoushan, Zhongyicun and Dahai Members) in Huainan region may be absent. The Liulaobei Formation is five formations below the phosphorite beds, a stratigraphic interval more than 600m. The interval contains several major hiatuses, especially below the glaciogenic Fengtai Formation. During the last ten years, despite extensive searches for fossils, no evidence indicative of a Cambrian age has been found in the Liulaobei Formation. Many samples have been analyzed for isotopic ages; none of them are younger than 600 Ma old. The Fengtai Formation is correlated with the Luoquan Tillite, and currently considered to be of Late Proterozoic age though other arguments have been proposed (Wang Yuelun et al., 1981; Guan Baode et al., 1986; Mu Yongji, 1981; Sun Weiguo et al., 1986). The abundant stromatolites from the Jiuliqiao and Sidingshan Formations, in association with mega- and micro-fossils, indicate a pre-Cambrian age (Cao Ruiji et al., 1985; Yang Qinghe et al., 1980; Yan Yongkui, 1982; Zheng Wenwu, 1980). It is suggested that the Liulaobei Formation probably belongs to the Late Proterozoic.

In some instances isotopic dates may be of value for stratigraphic correlation in the Proterozoic and Archaean. The Rb-Sr whole-rock method has given widely different results for the Liulaobei Formation, 716 Ma (cf. Yin Chongyu, 1985) and 840 Ma (Wang Guixiang, 1982). On the other hand, the possibility of any isotopic method involving clays being satisfactory seems remote, since the clay material may be derived from original source areas being eroded, from diagenetic reaction shortly after deposition, or from later low-grade metamorphism (James, 1981). The age, therefore, of the Liulaobei Formation is yet to be demonstrated by isotopic means.

Soft-bodied metazoan fossils play an important role in the correlation of Late Proterozoic strata. A probable soft-bodied fossil taxon, *Sinosabellidites huainanensis*, has been reported from the Liulaobei Formation, but it has not been found in other places. Mega-algal fossils, *Chuaria circularis*, *Tawuia dalensis* and *Tyrasotaenia* sp. (Zheng Wenwu et al., 1984, pl.11, fig.2), are abundant in the Liulaobei Formation, sometimes with swarms of specimens occurring in one hand-sample. They have been proved to range from the pre-Sinian to Early Cambrian, and thus their biostratigraphic significance is limited.

The classification of acritarchs is in a state of flux. Approximately nearly thirty genera and sixty species has been described from the Liulaobei Formation (Yan Yongkui, 1982; Yin Leiming, 1983; Yin Chongyu, 1985), but these need to be confirmed. The determination of *Leiopsophosphaera*, *Macroptycha*, *Quadratimorpha*, *Nucellosphaeridium* and other genera is questioned. Conclusions based on these taxa have to be emended.

In my study the microfossils from the formation include fourty sphaeromorphic acritarchs, eight filamentous forms, and many chitinozoan-like microfossils of which at least eight forms can be identified; but no *Skiagia* have been observed. Text-figure II-7 lists the distribution of sphaeromorphic acritarchs in the Liulaobei Formation, as well as in the Visingsö Beds, Sweden. Filaments and chitinozoan-like microfossils are excluded.

The following similarity coefficients have been used to analyse these assemblages (cf. Raup and Crick, 1979).

SIMPSON = 100 K/B   JACCARD = K/A+B-K   DICE = 2K/A+B

Where : A and B represent two assemblages, and B < A,
K represents the number of taxa common to two

assemblages of A and B.

The coefficients between the Visingsö Beds and the Liulaobei Formation are:

	SIMPSON	JACCARD	DICE
Coefficients between the Liulaobei Formation and the Lower and Middle Visingsö Beds	44	0.21	0.34
Coefficients between the Liulaobei Formation and the Upper Visingsö Beds.	56	0.28	0.44

Where A=39 (spheroidal species recorded from the Liulaobei Formation)

B=25 (spheroidal fossils found in the Visingsö Beds)

K=11 (common taxa between the Liulaobei Formation and the Lower and Middle Visingsö Beds)

K′=14 (common taxa between the Liulaobei Formation and the Upper Visingsö Beds)

According to Vidal (1976), the lower and middle parts of the Visingsö Beds correlate with the Upper Riphean, and the upper part with the Vendian. The acritarch assemblage from the Liulaobei Formation, therefore, is most likely to correlate with that of the Vendian.

Some acritarch species in the assemblage may suggest a relatively younger age. The occurrences of abundant *Micrhystridium* are usually considered to be an indication of younger age in the Late Proterozoic. Volkova (1969) found *M*. cf. *tornatum* occasionally encountered in the Late Proterozoic of the Russian Platform, and the abundance of *M*. cf. *tornatum* and *M*. sp. is a characteristic feature of the basal Cambrian assemblage. This viewpoint has been stated by Vidal and Knoll (1983).

The Liulaobei Formation yields abundant specimens with simple short spines referred to

Text-fig. II-7. Microfossils from the Liulaobei Formation, Huainan Group in the northern Anhui, central eastern China. Their stratigraphic distribution in China and the occurrence in the Visingsö Beds of Sweden has been shown. The symbol -- indicates the occurrence.

	China	Platforms			Sweden		Huainan
	Pre-Sinian	Lower Sinian	Upper Sinian	Lower Cambrian	Visingso Beds L.-M.	Upper	Liulaobei Formation
Alliumella baltica			- -	- -			- -
Ambiguaspora sp.			--				- -
Archaeoulothrix epikoila			- -				- -
Chuaria circularis	- -	- -	- -	- -	- -	- -	- -
Dictyotidium regulare			- -				- -
cf. *Eoaphanocapsa* sp.	- -	--	- -				- -
Favososphaeridium favosum	- -	--	- -			- -	- -
Gloeodiniopsis cf. *lamellosa*	--	--	- -				- -
Kildinosphaera chagrinata	- -	- -	- -	- -	- -	- -	- -
Kildinosphaera granulata	--	--	--	--	?	?	- -
Kildinosphaera verrucata	--	--	- -	- -			- -
Lathribiota annularis			- -				- -
Leiofusa bicornuta	- -		- -				- -
Leiomarginata ? simplex			--	- -			- -
Leiosphaeridia asperata	- -	- -	- -	- -	- -	- -	- -
Lophosphaeridium tuberosum			--	- -			- -
Lophosphaeridium sp.			- -				- -
Micrhystridium circulapertum			--	- -			- -
Micrhystridium oligum			--	- -			- -
Micrhystridium cf. *oligum*			- -				- -
Micrhystridium quadratapertum			- -				- -
Micrhystridium spinosum			- -	- -			- -
Micrhystridium sp.			- -				- -
Myxococcoides sp.	- -	- -	- -	- -			- -
Octoedryxium truncatum	--		- -			- -	- -
Paleasphaeridium zonale			- -	- -			- -
Protoleiosphaeridium densum	--	--	--	- -	?	?	- -
Protoleiosphaeridium flexuosum	- -	- -	- -	- -	- -	- -	- -
Protoleiosphaeridium laccatum	- -	- -	- -	- -	- -	- -	- -
Pterospermopsimorpha binata	- -		- -				- -
Pterospermopsimorpha spongia	--		--	- -			- -
Pyritosphaera barbaria	- -	- -	- -	- -	- -	- -	- -
Sinianella uniplicata	--	--	--	- -			- -
Sinianella scabrata	--	--	--	- -			- -
Stictosphaeridium sp.	- -	- -	- -	- -	- -	- -	- -
Synsphaeridium sp.	- -	- -	- -	- -	- -	- -	- -
Tawuia dalensis	--	--	--	- -			- -
Trachsphaeridium laufeldi	--	--	--		--	--	- -
T. cf. *laminaritum*	- -	- -	- -	- -	- -	- -	- -
Archaeotrichion contortum	--	--	--	- -			- -
Eomycetopsis parallela			- -				- -
Eomycetopsis robusta	--	--	--	- -			- -
Eomycetopsis spiralata			- -				- -
Heliconema ? sp.	--		- -				- -
Oscillatoriopsis spp.	--	--	--	- -			- -
Palaeolyngbya barghooniana	--	--	- -				- -
Siphonophycus sp.	--	--	--	- -			- -
cf. *Melanocyrillium* spp.	--	--	--	--		- -	- -

Micrhystridium. Six form-species have been described, of which two are new. *M. spinosum* and *M. oligum* are widely distributed in the Lower Cambrian rocks of the Soviet Union, Poland (Volkova, 1969; Volkova et al., 1979) Scotland, Norway, Greenland and other places (Downie, 1982). *M. circulapertum* sp. nov., a species with obtuse spines and a circular opening, has been found in the Lower Cambrian Gouhou Formation. *M. quadratapertum* sp. nov., is recorded from the lower part of the Liulaobei Formation; its processes are dense, hollow, sword-like and sharpened at the apices, and occasionally the vesicle has a irregular square opening. This species has been recorded exclusively from the Liulaobei Formation. *M.* cf. *oligum* has large specimens ornamented with very thick spines. Micrhystrids make up about 5% of the 3000 individuals counted from the formation. *Micrhystridium* occurs abundantly in the Lower Cambrian rocks in Europe (Downie, 1982; Volkova, 1969) and occasional specimens have been reported from the Yudoma Group, East Siberia (Su-Chu C. Lo, 1980; Cloud and Glaessner, 1982), and the upper Sinian Dengying Formation on the South China Platform (Xing Yusheng and Liu, 1982; Wang Fuxing et al., 1983; Wang Fuxing, 1985; Yin Leiming, 1986a). Several questionable micrhystrids have been reported from the Riphean of the South Urals (Jankauskas, 1982), and some recorded from the pre-Sinian Liubaitang Formation (Song, personal communication), but their frequencies can not compare with that of the Liulaobei Formation. Micrhystrid occurrences have been recorded from the early Late Proterozoic Bitter Springs Formation, Ediacarian Pertatataka Formation and Middle Cambrian Tempe Formation in the Amadeus Basin; but in the Bitter Springs Formation only one sample (MOP403) contains micrhystrids and they are relatively scattered. Abundant micrhystrid specimens occurring in the Liulaobei Formation suggest that the formation is in the younger part of the Late Proterozoic.

Alliumella baltica Vanderflit, a form-species with a tail-like appendage, is widely distributed in the Lower Cambrian of the Soviet Union. According to Volkova et al. (1979), it has been recorded from the Lower Cambrian Pirita Formation (Kaliningrad region), the Vergale Horizon and Rausve Horizon (Latvia, Ukraine and Poland). It also has been found from the Middle Cambrian Kibartu Horizon of Latvia and Poland. In Revinian, Belgium, it has been reported from the Middle and Upper Cambrian. The other species from the Liulaobei Formation, *Leiomarginata* cf. *simplex* Naumova, in which the vesicle has a thickened ring around the margin, also is widely recorded from the Lower Cambrian of the Russian and Siberia Platforms, Moscow Basin and other places (Volkova et al., 1979). Both species are observed from the Liulaobei Formation. However the two species in this study are also recorded from the early Late Proterozoic Bitter Springs Formation (Chapter IV of this thesis).

About sixteen specimens with a triradiate scar from the Liulaobei Formation are assigned to the genus *Ambiguaspora*, but are not given specific names. The triradiate scar does not seem to be a diagenetic feature even though some tetrahedral specimens have been questioned (Schopf and Blacic, 1971). Volkova (1976) erected *Ambiguaspora parvula* for what she considered to be "spores" with a triradiate tetrad scar. The specimens were described from two sections of the Upper Vendian Kotlin Formation, Latvia. The present specimens are more than double the size of the Russian specimens (which are less than 10*u*m in diameter). The occurrence of the "spores" may support a correlation of the two formations.

Favososphaeridium favosum Timofeev is widespread in the Atlantic region (Vidal, 1981; Vidal and Knoll, 1983) and the Russian and Siberian Platforms (Timofeev, 1966). Wherever it occurs it is of Vendian to Middle Cambrian age. The species has been found from the lower Sinian Nantuo Formation of Yangtze Gorges (Zang, in this thesis, Chapter III), and the upper Sinian Wangshan Formation, Huaibei Group in northern Anhui (Yan Yongkui, 1984, pl.16, figs.5a-6b). It was reported by Timofeev (1966) from the "lower Sinian" Kuto "System" in the northern China. The age of the "System" is uncertain. Work in the last decade suggests that at least part of it may be older than Sinian. In Australia similar specimens have been described from the Middle Proterozoic Roper Group (1500 Ma) (Peat et al. 1978). The occurrence of this species in the Liulaobei Formation does not provide precise age information.

A new species, *Dictyotidium regulare*, is erected for specimens with a relatively regular, rectanglar meshwork arranged in a centrally concentric pattern. This is a different pattern from that of the Lower Cambrian species of the same genus, *D. birvetense* and *D.*

proscum. Specimens of this genus have not been recorded from the Late Proterozoic. Its occurrence in the Liulaobei Formation indicates an extension of the range downwards. *Lophosphaeridium tuberosum* sp. nov. differs from other Cambrian species of the genus by the presence of a small vesicle with relatively large tubercles and a circular opening. The species has been recorded from the Lower Cambrian Gouhou Formation in the Huaibei region, the Qiongzhusi Formation on the South China Platform, as well as the early Late Proterozoic Bitter Springs Formation and Middle Cambrian Tempe Formation in the Amadeus Basin (Chapter IV).

Sinianella (Yin. L.) emend. differs from other genera by its bottle-shaped form with a single prominent process drawn out from the vesicle, and its colonies have a linear interlocking arrangement. The two species, *S. uniplicata* (Yin Leiming) and *S. scabrata*, are distinguished by their surface textures: smooth or scrabous. They have been found in the Lower Cambrian Gouhou Formation, the Huaibei Group and the Shipai Formation of the Yangtze Gorges. Questionable specimens have been recorded from the lower Sinian Nantuo Formation in the Yangtze Gorges (Zang, in this thesis, Chapter III). Damassa and Knoll (1986) have reported one specimen from Ediacarian rocks in South Australia. Some specimens have been observed from the Bitter Springs Formation in the Amadeus Basin. Thus the species may range from the Late Proterozoic to the Cambrian.

The genus *Pterospermopsimorpha* is represented by two species, *P. binata* Timofeev, 1966 and *P. spongia* sp. nov. in the Liulaobei Formation. They differ from *P. concentrica* (Sin et Liu) Vidal in lacking a porous radially ornamented outermost lighter layer. *P. spongia* sp. nov. has a spongy outer lighter layer and a slit-like opening. The species has been found in the Late Proterozoic Bitter Springs and Pertatataka Formations in the Amadeus Basin, central Australia. Its stratigraphic range needs more investigation. Nevertheless recent discovery suggests they occur in the Late Proterozoic. *P. binata* Timofeev is simply constructed with an inner darker body and a surrounding lighter layer. This species, which is poorly known and difficult to identify, has been found from the Changchengian Chuanlinggou Formation (Timofeev, 1966), dated at approximately 1700 Ma (Chen Jinbiao et al., 1980). It therefore has a long time range, if the radiometric ages are reliable.

Archaeoulothrix epikoila gen. et sp. nov. is chain-like, and each vesicle has an opening in its reproductive stage. This character is obviously different from any *Nostoc* or other cyanobacteria. The new genus is so named because of similarity to the modern green alga, *Ulothrix*. The chain structure must be difficult to preserve because diagenesis and laboratory processing may disrupt the elements. In the Liulaobei Formation few satisfactory specimens have been observed. Its stratigraphic range is unknown.

The name of *Lathribiosa annularis* gen. et sp. nov. is proposed for specimens forming annulated empty tubes with the annulations constricted at the one end, and tapering to a possible proboscis-like structure. The structure differs from that of cyanobacterial *Oscillatoriopsis*, in its annulation and open apical structure. The annulations of *L. annularis* are closely associated to support an empty tube. It has been suggested that it is an animal structure (personal discussion with Sun Weiguo) and similar to the worm-like fossil *Pararenicola huaiyuanensis* Wang, except for its tiny size. The observation of one modern worm *Nematoda* from Hamelin Pool, Shark Bay, Western Australia demonstrates their tubular bodies have a major diameter range of 30-60*um* (pers. commu. with Dr. J. Bauld, BMR, Canberra). Similar specimens have been reported from the Upper Riphean of northern Russia and they have been named as *Siphonophycus costatus* (Jankauskas, 1980, 1982). These annulated tubes seem to be very unlike any species of *Siphonophycus*. The Russian specimens are here considered to be so closely related to the Liulaobei material.

Many colonial microfossils have been found in the Liulaobei Formation. They include *Paleasphaeridium zonale* Yin. Ch., the vesicles of which are connected by a sheath and the vesicles are thickened around the margin; *Pyritosphaera barbaria* (=*Bavlinella faveolata*) is a spheroidal aggregate of numerous closely packed spheroidal cells; *Myxococcoides* sp. and *Synsphaeridium* sp. are vesicles arranged without order. Of these form taxa, *Paleasphaeridium zonale* has been recorded from the Middle Cambrian Tempe Formation in the Amadeus Basin and other species have been considered to have a long stratigraphic range.

The Liulaobei Formation contains abundant specimens of three species of the genus

Kildinosphaera, but it does not contain the other known species *K. lophostriata* (Jankauskas) Vidal. This species is distributed in the Upper Riphean sequences of the Soviet Union (Jankauskas, 1980), the Klubbnes and Andersby Formations of the Vadso Group and the Batsfjord and Basnaering Formations of the Barents Seas Group in Varanger Peninsula, Norway, and the Chuar Group in Arizona; the species has been considered as indicative of a Late Riphean age (Vidal, 1981b, Vidal and Siedlecka, 1983; Vidal and Ford, 1985). The absence of this species, but the presence of the other three long range species may suggest that the Liulaobei Formation is younger than the Upper Riphean.

The rocks of the Liulaobei Formation also yield several taxa, such as *Octoedryxium truncatum* (Rudavskaja) Vidal and *Leiofusa bicornata* Sin et Liu, that range back into the Middle Proterozoic. Both taxa have been recorded in the Hongshuizhuang Formation, Jixian, Hebei Province, northern China (Sin and Liu, 1973). Previously the Hongshuizhuang Formation was considered as Sinian (Sin and Liu, 1973; Vidal, 1976), and recently has been dated at 1200 Ma (Wang Yuelun et al., 1980). In the opinion of Vidal (1976) and Vidal and Knoll (1983), *O. truncatum* is an important species of the Vendian assemblage. Most likely, the species is long ranging, reaching maximum abundance in the Vendian. *L. bicornuta* has a simple form, both ends of the fusiform vesicle rapidly tapering into the spines. Such simple forms of vesicle have a long stratigraphic range. One specimen has been described from the Middle Cambrian Tempe Formation in the Amadeus Basin (Chapter IV in this thesis).

Filamentous microfossils are well-known for their long stratigraphic range. In the Liulaobei Formation more than eight form-species have been described, of which two are new. Many similar cyanobacterial filaments have been recorded from the Bitter Springs Formation in the Amadeus Basin, central Australia (Schopf, 1968; Schopf and Blacic, 1971). They are widely distributed in the chert sections from the Changchenian Tuanshanzi Formation (1800 Ma), northern China (Zhu Shixing, 1982b), the Sinian System of southern China (Wang Fuxing et al., 1983; Zhang Zhongying, 1986), the Vendian Yudoma Suite, Siberia Platform (Su-chu C. Lo, 1980) and many other places. Because of their simple and conservative structure, such filaments are of little biostratigraphic value.

Many microfossils resembling chitinozoans have been found in the Liulaobei Formation. Chitinozoan-like (or vase-shaped) microfossils have been reported in the Proterozoic from the Upper Riphean to the Vendian (Vidal and Knoll, 1983; Knoll, 1982; Knoll and Vidal, 1980; Knoll and Calder, 1983; Bloeser et al., 1977; Bloeser, 1985). The chitinozoan-like microfossils from the Liulaobei Formation are diverse and display complicated structures; one specimen (pl.XVI, fig.H) looks like a Late Proterozoic species *Desmochitina acrollaris* Eisenack, 1959, but it has a spongy wall. Some are very large (180*u*m) (pl.XVI, fig.K), and some seem to have an operculum structure (pl.XVI, fig.B), and others display a long neck or double walls (pl.XVI, fig.C). Further research is needed. A younger rather than an older date for the occurrence is more probable on the basis of this information.

Nine limestone samples have been processed from the Liulaobei Formation and their isotopic $\delta^{13}C$ values range from +0.8 to +2.3 per mil. These values are very similar to those from the upper Sinian sequence in the Yangtze Gorges, south-central China (Lambert et al., 1987), and possibly suggest that the sediments are older than the Cambrian. Rapid shifts of $\delta^{13}C$ values from the positive to negative usually happen across the Proterozoic - Cambrian transition (see Lambert et.al., 1987; Zang et al., in preparation).

It is concluded that the Liulaobei Formation is not older than the Sinian. Most likely it belongs to the late Sinian and was deposited after the Nantuo glaciation. A difficulty with the data available at present is that the ranges of some species do not overlap. Some indicate an age no older than Cambrian and some no younger than Sinian. Though a late Sinian age has been preferred, we cannot exclude older or younger ages.

2.3.8. Fengtai Formation

The diamictite of the Fengtai Formation disconformably overlies the Sidingshan Formation and disconformably underlies the Lower Cambrian Houjiashan Formation. Most of the clasts in the diamictite come from the underlying Sidingshan dolomite, some from the Jiuliqiao limestone and Shouxian sandstone, and few from the Liulaobei shale or metamorphic basement rocks. The clasts are generally angular, from several millimetres to dozens of centimeters, and the largest ones up to 70-90cm. The matrix is hematitic silty carbonate, and pinkish or brownish in weathering colour. The Fengtai Formation is distributed in several restricted localities in the Huainan - Huoqiu region, with a thickness of 0 - 210m.

The Fengtai Formation is probably a glacial deposit. Striated pavements on the Sidingshan dolomite and striated stones have been recorded (Zheng Wenwu and Dou, 1980; Ren Runsheng, 1982). Several varve-like layers are exposed in the middle part of the diamictite. The layers are dolomitic silty deposits, and well-laminated. Each lamina is slightly different in colour. Some small dropstones or pebbles occur in the laminae, displaying disruptive laminae at the bottom and draping of sediment over the top of the pebbles (pl.I, fig.C).

The stratigraphic correlation of the diamictite has been discussed differently. It has been considered as Early Cambrian (Zheng Wenwu, 1980), or latest Proterozoic (Ren Runsheng, 1982), or the equivalent of the Nantuo glacials (Sun Weiguo et al., 1986). Currently the diamictite is correlated with the Luoquan Tillite in Henan Province, central China (Ren Runsheng, 1982). The Luoquan Tillite has been suggested to be correlative with the Nantuo Formation (Li Qingzhong, 1980; Mu Yongji, 1981), the Varangerian (Chumakov, 1981), the latest Proterozoic (Wang Yuelun et al., 1980; Guan Baode et al., 1980, 1983, 1986), and the earliest Cambrian (Wang Yuelun et al., 1981).

The Fengtai Formation (corresponding to the Luoquan Tillite) is difficult to correlate with the Nantuo Formation because the two glaciations occurred on different platforms, which were separated widely based on palaeomagnetic evidence (Lin Jinlu et al., 1985). The Fengtai Formation has a reversed magnetic polarization, but no evidence of this occurs in the Nantuo Formation (Yan Yongkui et al., 1984, p.147). After studying microfossil assemblages from the Dongjia Formation and Luoquan Tillite, and stratigraphic distribution of the tillites, Guan Baode et al. (1986) suggested the Luoquan Tillite was of a post-Nantuo or a post-Varangerian age. In the Huainan region, the microfossil assemblage in the Liulaobei Formation, which is exposed more than 500m below the Fengtai Formation, probably indicates a late Sinian age. The Fengtai diamictite, therefore, cannot be older than late Sinian.

Tillites are widely distributed in the Late Proterozoic. In Kuruktag, Xinjiang, northern China, there are three tillites units separated by normal marine deposits (Wang Yuelun et al., 1981; Gao Zhenjia et al., 1983). The Fengtai Formation has been considered to correlate with the uppermost Hangeerqiaoke Formation, belonging to the latest Proterozoic (Dou Shouchu et al., 1983).

2.4. HUAIBEI GROUP

2.4.1. Definition and Age

Upper Proterozoic Huaibei Group (cf. Cao, Zhao and Xia, 1985) consists of carbonates and clastic deposits exposed in the north on the Huaihe River, northern Anhui and Jiangsu Provinces. The group includes thirteen formations, which are exposed at several separated localities. It is more than four thousand meters thick. Several schemes of the subdivision for the group have been proposed (Text-figure II-8).

The stratigraphic column (Text-figure II-9) of the Huaibei Group is mainly based on the correlation by lithology and stromatolites, and is very tentative. The Lanling, Xingxing and Jushan Formations exposed in southern Shandong Province are suggested as the lowest units in the Huaibei Group (Yang Qinghe et al., 1980; Zhang Shien et al., 1984; Cao Ruiji et al., 1985), but Zhang Pifu (1985) considered they were correlated with the Jingshanzhai Formation, the uppermost part of the group. Metamorphic or granitic basement is not exposed in the region and the limestones of the Jiayuan Formation (the lowest formation of the group in this region) are dated at 738.5 Ma by the K-Ar method (Yang Qinghe et al., 1980; Zhang Shien et al., 1984). The upper part of the group is the Jingshanzhai and Gouhou Formations, which are disconformably overlain by the Lower Cambrian Houjiashan Formation. The two formations were previously considered as the Upper Sinian, but recently shelly fossils, *Actinotheca* sp. and *Chancelloria* sp. have been found in the lower part of Jingshanzhai Formation (Zhou Benhe et al., 1984).

Stratigraphic correlation between the Huaibei Group and other Upper Proterozoic sequences is not satisfactory. The use of stromatolites for stratigraphic correlation in this region has been doubted, because the morphogenesis of these bio-sedimentary constructions is more or less controlled by environment and the constructing organisms (Walter, 1977); a number of forms of stromatolites are demonstrated as long ranging; and furthermore, in this region there are taxonomic problems. More detailed work is necessary.

Yang et al. 1980			Yao and Zhang, 1983			Zhang et al., 1984		Cao et al., 1985	
Sinian	Suxian Group	Gouhou Fm.	Sinian	Lan'gan Group	Gouhou Fm.	Sinian	Gouhou Fm.	Huaibei Group	Gouhou Fm.
		Jingshanzhai Fm.			Jingshanzhai Fm.		Jingshanzhai Fm.		Jingshanzhai Fm.
Qingbeihouan	Xuhuai Group	Wangshan Fm.		Suxian Group	Wangshan Fm.		Wangshan Fm.		Wangshan Fm.
		Shijia Fm.			Shijia Fm.		Shijia Fm.		Shijia Fm.
		Weiji Fm.		Xuhuai Group	Weiji Fm.		Weiji Fm.		Weiji Fm.
		Zhangqu Fm.			Zhangqu Fm.		Zhangqu Fm.		Zhangqu Fm.
		Jiudingshan Fm.			Jiudingshan Fm.		Jiudingshan Fm.		Jiudingshan Fm.
		Niyuan Fm.			Niyuan Fm.		Niyuan Fm.		Niyuan Fm.
		Zhaowei Fm.			Sidingshan Fm.		Zhaowei Fm.		Zhaowei Fm.
	Huainan Group	Jiayuan Fm.			Jiuliqiao Fm.		Jiayuan Fm.		Jiayuan Fm.
		Jushan Fm.		Bagonhshan Group	Sishilichangshan Fm.		Jushan Fm.		Jushan Fm.
		Xingxing Fm.			Liulaobei Fm.	Qingbei-Kouan	Xingxing Fm.		Xingxing Fm.
		Langling Fm.			Wushan Fm.		Langling Fm.		Langling Fm.

Text-fig. II-8 Subdivision schemes of the Upper Proterozoic sequences in the Huaibei region, northern Anhui and Jiasngsu Provinces, central eastern China.

Isotopic dates from the group are questionable. For example, the Shijia Formation has been dated by the K-Ar method at 780 Ma, 787 Ma, 765 Ma, 738 Ma (Yang Qinghe et al., 1980), and 681 Ma (Fang Dajun et al., 1983). The rocks considered as the lower parts of the group, the Lanling, Xingxing and Jushan Formations, are dated as younger than 700 Ma old (Yang Qinghe et al., 1980). The Jingshanzhai Formation was previously dated as 647 Ma (K-Ar), but small shelly fossils have been found in the lower part of the formation. The microfossil investigation of the Huainan Group contains the material collected from the upper ten formations and the lower three formations: the Lanling, Xingxing, Jushan Formations were not included in this study.

2.4.2. Description of Stratigraphy

The Huaibei Group in southern Shandong Province, eastern China unconformably overlies the metamorphosed basement of the Taishan Group (Archaean?), and disconformably underlies the Lower Cambrian Houjiashan Formation in northern Anhui and Jiangsu Provinces. The group contains very thick carbonate sediments (more than 2500m) and some clastic rocks near the top. Abundant stromatolites have been collected; in particular, reddish stromatolitic limestone of the Weiji Formation has been mined as an ornamental building material.

Jiayuan Formation. The formation consists of grey limestone and silty limestone of lithofacies 3. The thickness of the unit varies from 187-689m and the lower part of the formation is covered. Based on the drill core at the Nizhuang, Pixian of northern Jiangsu, the limestone conformably lies on quartz sandstone (Yang et al., 1980). Some well-bedded silty limestones contain microfossils. An isotopic age for chlorite is 738 Ma (Yang Qinghe et al., 1980).

Zhaowei Formation. This unit consists mainly of limestone with some dolomite, calcaceous shales and silty limestone. The limestone contains two layers of stromatolites and is attributed to lithofacies 2. The formation is relatively stable in thickness (210-457m) and well exposed at the Zhaowei section of northern Jiangsu and the

Qingtongshan section, Suxian of northern Anhui; it conformably overlies the Jiayuan Formation and underlies the Niyuan Formation; however, at the Mandingshan section, Suxian County of northern Anhui, it is overlapped by Cambrian sediments. Some silty limestones yield microfossils.

Niyuan Formation. At the base are several layers of intraclast limestone which conformably overlie the Zhaowei Formation. The unit consists of 140-400m of dolomite; argillaceous composition increases from the lower to upper part. Chert nodules or chert "belts", which yield abundant microfossils (mainly cyanobacterial filaments) have been found in the lower part of the formation. Intraclast structures sometimes occur interbedded with well-laminated beds in the basal formation. In the upper part, parallel layers dominate and some beds contain ripple marks and desiccation cracks.

Jiudingshan Formation. This formation contains three layers of stromatolites and its depositional environment belongs to that of lithofacies 2. Basal light-grey limestones are like "a flock of sheep" in distant view. In the Longshan section of Lingpi County, the unit contains three beds of intraclasts near the base. The formation is 117-370m thick, and is conformable with overlying and underlying units. The upper part of the formation contains cherts which yield microfossils.

Zhangqu Formation. This unit consists mainly of limestone and outcrops completely in the type section near Zhangqu Village, Lingpi County of northern Anhui, about 370m thick. The upper part of the formation contains stromatolites and at the base is a bed of 10cm thick intraclast limestone. Parallel beds dominate the sediments.

Weiji Formation. The formation consists of limestone interbedded with dolomite, silty limestone and shales, 211-319m thick. It conformable overlies the Zhangqu Formation. Its upper part contains abundant stromatolite bioherms; more than three groups have been described from its lower part. Interbedded shales yield *Chuaria circularis* (Zhang Shien et al., 1984). The limestone belongs to lithofacies 2.

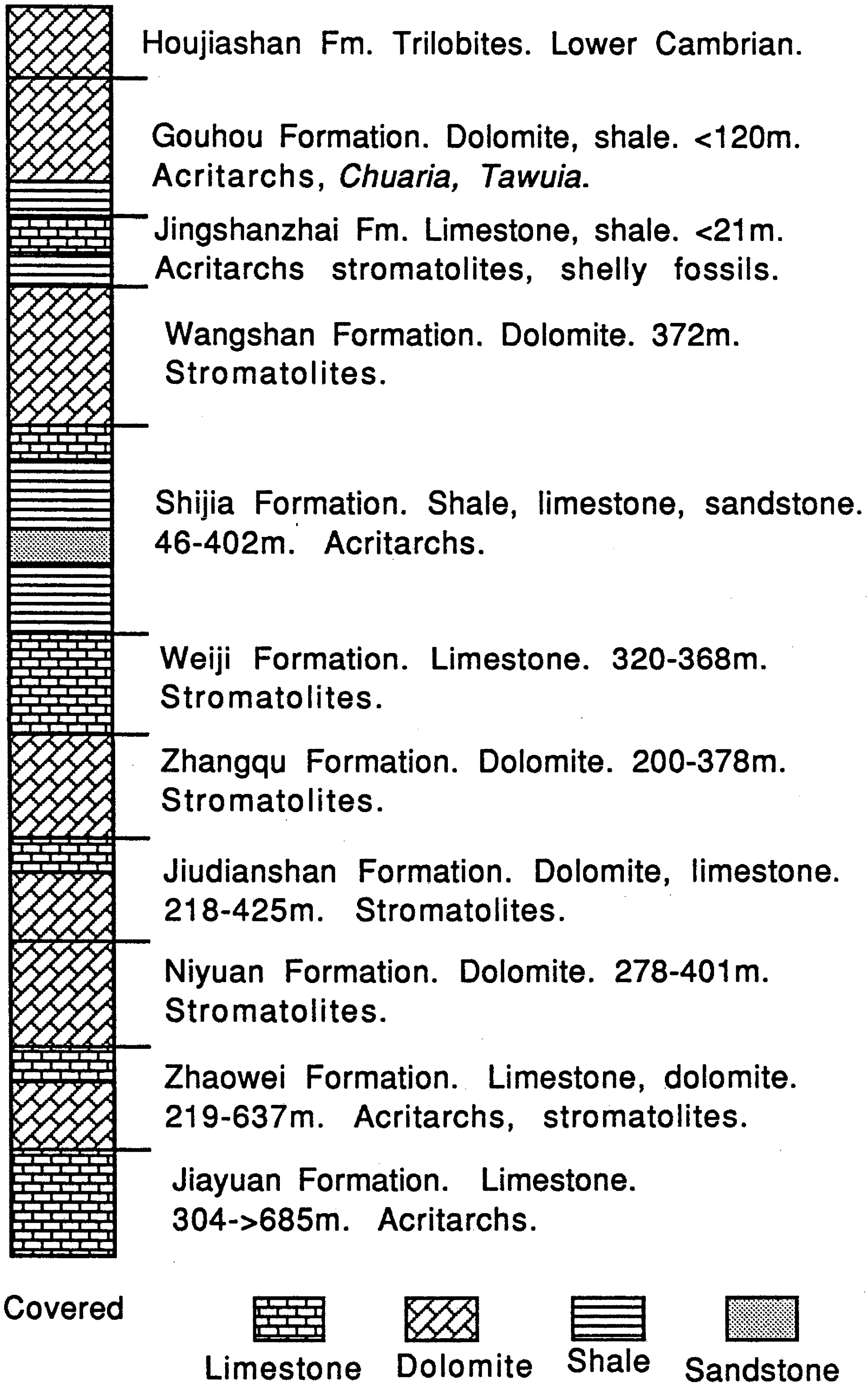
Shijia Formation. The unit consists of shale interbedded with silty limestone and sandstones. The formation is mainly exposed at the Shijia - Heifengling district in Suxian

County of northern Anhui, 380-400m thick and belongs to lithofacies 5. Its shales yield abundant organic matter, including mega-algal fossils *Chuaria circularis*, *Tawuia dalensis* and microfossils; its interbedded silty limestones contain stromatolites and intraclast structures. The formation grades upward into the carbonates of the Wangshan Formation.

Wangshan Formation. This consists of carbonate and is 470-566m thick at the Wangshan - Jingshanzhai district in Suxian County, northern Anhui. Its lower part consists of interbedded limestone, dolomitic limestone and calcaceous shale. Parallel beds dominate, and no stromatolites have been found (lithofacies 1). The upper part of the formation contains stromatolites; some large ripple marks, synaeresis cracks and chert nodules are observed (lithofacies 2). Some microfossils have been collected from the interbedded calcaceous shales (Yan Yongkui, 1984).

Jingshanzhai Formation. The basal 20-70cm of the formation consists of siliceous conglomerate which unconformably overlies the Wangshan Formation. A bed of silty dolomite, which contains small stromatolites, overlies the conglomerate, then covered by about 2m of green, grey or dark grey shales. The shales of the formation yield microfossils, *Chuaria circularis* and *Tawuia dalensis*, and possible soft-bodied metazoan fossils (Zhang Shien et al., 1984). The upper of the formation consists of stromatolitic limestone with several thin beds of shales at the top. The formation is 21-22m thick and belongs to lithofacies 2.

Gouhou Formation. The formation is the uppermost unit of the Huaibei Group, and is 115-119m thick. It conformably overlies the Jingshanzhai Formation and unconformably underlies the Lower Cambrian Houjiashan Formation. The distribution of the formation is restricted to the Heituwo - Lushan district in Suxian County. The formation consists of dolomite interbedded with shale and silty limestone, and it contains desiccation cracks, ripple marks, cross-bedding, and halite pseudomorphs. It has been referred to lithofacies 4. The shales yield abundant microfossils.



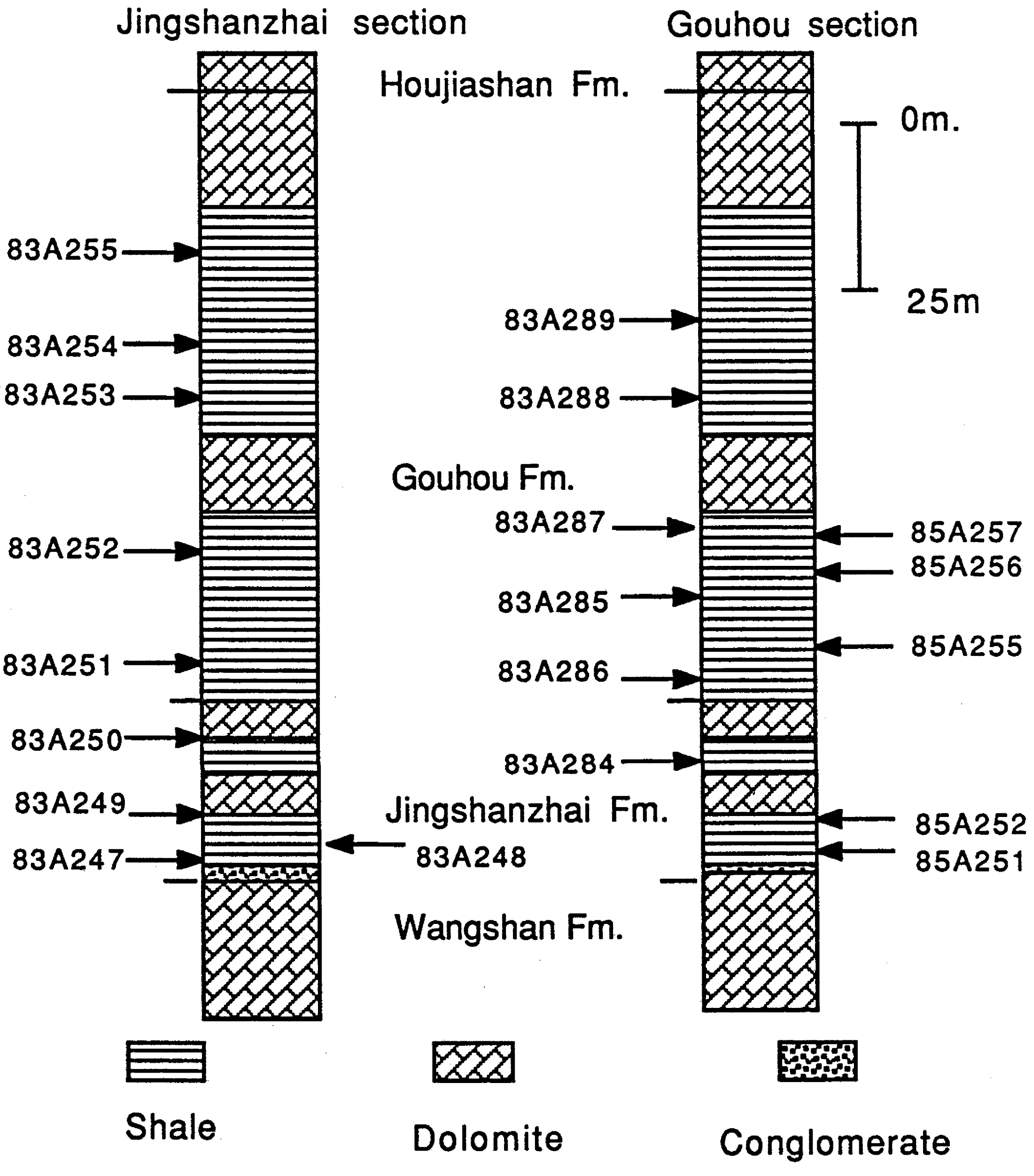
Text-fig. II-9. Generalized sequence of the Huaibei Group in the Huaibei region, northern Anhui and Jiangsu, central eastern China.

2.4.3. Microfossils from the Gouhou Formation

The Jingshanzhai and Gouhou Formations are the uppermost rock units of the Huaibei Group, and disconformably underlie the Lower Cambrian Houjiashan Formation and overlie the Upper Proterozoic Wangshan Formation. Both formations consist of silty limestones and interbedded shales. As mentioned above, sedimentary structures indicate arid littoral, supralittoral or lagoonal environment. The Jingshanzhai Formation contains stromatolites and the Gouhou Formation contains abundant microfossils, which provide evidence for the biostratigraphic correlation. Samples for microfossil investigation were collected from interbedded shales (Text-figure II-10).

The two formations are traditionally considered as Late Proterozoic in age (Yang Qinghe et al., 1980; Zhang Shien et al., 1984; Cao Ruiji et al., 1985; Yao Zhongbo et Zhang, 1983). The K-Ar method has given an age of 647 Ma for the Jingshanzhai Formation (Yang Qinghe et al., 1980). This formation contains abundant stromatolites: *Acaciella multia* Cao, Zhao and Xia, *Xiejiella formosa* Cao, Zhao and Xia, *X. nodosa* Cao, Zhao and Xia, *Jinshanzhaiella pulchellusa* Cao, Zhao and Xia, *Boxonia jinshanzhaiensis* Cao, Zhao and Xia, and *Acaciella gouhouensis* Cao, Zhao and Xia (Cao, Zhao and Xia, 1985). Previous microfossil investigation on the Gouhou Formation suggested the assemblage belonged to the late Sinian (Yan Yongkui, 1984).

However, stratigraphic correlation of the Jingshanzhai and Gouhou Formations has been questioned. Yang Qinghe et al. (1980) considered that the disconformity between the Gouhou and Houjiashan Formations was not clear; the upper Gouhou Formation and lower Houjiashan Formation were similar grey or yellow silty dolomites or silty limestones, and both formations contain halite pseudomorphs; the identification of a disconformity was based on the presence of a layer 10-20cm thick of fine conglomeratic, silty dolomitic limestone; the rocks below and above the layer seem identical. Thus if the hiatus exists, it may be only a small break. The rocks 25m above the disconformity yield the trilobite *Megapalaeolenus fengyangensis*, which indicates a mid-Early Cambrian age. It must be noted that shelly fossils *Actinotheca* sp. and *Chancelloria* sp. have been reported from the lower Jingshanzhai Formation (Zhou Benhe et al., 1984). These shelly fossils have been found from the Lower Cambrian rocks on the South China Platform.



Text-fig. II-10. Generalized geological log of the Jingshanzhai and Gouhou Formations. Sample levels are indicated by arrows.

The K-Ar date from the Jingshanzhai Formation is possibly not reliable. In the Huaibei Group, K-Ar dates of 662 Ma for the lowest Lanlin Formation, 669 Ma for the Xingxing Formation, and 661 Ma for the Jushan Formation have been obtained, but ages for the overlying Shijia Formation are older than 730 Ma (Yang Qinghe et al., 1980). The stromatolites from the Jingshanzhai Formation consists of six forms (Cao, Zhao and Xia, 1985), but all are known only from the Jingshanzhai - Gouhou district.

The microfossils from the Gouhou Formation in this study suggest that the formation may belong to Lower Cambrian. The assemblage consists of thirty species and some unidentified specimens. The microfossils are listed in Text-figure II-11.

Volkovia was erected by Downie (1982) for vesicles bearing a single prominent spine at one pole and an operculum or opening at the other. Previously these specimens were referred to *Deunffia* Downie (Volkova, 1969; Jankauskas, 1975). *Volkovia flagellata* (Jankauskas, 1975) Downie, 1982 (= *Deunffia flagellata* Jankauskas, 1975, pl.XI, fig.47-50, 55) was described as ovate vesicles with one pole terminating in a short pointed flagelliform process and the other pole with smoothly rounded opening. The specimens have been recorded from the Lower Cambrian Vergale and Rausve Horizons of the Baltic region (Jankauskas, 1975). This species has been found from the Gouhou Formation and on information available at present it probably indicates a Lower Cambrian age.

Complanate-ovate vesicles with an opening at one pole are assigned to genus *Ovulum* Jankauskas, 1975. The species, *Ovulum saccatum* Jankauskas, is characterized by smooth, ovate, saccate vesicles, with one pole rounded and the other having a large oval opening. Eleven specimens belonging to this species have been observed from the Gouhou Formation. The species has been reported from the Lower Cambrian Vergale Horizon (Latvia, Lithuania, Ukraine), Rausve Horizon (Estonia, Latvia, Lithuania, Ukraine); Lower? Cambrian Izhora Horizon (Leningrad); Middle Cambrian Kibartai Horizon (Latvia); and Scottish Lower Cambrian Fucoid Beds (Jankauskas, 1975). No specimens have been reported from the Late Proterozoic so far.

Micrhystrids in the assemblage include *Micrhystridium brevicornum*, *M. circulapertum* sp. nov. and some unidentified specimens. *M. brevicornum*, characterized by its short spines with semicircular or truncate apices, has been found from the Lower Cambrian Vergale Horizon of the Soviet Union (Volkova et al., 1979), and the Lower Cambrian from Greenland, Norway, Alberta and Scotland. *M. brevicornum* is possibly a Cambrian taxon. *M. circulapertum* sp. nov. is a persistent taxon, and has been found in the late Sinian Liulaobei Formation and early Late Proterozoic Bitter Springs Formation.

The micrhystrids in the Gouhou Formation include some new forms. One unnamed specimen (pl.XIX, fig.D) has the processes thickened or rounded at the apices. Insufficient material is available to discuss its nomenclature in this study.

Archaeodiscina umbonulata Volkova, 1968, is a questionable form-taxon, a smooth spheroid with an umbrella-like inner darker body. The darker body (or black spot) has been interpreted in different ways in literature. Timofeev (1966, 1969) considered the darker spots in the vesicles were the remains of nuclei, and he proposed a new genus *Nucellosphaeridium*. According to Downie (1982), *Nucellosphaeridium* Timofeev is congeneric with *Archaeodiscina*. In previous descriptions, at least some of the species of *Nucellosphaeridium* have been transferred to *Pterospermopsimorpha* Timofeev (Vidal, 1976). Such spot structures have generated much debate (Schopf, 1968; Oehler, D., 1976; Oehler, J., 1977; Nyberg and Schopf, 1984; Awramik et al., 1972; Knoll and Barghoorn, 1975; Peat et al., 1978). The observation of a green alga, *Enteromorpha lingulata*, suggests that all the cell contents, such as nucleus and organelles, would get concentrated to form a darker spot when cells died (pl.III, fig.D). Thus darker spots interpreted as the remains of nuclei or pyrenoids may be questioned. The darker spot structure of *A. umbonulata* is regular umbrella-like form, and it is probably different from those darker spot structure of *Nucellosphaeridium*. *A. umbonulata* has been reported from the Lower Cambrian of the Soviet Union (Volkova et al., 1979), Scotland, Alberta, Newfoundland and Norway (Downie, 1982), Spitsbergen (Knoll and Swett, 1987) and the Lower Cambrian Qiongzhusi Formation on the South China Platform (Chapter III in this thesis). Three specimens have been found in the Gouhou Formation.

Leiomarginata cf. *simplex*, as mentioned above, has been widely recorded from the

	Late Proterozoic			Northern Anhui	
	Lower Sinian	Upper Sinian	Lower Cambrian	Liulaobei Fm.	Gouhou Fm.
Archaeodiscina umbonulata		- -	- -		- -
Chuaria circularis	- -	- -	- -	- -	- -
Dictyotidium regulare	- -	- -	- -	- -	- -
Gloeodiniopsis cf. *lamellosa*	- -	- -	- -	- -	- -
Kildinosphaera chagrinata	- -	- -	- -	- -	- -
Kildinosphaera granulata	- -	- -	- -	- -	- -
Kildinosphaera verrucata	- -	- -	- -	- -	- -
Leiofusa sp.			- -		- -
Leiomarginata ? *simplex*		- -	- -	- -	- -
Leiosphaeridia asperata	- -	- -	- -	- -	- -
Lophosphaeridium tuberosum		- -	- -	- -	- -
Micrhystridium brevicornum			- -		- -
Micrhystridium circulapertum		- -	- -	- -	- -
Micrhystridium sp.		- -	- -	- -	- -
Ovulum saccatum			- -		- -
Protoleiosphaeridium densum	- -	- -	- -	- -	- -
Protoleiosphaeridium flexuosum	- -	- -	- -	- -	- -
Protoleiosphaeridium laccatum	- -	- -	- -	- -	- -
Pyritosphaera barbaria	- -	- -	- -	- -	- -
Sinianella uniplicata		- -	- -	- -	- -
Sinianella scabrata		- -	- -	- -	- -
Stictosphaeridium sp.	- -	- -	- -	- -	- -
Synsphaeridium sp.	- -	- -	- -	- -	- -
Tawuia dalensis		- -	- -	- -	- -
Trachysphaeridium cf. *laminaritum*	- -	- -	- -	- -	- -
Volkovia flagellata			- -		- -
Eomycetopsis robusta	- -	- -	- -	- -	- -
Siphonophycus sp.	- -	- -	- -	- -	- -
cf. *Melanocyrillium* spp.	- -	- -	- -	- -	- -

Text-fig. II-11. Microfossils from the Lower Cambrian Gouhou Formation in northern Anhui and the occurrence in the Liulaobei Formation is indicated. Their stratigraphic ranges in the Sinian and Lower Cambrian in China are shown. The symbol -- indicates the occurrence.

Cambrian in the Soviet Union (Volkova et al., 1979), and from the Sinian Liulaobei Formation. The study of the Australian material suggests this species are abundant in the early Late Proterozoic Bitter Springs Formation in the Amadeus Basin. The species is a long-ranging taxon.

The microfossil assemblage of the Gouhou Formation contains some unidentified specimens. Three specimens display a "median split" on the surface (pl.XIX, fig.S). The "median split" is 0.5 - 1*um* wide, straight or slight sinuous and does not reach the margin of the vesicle. The split does not seem to be a deformation structure because the surface ornamentation of vesicle has not been diagenetically damaged. The appearance of a "median split" may suggest an evolutionary innovation. One questionable specimen (pl.XIX, fig.O) has many relatively regular openings.

The microfossils from the Gouhou Formation include many pre-existing taxa. Of a total of thirty form-taxa include twenty-four also occur in the Liulaobei Formation. The following similarity coefficients have been calculated for the two formations.

SIMPSON CO. = 80
JACCARD CO. = 0.47
DICE CO. = 0.64

However, in interpreting these coefficients we should note the presence of very simple spheroidal acritarchs, which are independent of the environment, and generally have a long stratigraphic range. The species *Kildinosphaera chagrinata*, *K. granulata*, *K. verrucata*, *Leiosphaeridia asperata*, *Protoleiosphaeridium densum* (Timofeev), *P. flexuosum*, *P. laccatum*, *Stictosphaeridium* sp., *Synsphaeridium* sp., *Trachysphaeridium* cf. *laminaritum* (Timofeev), *Pyritosphaera barbaria*, and *Sinianella uniplicata* are known ranging from the Late Proterozoic to Late Palaeozoic; some may even go further back to the Middle or Early Proterozoic, and hence have no significance for stratigraphic correlation.

The *Chuaria* - *Tawuia* assemblage in the Gouhou Formation may be the youngest occurrence so far reported. In the Huaibei Group, at least other three underlying formations have been found to contain this assemblage; they are Weiji, Shijia and Jingshanzhai Formations.

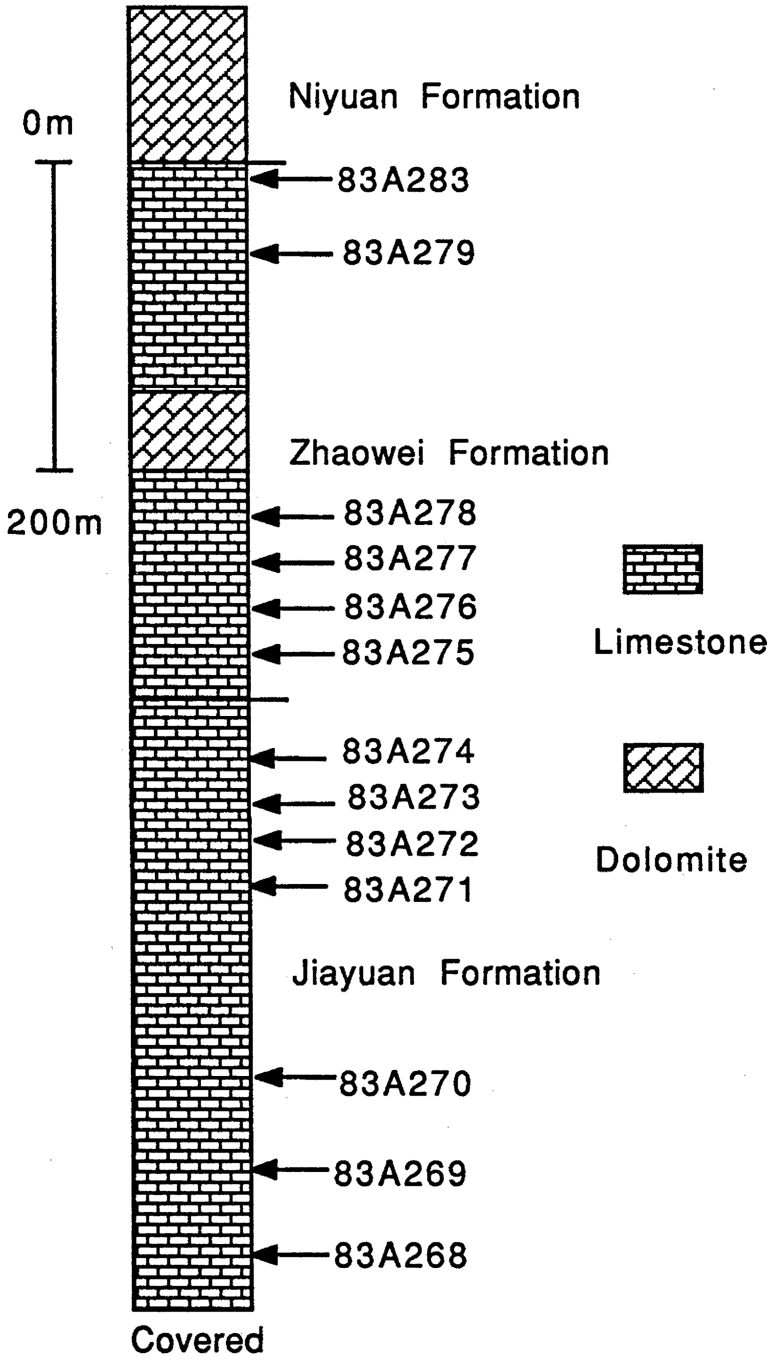
$\delta^{13}C$ analysis for the dolomite from the Gouhou Formation gives a negative value (-2.58 per mil) at the Jingshanzhai section. Six carbonate samples from the underlying Wangshan Formation are positive (+3.1 to +5.65 per mil) and one negative value has been detected from the Jingshanzhai Formation. The shift of the values in the Proterozoic - Cambrian transition, in correlating with the values from the Sinian sequence in the Yangtze Gorges, may suggest a Cambrian age for the Gouhou Formation (Lambert et al., 1987; Zang et al. in preparation).

2.4.4. Microfossils from Silty Carbonates

The Jiayuan, Zhaowei, Niyuan and Jiudingshan Formations consist mainly of carbonate rocks, about 2000m thick. The rocks contain stromatolites and black cherts in which well preserved microfossils have been found. The Jiayuan and Zhaowei Formations at the Zhaowei section, Tongshan County, Jiangsu Province contain interbedded argillaceous limestones which yield microfossils (Text-figure II-12).

The carbonate sequence of the Huaibei Group has been considered as Sinian (Zhang Shien et al., 1984), or Qingbeikouan (Yang et al., 1980). Cao Ruiji et al., (1985) subdivided stromatolites from the Huainan and Huaibei Groups into three sub-assemblages. The stromatolites from the Jiayuan Formation include *Jurusania* cf. *cylindrica* Krylov and *Baicalia dentata* Cao, Zhao et Xia, and from the Zhaowei Formation include *Jurusania* cf. *alicia*, *Tungussia* and *Conophyton lijiadunensis*, and many forms also known from the Jiudingshan Formation. The stromatolites of the Jiudingshan Formation belong to the second sub-assemblage, which includes *Katavia*, *Gymnosolen*, *Linella*, *Tungussia*, *Inzeria*, *Baicalia*, *Jurusania*, and *Conophyton lijiadunensis*. The sub-assemblage, according to Cao Ruiji et al. (1985), could be correlated with stromatolite assemblage in east Liaoning, and is similar to that of the Loves Creek Member of the Bitter Springs Formation in the Amadeus Basin of central Australia. Thus the formation has been thought to be older than the Sinian.

Stromatolite growth is controlled by water conditions and sunlight (Walter, 1977). The



Text-fig. II-12. Geological log of the Jiayuan and Zhaowei Formations at the Zhaowei section, northern Jiangsu, central eastern China. Sample levels are indicated by arrows.

forms may vary for different direction or velocity of water current, thus identification is always a problem. The use of stromatolites for intercontinental stratigraphic correlation has been seriously questioned.

The abundant microfossils have been described from the chert sections of the Niyuan and Jiudingshan Formations, including *Eomycetopsis*? *campylomitus* Lo, *Siphonophycus* sp., *Eoentophysalis yudomatica* Lo, *Eoentophysalis*? sp., *Aphetospora entheia* Lo, *Globophycus rugosum* Schopf, *Gloeodiniopsis lamellosa* Schopf, *Bigeminococcus* sp., *Huroniospora* sp., *Eozygion* sp., *E.* sp., *Tetraphycus* sp., *Caryosphaeroides* sp., *Eotetrahedrion* sp., *Micrhystridium* sp., and other unnamed forms (Zhang Zhongying and Yan, 1984). This assemblage is somewhat similar to that of the lower Yudoma Suite, eastern Siberia (Su-chu C. Lo, 1980).

The acid-resistant microfossils from the argillaceous limestones of the Jiayuan and Zhaowei Formations are relatively abundant. Cyanobacterial filaments include *Eomycetopsis robusta*, *E. spiralata* and *Siphonophycus* sp.. Spheroidal acritarchs contain 17 species and their assemblage resembles, in correlation with other assemblages in northern Anhui and Jiangsu Provinces, that of the Sinian Liulaobei Formation rather than that of the Lower Cambrian Gouhou Formation (Text-figure II-13). Coefficients used to correlate the Liulaobei Formation and the Gouhou Formation are as follows:

With the Liulaobei Formation: SIMPSON Co. = 100
JACCARD Co. = 0.54
DICE Co. = 0.70
Where: A=39, B=21, K=21.

With the Gouhou Formation: SIMPSON Co. = 76
JACCARD Co. = 0.50
DICE Co. = 0.67
Where: A=27, B=21, K=16.

The coefficients suggest the assemblage probably has a Sinian age.

	Zhaowei-Jiayuan Formations	Liulaobei Formation	Gouhou Formation
Alliumella baltica	--	--	
Dictyotidium regulare	--	--	--
Favosophaeridium favosum	--	--	--
KIldinosphaera chagrinata	--	--	--
Kildinosphaera granulata	--	--	--
Leiofusa bicornuta	--	--	
Leiomarginata ? simplex	--	--	--
Leiosphaeridia asperata	--	--	--
Lophosphaeridium tuberosum	--	--	--
Lophosphaeridium sp.	--	--	
Micrhystridium oligum	--	--	
Micrhystridium sp.	--	--	--
Octoedryxium truncatum	--	--	
Protoleiosphaeridium densum	--	--	--
P. flexuosum	--	--	--
P. laccatum	--	--	--
Pyritosphaera barbaria	--	--	--
Sinianella uniplicata	--	--	--
Stictosphaeridium sp.	--	--	--
Synsphaeridium sp.	--	--	--
Trachysphaeridium laminaritum	--	--	--
Eomycetopsis robusta	--	--	--
Eomycetopsis spiralata	--	--	
cf. *Melanocyrillium* sp.	--	--	--

Text-fig. II-13. Microfossils from the Zhaowei and Jiayuan Formations in northern Anhui and Jiangsu Provinces, central eastern China. Their occurrences in the Liulaobei and Gouhou Formations have been shown. The symbol -- indicates the occurrence.

Alliumella baltica, Micrhystridium sp. and other spheroidal species probably range from the Late Proterozoic to Early Cambrian and do not indicate a precise stratigraphic position. The Jiayuan and Zhaowei Formations in northern Anhui and Jiangsu Provinces are more than two thousand meters below the possible Proterozoic - Cambrian transition and no tillites exposed. In association with the other information from the cherty microfossil assemblage (Zhang Zhongying and Yan, 1984), it is suggested that the Jiayuan and Zhaowei Formations are possibly of late Sinian age.

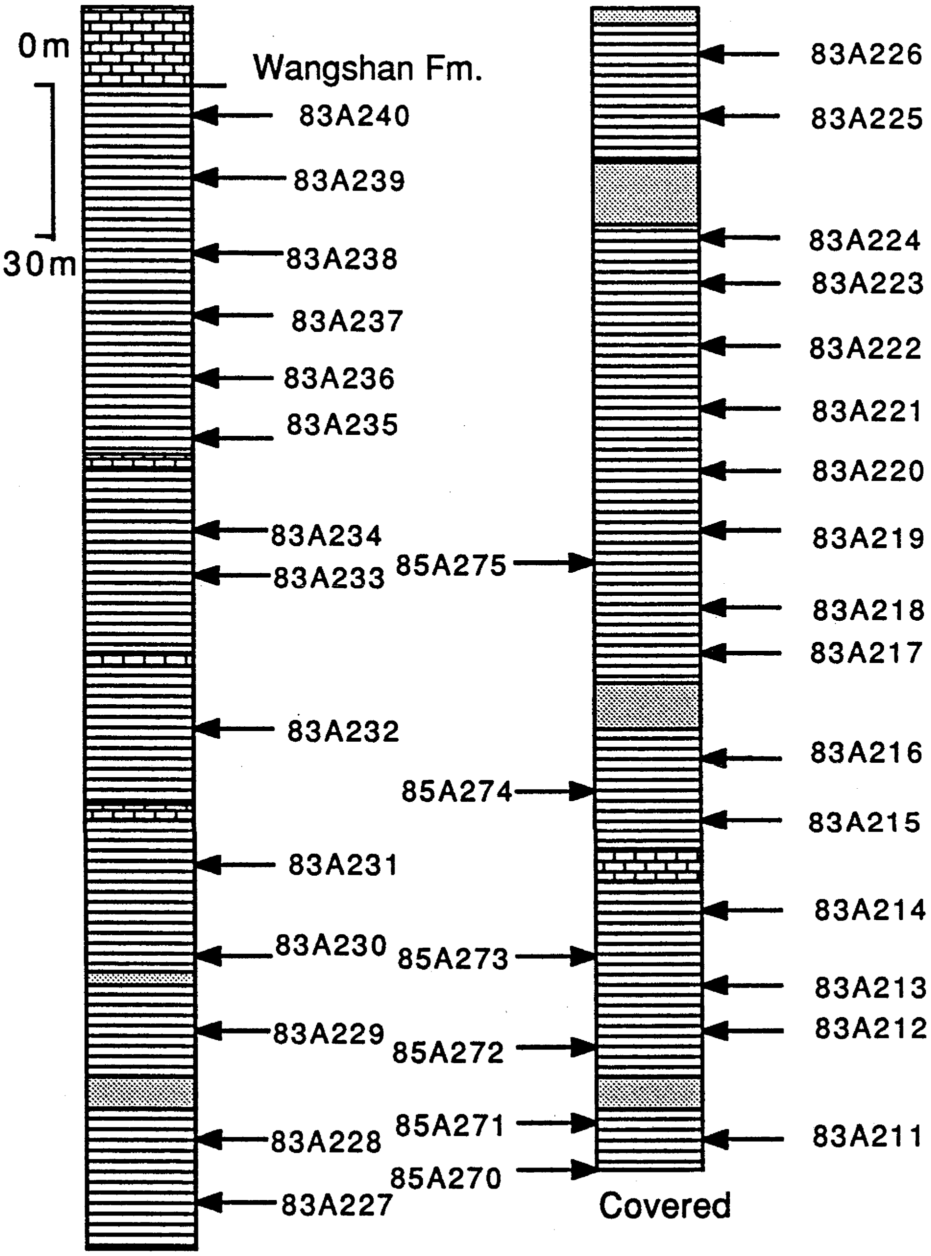
2.4.5. Microfossils from the Shijia Formation

The Shijia Formation outcrops mainly in the Heifengling - Wangshan district, Suxian County in northern Anhui. The lower part of the formation contains shales interbedded with silty dolomites. The rocks are folded and slightly metamorphosed, and few microfossils have been found. The lower part of the formation at the Heifengling section is exposed separately with the upper part at the Shijia section.

The Shijia Formation contains the stromatolite *Katavia dalijiaensis* Cao et Zhao, which belongs to the second stromatolite sub-assemblage (Cao Ruiji et al., 1985). Isotopic dating, 738, 765, 787, 780 Ma (K-Ar) (Yang Qinghe et al., 1980) and 681 (K-Ar) (Fang Dajun et al., 1983), give no consistent age.

The samples for microfossil study were collected from the Shijia section (Text-figure II-14) and the assemblage contains abundant *Chuaria circularis, Tawuia dalensis, Leiosphaeridia asperata, Lophosphaeridium tuberosum,* and other spheroids in *Protoleiosphaeridium, Trachysphaeridium, Kildinosphaera, Pyritosphaera, Sinianella* and *Stictosphaeridium.* No micrhystrids or other spinose acritarchs have been observed. This assemblage does not provide good evidence for biostratigraphic correlation.

The Shijia Formation is probably of a late Sinian age. It occurs between the Lower Cambrian Gouhou Formation and the Sinian Jiayuan and Zhaowei Formations. Thus the formation is possibly younger than the isotopic dates indicate. Wang Guixiang and Yan



Text-fig. II-14. Geological log of the Shijia Formation at the Shijia section in the Huaibei region, central eastern China. Sample levels are indicated by arrows.

Yongkui (1984) reported some worm-like fossils, which would help to demonstrate the age.

2.5. STRATIGRAPHIC CORRELATION

2.5.1. Intracontinental Correlation

The North China Platform was once widely separated from the South China Platform (Lin et al., 1985). The transitional belt is considered tectonically complex. It has been doubted that the two groups considered here were deposited in the same sedimentary basin in the Late Proterozoic even though now they are separated by less than one hundred kilometers.

Zhang Shien et al. (1984) considered the Huainan and Huaibei Groups had been deposited in one sedimentary basin, because the similar Shouxian Formation is exposed at the localities of Tushan, Mongchen, and Wangbu, Tongshan on the north of the Huaihe River, as well as in the Huainan and Fengyang regions on the south of the river. The detritus in the sandstone consists of quartz and feldspar. It overlies the Liulaobei Formation in both regions; chemical analysis of the rocks from the Jiuliqiao Formation of the Huainan Group and the Zhaowei and Jiayuan Formations of the Huaibei Group indicates the rocks contain the elements Ba, Ti, Ga, Co, Mo in similar proportions; both sequences contain similar sedimentary cycles; and both groups have comparable isotopic dates.

However the other evidence does not strongly support this viewpoint. In the Huainan Group, two reversed magnetic polarizations have been measured from the sandstone of the Shouxian Formation, but there is no report from the sandstone presumed as same level in the Huaibei Group (Fang Dajun et al., 1984). The Jiuliqiao Formation in the Huainan Group, according to Cao Ruiji et al. (1985), yields the stromatolites *Minjaria uralica* Krylov, *Inzeria anhuiensis* Cao, Zhao et Xia, *Baicalia* f., and *Jurusania nisvensis* Raaben; in the Huaibei Group, the Jiayuan Formation contains the stromatolites *Jurusania* cf. *cylindrica* Krylov, *Baicalia dentata* Cao, Zhao et Xia, and the Zhaowei Formation *Jurusania* cf. *alicia* Cloud et Semik, *Conophyton lijiadunensis* Tsao et Liang, and *Tungussia* f.; none of the same stromatolites are recorded from both regions. The Jiuliqiao Formation contains worm metazoan fossils, and *Chuaria - Tawuia* assemblage, but these have not been recorded from the Jiayuan and Zhaowei Formations; the silty limestones of the Jiayuan and Zhaowei Formations yield abundant microfossils, including micrhystrids, but these have not been found in the Jiuliqiao Formation. Zhang Shien et al. (1984) proposed that the Jiuliqiao Formation of Huainan Group consisting of the Jiayuan and Zhaowei Members, could be correlated with the Jiayuan and Zhaowei Formations of the Huaibei Group, but this correlation is probably not reliable because the two equivalent rock units in the same basin may not provide so different fossil assemblages. Furthermore any chemical analysis or isotopic measurement from weathered rocks may be questioned.

The stratigraphic sequences from the two groups are different. Both groups underlie Lower Cambrian rocks. The rocks underlying the Houjiashan Formation in the Huainan region consist of the latest Proterozoic Fengtai glacial diamictites and a bed of the Lower Cambrian phosphorites; in the Huaibei region the rock underlying the Houjiashan Formation are the Lower Cambrian Jingshanzhai and Gouhou Formations, but no diamictites and phosphorites are found. The Huaibei Group contains more than 2500m of carbonates and the Huainan Group is mainly clastics. The Huaibei Group overlies the Archaean metamorphosed rocks of the Taishan Group, which is exposed in Shandong Province, eastern China, several hundred kilometers distance from the metamorphosed basement of the Huainan Group, the Proterozoic Fengyang Group (895 Ma, K-Ar). Thus the two sedimentary regions were probably independent in the Late Proterozoic, at least with a major depositional separation.

Because of geographic separation the biological communities in the two regions are different. Stromatolites have few forms that are similar in the two groups. In the Huainan region, some soft-bodied worm-like fossils have been found, but few have been described from the Huaibei region so far.

Both groups yield the *Chuaria-Tawuia* assemblage. In the Huainan Group the assemblages occur in the Liulaobei and Jiuliqiao Formations; both the formations yield worm-like fossils and are determined as Late Sinian. In the Huaibei Group they are collected the late Sinian Shijia and Weiji Formations, and Lower Cambrian Jingshanzhai and Gouhou Formations which contains shelly fossils. However this assemblage has been recorded from the Middle Proterozoic Little Dal Group, northwestern Canada (Hofmann et al., 1979). Because it has a long stratigraphic range, it may be of little stratigraphic significance.

Micrhystrid acritarchs occur in both groups. In the Liulaobei Formation they are about five percent (5%) of the spheroidal acritarchs, but few micrhystrids are found from the Jiayuan and Zhaowei argillaceous limestones and the Jiudingshan and Niyuan chert sections (Zhang Shien et al., 1984). Though they suggest a late Sinian age they do not provide accurate information for correlation. Thus we should try other means for correlation.

2.5.2. Intercontinental correlation

The Sinian sequence in the Yangtze Gorges, central China, was first investigated by Lee and Chao (1924). The upper Sinian consists of the Doushantuo and Dengying Formations. The Doushantuo Formation unconformably overlies the tillite of the Nantuo Formation and conformably underlies the Dengying Formation which yields soft-bodied fossils of the Ediacara fauna (Ding and Chen, 1981; Sun Weiguo, 1986) and abundant shelly fossils in the upper part. The two formations are thought to be in a range of 700-600 Ma (Zhao Ziqiang et al., 1980).

The acid-resistant microfossils from the Sinian sequence have been well investigated (Zhao Ziqiang et al., 1980; Yin Leiming et Li; 1978). Few valuable specimens have been recorded and many species have recently been considered invalid. I have processed over twenty samples from the Doushantuo Formation and demonstrated poor preservation. Shales of the Doushantuo Formation have been slightly metamorphosed and the temperature has reached the oil window (personal discussion with Ian Lambert, CSIRO). Nevertheless some micrhystrids have been found (Yin Leiming and Li, 1978, pl.3, fig.27). Wang Fuxing and Chen (1987) described a microfossil assemblage from the Lower Cambrian Meishucun Stage on the South China Platform and it contains *Baltisphaeridium*.

The chert sections from the upper Sinian yield abundant planktonic microfossils. Yin Leiming and Li (1978) reported spinose *Tianzhushania spinosa* Yin Leiming and Li, *Asterocapsoides sinensis* Yin and Li and other species from the upper Sinian Doushantuo Formation. Micrhystrids found in the Dengying Formation include *Micrhystridium setulerum* Wang et Luo (Wang Fuxing et al., 1983), *M. minimum* Xing, and *M. ningqiangense* Xing (Xing Yusheng et al., 1983), *M. ampliatum* Wang, and *M.* spp. (Wang Fuxing, 1985). Other lavishly ornamented spinose forms of *Baltisphaeridium* and *Comasphaeridium* have been reported from the Doushantuo Formation recently (Zhang Zhongying, 1984; Awramik et al., 1985; Yin Leiming, 1986a). Also abundant large microfossils have been reported from the phosphorites (Tang Tianfu et al., 1978; Chen Meng'e et al., 1986; Zhang Yun, 1987); some specimens are up to several hundred microns in diameter and have beautifully preserved spines. The frond-like metazoan fossil *Paracharnia dengyingensis* (Ding and Chen) (Sun Weiguo, 1986) and worm fossils have been described from the Dengying Formation (Tang Tianfu et al., 1978; Luo Huilin and Zhang Shishan, 1986), in addition to *Vendotaenia, Chuaria*, *Tawuia* and other megascopic filaments (discuss in Chapter III in this thesis). The assemblage of fossils from the upper Sinian in the Yangtze Gorges more or less resembles that of the Huainan Group.

The Huainan Group contains two depositional cycles. It has been suggested that each cycle is correlated with one formation of the upper Sinian, e.g. the Shouxian, Jiuliqiao and Sidingshan Formations are suggested to correlated with the Dengying Formation, and the Liulaobei, Guanjiaying, Bagongshan and Caodian Formations with the Doushantuo Formation. This correlation leaves much to be desired. Because the hiatus between the Doushantuo and Nantuo Formations in the Yangtze Gorges cannot be measured, some upper Sinian units in the Huainan region, such as the Bagongshan and Caodian Formations, might have no equivalents in the Yangtze Gorges.

The microfossils from the Qingbeikouan (800-1000 Ma) Xiamaling Formation and the Jixianian (1000-1400 Ma) Hongshuizhuang Formation of northern China are in assemblages with low diversity. The Xiamaling assemblage contains *Trachysphaeridium*, *Microconcentrica* and other spheroids, and no spinose specimens have been reported (Luo Qiling et al., 1981). The Hongshuizhuang assemblage includes *Octoedryxium truncatum* (Rudavskaja) Vidal, *Pterospermopsimorpha concentrica* (Sin et Liu) Vidal, *Leiofusa bicornuta* Sin and Liu, *Triangumorpha striata* Sin and Liu and other common spheroids, but no micrhystrids (Sin et Liu, 1973). The microfossil assemblage from the Liulaobei Formation of the Huainan Group is more diverse and contains abundant micrhystrids. Thus the Liulaobei Formation is considered to be younger than the Xiamaling and Hongshuizhuang Formations.

After investigating the Late Proterozoic and Middle Cambrian acritarch distribution from northeastern Poland, Volkova (1969) proposed five acritarch assemblages: one for the Late Proterozoic, three for the Lower Cambrian and the other for the Middle Cambrian. The Late Proterozoic assemblage contains abundant specimens of *Leiosphaeridia*, some *Micrhystridium* cf. *tornatum*, many filaments and organic pieces, and Volkova stated that *Leiosphaeridia*-dominated assemblages were a characteristic feature of the Valdaian Series on the Russian Platform. The acritarch assemblage of the lower part of the Lower Cambrian contains *Leiosphaeridia* spp., *Micrhystridium* cf. *tornatum*, *Granomarginata prima*, *G. squamacea*, *Leiomarginata simplex*, and *Tasmanites*? *tenelus* (Volkova, 1969). The assemblages from the upper part of the Lower Cambrian and the Middle Cambrian are characterized by the occurrence of *Skiagia*, *Baltisphaeridium*, *Cymatiosphaera*, *Estiastra*, *Deunffia*, *Archaeodiscina*, *Lophosphaeridium*, abundant *Micrhystridium*, *Leiosphaeridia*, *Granomarginata*, *Pterospermopsimorpha* and other genera (Volkova, 1969). Similar assemblages have been reported by Moczydlowska (1981). Vidal and Knoll (1983) considered the first appearance of the distinctive species *Granomarginata squamacea* is a particularly good marker for the lowest Cambrian, and a drastic change follows the extremely diverse assemblages of morphologically complex acritarchs after the period of the *Holmia* " stage" (Vidal and Knoll, 1983). Further investigation has suggested that the abundant occurrences of *Skiagia* marked the Lower Cambrian acritarch assemblages (Downie, 1982; Moczydlowska and Vidal, 1986; Knoll and Swett, 1987).

The microfossil assemblages in northern Anhui and Jiangsu Provinces are slightly different from those of the Russian Platform. Such species as *Leiomarginata* cf. *simplex*, *Lophosphaeridium* sp., *M. spinosum* and other species occurring in the Lower Cambrian rocks on the Russian Platform have been found in the Sinian sequences in northern Anhui. The Lower Cambrian microfossil assemblage of the Gouhou Formation seems to resemble that of the Lower Cambrian assemblage of the Baltic region, which is dominated by specimens to *Ovulum*, *Volkovia*, and spinose forms (Jankauskas, 1975). The Lower Cambrian microfossil assemblage on the Russian Platform is similar to that on the South China Platform, which is characterized by abundant *Skiagia*, *Baltisphaeridium*, and other innovations (Volkova et al., 1979; Zang, in this thesis, Chapter III).

The Vendian assemblages recorded from the Ukraine contain abundant *Protoleiosphaeridium* sp., *Leiosphaeridia* sp., *Stictosphaeridium* sp., *Trachysphaeridium* sp. and other common species (Velikanov et al., 1983). Such an assemblage is very common throughout the Late Proterozoic. The microfossils described on the Siberian Platform by Pychova (1969) contain many specimens that could be pseudomicrofossils (Wang Fuxing and Luo Qiling, 1982). The microfossil assemblage from the cherts of the Yudoma Suite (Su-chu C. Lo, 1980) consists of micrhystrids, spheroidal mat-builders and cyanobacterial filaments, resembling those from the Jiudingshan and Niyuan Formations of the Huaibei Group.

Timofeev (1959, 1966, 1969, 1973) described many acritarchs from the Soviet Union, but the classification is in a state of flux, some genera and species, such as *Kildinella*, *Macroptycha*, *Turuchanica* and *Nucelosphaeridium*, being invalid or emended.

The Late Proterozoic microfossils from the Visingsö Beds in southern Sweden were well investigated (Vidal, 1974, 1976). The Visingsö microfossils include twenty-five spheroidal acritarchs. Vidal (1976) considered the lower and middle units of the Beds belonged to the Upper Riphean and the upper to the Lower Vendian. Using the coefficients for correlation, as mentioned above, the Liulaobei microfossil assemblage is more likely to be correlated with the upper unit.

However the Liulaobei assemblage is slightly different from that of the Visingsö Beds. In the Liulaobei Formation, six form species of *Micrhystridium* have been recorded, but in the Visingsö Beds, no micrhystrids occur, but one morphologically complex species *Vandanosphaeridium reticulatum* (Vidal) Vidal, 1981 has been found. This species has vesicles with simple or branching processes supporting an external membrane completely enclosing the vesicle and processes. Both rock units produce *Chuaria*, but the Liulaobei Formation yields *Tawuia* and *Tyrasotaenia*, and the worm-like fossil *Sinosabellidites huainanensis* Zheng. These occurrences may suggest the Liulaobei Formation is younger than the Visingsö Beds.

Downie (1984) summarized British acritarch stratigraphy. Late Proterozoic acritarchs are poorly preserved and a few forms have been illustrated. These include *Favososphaeridium*, *Protoleiosphaeridium*, *Octoedryxium*, *Pyritosphaera* and other spheroids (Downie, 1984). The Lower Cambrian acritarchs are characterized by the occurrence of *Skiagia*, *Baltisphaeridium*, *Goniosphaeridium*, *Comasphaeridium*, *Volkovia* and *Ovulum* (Downie, 1982), and this assemblage is similar to that of the Soviet Union, southern China and elsewhere, probably with a cosmopolitan distribution.

The Late Proterozoic Chuar Group, Grand Canyon, Arizona, the United States yields *Chuaria circularis* (Ford and Breed, 1973) and vase-shaped microfossils *Melanocyrillium fimbriatum*, *M. hexodiadema* and *M. horodyskii* (Bloeser, 1985). Vidal and Ford (1985) reported some acritarchs from the group including *Kildinosphaera lophostriata*, *Tasmanites rifejicus*, large spinose forms of *Vandalosphaeridium walcotti*, and cf. *Cymatiosphaeroides kullingii*, and other common spheroids. *K. lophostriata*, *T. rifejicus* and *Vandalosphaeridium* sp., according to Vidal and Knoll (1983), are characteristic species in the Upper Riphean and Lower Vendian. Thus the Liulaobei Formation of the Huainan group is probably younger than the Chuar Group.

	Liulaobei Formation	Shijia Fm.	Gouhou Formation	Zhaowei-Jiayuan Formation
Alliumella baltica	R	N	N	R
Ambiguaspora sp.	C	N	N	N
Archaeodiscina umbonulata	N	N	R	N
Archaeoulothrix epikoila	R	N	N	N
Chuaria circularis	V	V	V	N
Dictyotidium regulare	R	N	R	N
cf. *Eoaphanocapsa* sp.	R	R	R	N
Favososphaeridium favosum	R	N	N	R
Gloeodiniopsis cf. *lamellosa*	C	N	R	N
Kildinosphaera chagrinata	V	C	C	C
Kildinosphaera granulata	A	R	R	R
Kildinosphaera verrucata	C	C	R	N
Lathribiota annularis	C	N	N	N
Leiofusa biocornuta	R	N	N	N
Leiofusa sp.	N	N	R	N
Leiomarginata ? simplex	C	N	R	R
Leiosphaeridia asperata	V	V	V	C
Lophosphaeridium tuberosum	A	R	R	R
Lophosphaeridium sp.	N	N	N	R
Micrhystridium brevicornum	N	N	R	N
Micrhystridium circulapertum	C	N	R	N
Micrhystridium oligum	R	N	N	N
Micrhystridium cf. *oligum*	R	N	N	N
M. quadratapertum	R	N	N	N
Micrhystridium spinosum	C	N	N	N
Micrhystridium sp.	N	N	N	R
Octoedryxium truncatum	R	N	N	R
Ovulum saccatum	N	N	R	N
Paleasphaeridium zonale	C	N	N	N
Protoleiosphaeridium densum	V	C	C	R
P. flexuosum	V	A	A	C
P. laccatum	C	C	R	N
Pterospermopsimorpha binata	R	N	N	N
P. spongia	C	N	N	N
Pyritosphaera barbaria	A	C	C	R
Sinianella uniplicata	V	C	C	R
Sinianella scabrata	A	R	R	N

Text-fig. II-15. page1-2. (1)

	Liulaobei Formation	Shijia Fm.	Gouhou Formation	Zhaowei-Jiayuan Formation
Stictosphaeridium sp.	A	C	C	C
Synsphaeridium sp.	A	C	C	C
Tawuia dalensis	V	A	A	N
Trachsphaeridium laufeldi	R	N	N	N
T. cf.*laminaritum*	C	C	C	R
Volkovia flagellata	N	N	R	N
Archaeotrichion contortum	A	A	C	N
Eomycetopsis parallela	A	N	N	N
Eomycetopsis robusta	V	V	V	C
Eomycetopsis spiralata	R	N	N	R
Heliconema ? sp.	R	N	N	N
Oscillatoriopsis spp.	C	N	N	R
Palaeolyngbya barghooniana	R	N	N	N
Siphonophycus sp.	V	C	C	R

Text-fig. II-15. Microfossils from the Huainan and Huaibei Groups in the northern Anhui and Jiangsu Provinces, central eastern China. V-very abundant (more than 50 specimens), A-abundant (20-50 specimens), C-common (5-20 specimens), R-rare (1-5 specimens) and N-nil.

2.6. SYSTEMATIC PALAEONTOLOGY

Microfossil study recently has been divided into biostratigraphical and palaeobotanical schools (Diver and Peat, 1979). Working in the palaeobotanical school, the geologists emphasize biological interpretation of the microfossils, and the specimens, usually from black cherts, are identified by the taxonomic system employed by modern biologists (Barghoorn and Tyler, 1965; Schopf, 1968; Schopf and Blacic, 1971). In the other school, the microfossils, generally from shales by acid-resistant, have been assigned to an unknown biological affinity, the acritarchs, and the microfossil assemblages have been considered biostratigraphically valuable (Volkova, 1969; Vidal, 1981a; Vidal and Knoll, 1983; Moczydlowska and Vidal, 1986).

Group Acritarcha was proposed by Evitt (1963a) to include those microfossils of organic composition and unknown affinity. Evitt (1963b) defined the Acritarcha as that "small microfossils of unknown and probably varied biological affinities consisting of a central cavity enclosed by a wall of single or multiple layers and of mainly organic composition; symmetry, shape, structure, and ornamentation varied; central cavity closed or communicating with the exterior by varied means, for example: pores, a slit-like or irregular rupture, a circular opening (the pylome)". Downie and others (1963) subdivided the group into thirteen subgroups. Diver and Peat (1979) proposed an other informal group, the Cryptarcha.

Diver and Peat (1979) considered the difference between the biostratigraphical school and the palaeobotanical school was not absolute and an improved evolutionary pattern of microorganisms needs them to be combined. More and more microfossils previously recorded from the black cherts have been found in maceration and some acid-resistant planktonic microfossils have been found in chert sections (Knoll, 1984; Awramik et al., 1985; Yin Leiming, 1986a). It is necessary to establish a taxonomic system to apply to both schools. The problems are not discussed in this paper. The systematic description herein is based on alphabetical order.

2.6.1. Spheroidal Microfossils

Genus *Alliumella* Vanderflit, 1971
Alliumella baltica Vanderflit, 1971
(pl.XV, figs.I-J)

Alliumella baltica Vanderflit gen. et sp. nov., Umnova et Vanderflit, 1971, pp.69, 70, pl.2, figs.42-48.

Alliumella baltica, Volkova, 1974, pl.XXXVII, fig.17.

Alliumella baltica, Vanguestaine, 1974, pl.I, fig.10.

Alliumella baltica, Volkova et al., 1979, pl.XXVIII, figs.7-11.

Alliumella baltica, Moczydlowska, 1981, fig.5-M.

Phycomycetes sp., Yin Chongyu, 1985, pl.IV, fig.19.

Material. Five specimens.

Description. Specimens tadpole-like, consisting of a spheroidal, elliptical or irregular head-like part and a long tail-like appendage; head-like part with psilate, shagreen or fine-granular surface texture and occasionally folded; no opening observed; long tail-like appendage drawn out from the head-like vesicle; wall of the appendage not differentiated from that of the head-like vesicle; appendage gradually tapering to a truncate or blunt end.

Dimensions. The head-like parts are 14 - 21 *um* in diameter, and the appendage 10 - 45*um* long, 2 - 7*um* wide. The specimens in Volkova et al. (1979) are 18-33*um* in diameter for the head-like parts and 5-30*um* in length for the appendages.

Remarks. *A. baltica* is a form-taxon with a peculiar tadpole-like structure. The tail-like structure may be functionally useful in the floating life.

The specimens referred to *Phycomycetes* by Timofeev (1969, pl.XXXIV, fig.3, 5, 6) have similar structure, but they differ form *A. baltica* in their granular surface texture. The relationship of two species needs more information.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group in the Huainan region, central-eastern China. Previously recorded from the Lower Cambrian Pirita Formation (Byelorussia, Kaliningrad region), Vergale and Rausve Horizons (Latvia, Ukraine, Poland), Middle Cambrian Kibartu Horizon (Latvia, Poland), Middle-Upper Cambrian (Revinian, Belgium) (Volkova et al., 1979). Some specimens have been observed from the Bitter Springs Formation in the Amadeus Basin, central Australia.

Stratigraphic range. Late Proterozoic to Cambrian.

Genus *Ambiguaspora* Volkova, 1976

Type species. *Ambiguaspora parvula* Volkova, 1976

Ambiguaspora sp.
(pl.IX, figs.F-G)

Material. 10 specimens.

Description. Vesicles circular or irregular circular in outline, originally spheroidal; wall moderately thin, psilate to granular, sometimes folded; vesicles ornamented with a triradiate tetrad scar; scar not reaching the margin of the vesicles; specimens yellow or yellow-brown in colour.

Dimensions. Vesicle diameters are 8 - 25*u*m.

Remarks. Volkova (1976) erected *Ambiguaspora* and described the species *A. parvula*. She suggested those specimens were possibly the spores of semi-aquatic plants. *A. parvula* Volkova, 1976 is characterized by its small size (less than 10*u*m in diameter), smooth surface texture and a triradiate tetrad scar which reaches the equator. Present specimens are collected from the Liulaobei Formation, differing in their relatively large vesicles, granular surface texture and the triradiate scar not reaching the margin or equator of the vesicles.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group in the Huainan region.

Genus *Archaeodiscina* Naumova, 1960, emend. Volkova, 1968

Type species. *Archaeodiscina granulata* Naumova, 1960

Archaeodiscina umbonulata Volkova, 1968

(pl.XIX, fig.A)

Archaeodiscina umbonulata Volkova sp. nov., Volkova, 1968, p.27, pl.V, figs.1-8; pl.XI, fig.8.

Archaeodiscina umbonulata, Volkova, 1969, p.235, pl.XLIX, figs.8-9.

Archaeodiscina umbonulata, Vanguestain, 1974, pl.I, fig.1.

Archaeodiscina umbonulata, Volkova et al., 1979, pl.XII, figs.1-9.

Archaeodiscina umbonulata, Downie, 1982, fig.11, i-J.

Material. Two specimens.

Description. Vesicle circular or subcircular, originally spheroidal; surface smooth or psilate texture, more or less folded; a central darker disc observed; disc generally circular, displaying some tapering stripes radiating from the centre; stripes only sometimes reaching to the margin of the vesicle; no excystment structures observed; specimens yellow to brown.

Dimensions. Vesicles diameters are 21 - 35*um* and the discs 7 - 11*um* across. Previous measurement: 18 - 42*um* in diameter (Downie, 1982).

Remarks. The species is characterized by its central disc-like darker spot with radiate stripes. The darker disc is very similar to the spots without radiate stripes in other genera, such as *Nucellosphaeridium*. Darker spots have been considered as the relict of the cell inclusions. The stripes of the present specimens seem to draw out from the central darker disc and it is unlikely to be cell inclusion. The biological explanation needs more detailed study.

The genus is questioned for its validity. Since Volkova (1968) emended the diagnosis, she still used *A. granulata* Naumova, 1960 as the type species, which was invalidly published.

Distribution. Lower Cambrian Gouhou Formation, Huaibei Group, northern Anhui. Previously recorded from Lower Cambrian; Lukati Horizon (Estonia, Latvia, Ukraine; Poland), Vergale Horizon (Latvia, Lithuania, Ukraine, Poland), Rausve Horizon (Latvia, Poland), Norretorp Sandstone (Sweden), Mickwitzia Sandstone (Sweden), Lingulid Sandstone (Sweden), Upper Devillian (Belgium), Hells Mouth Grit (Wales), Hollybush Sandstone (England). ?Lower Cambrian; Izhora Beds (Leningrad). Lower Cambrian Fucoid Beds (Scotland), Gog Formation (Alberta), Burin Peninsula (Newfoundland) and Holmia Shales (Norway) (Downie, 1982; Volkova et al., 1979). Some specimens have been found from the Lower Cambrian Qiongzhusi Formation on the South China Platform (Chapter III in this thesis).

Stratigraphic range. Cambrian, possibly Late Proterozoic.

Genus *Archaeoulothrix* gen. nov.

Type species. *Archaeoulothrix epikoila* gen. et sp. nov.

Etymology. With reference to the Late Proterozoic age and similarity to modern green alga *Ulothrix*.

Diagnosis. An unbranched chain-like colony; cells in the chain identical or different sizes; each cell having an opening in its reproductive stage.

Remarks. Modern algae and cyanobacteria, such as the cyanobacterial *Nostoc*, the green algae *Ulothrix*, *Stichococcus*, and other genera commonly have a chain-like form. No openings have been found on *Nostoc*, but in the green alga *Ulothrix*, an opening has been observed in reproductive stages. *Nostoc* always shows some heterocysts in the chain, but in fossil forms, these structures are difficult to be identified with certainty because of imperfection in the preservation.

Archaeoulothrix has an unbranched chain structure like in *Nostoc*, or *Ulothrix*. The cells of *Archaeoulothrix* commonly have an opening; based on this feature, the genus is regarded as a probable green alga affinity.

The new genus is monotypic.

Archaeoulothrix epikoila sp. nov.

(pl.XII, figs.A-F)

Etymology: epikoila, Gr., spongy, porous.

Holotype. pl.XII, figs.A-B, slide 82AL17-11, (13x12) from the Liulaobei Formation, Huainan Group.

Diagnosis. Chain-like specimens; cell size variable in the chain; cells commonly having an opening in their reproductive stages; cell wall spongy.

Description. The holotype consists of about fifty cells which vary gradually in size along the chain. The large cells commonly have an opening, but the small may not. The openings vary in shapes, circular to slit-like or irregular, which are due to the diagenesis deformation. The wall is porous, smooth or psilate, occasionally with folds. Each cell is connected with adjacent ones by sheath-like membrane (pl.XII, fig.D). The specimens are yellow or yellow-brown in colour.

Dimensions. The chain is up to several hundred microns long, and cells are 5-35*um* in diameter.

Remarks. The chain-like fossil species include *Anabaenidium johnsonii* Schopf, 1968, *Nostocopsis desmoides* Yin et Li, 1978 and *Nostocomorpha prisca* Sin et Liu, 1978. These species are commonly described in the Family Nostocaceae. *A. epikoila* differs from these species in its relatively large cells and each cell having an opening in life cycle. The solitary specimens of the new taxon are similar to *Protoleiosphaeridium flexuosum*, which also has spongy wall and an opening, but the colonies of *P. flexuosum* are irregular arrangement of spheroidal aggregates (pl.X, fig.K).

Distribution. Upper Sinian Liulaobei Formation, Huainan Group in northern Anhui.

Stratigraphic range. Late Sinian.

Genus *Chuaria* Walcott, 1899

Type species. *Chuaria circularis* Walcott, 1899

Chuaria circularis Walcott, 1899

(pl.IV, figs.A-C, F-I)

Synonymy. See Duan (1982, p.59), Hofmann (1977, table 1) and Sun (1986).

Shouhsienia curymarginata Yan (sp. nov.), Wang Guixiang, 1984, ed., pl.8, fig.1.

Shouhsienia shouhsienensis (Sin) Zheng, Wang Guixiang, 1984, ed., pl.8, fig.2, 3, 8, 13, 17, 20, 23, 19c; pl.13, fig.5.

Ovidiscina pakungshania Zheng, Wang Guixiang, 1984, ed., pl.8, fig.4, 9, 16.

Chuaria circularis Walcott, Wang Guixiang, 1984, ed., pl.8, fig.14, 19a, 19b, 21a; pl.9, fig.15b; pl.10, fig.15a; pl.11, fig.4; pl.12, fig.2, 6, 8, 10, 13; pl.13, fig.1, 4, 12c.

Huainania comma Zhou (gen. et sp. nov.) Wang Guixiang, 1984, ed., pl.8, fig.15, 18, 21b.

Microcircula simplex Yan et Zhang (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.8, fig.22; pl.12, fig.7.

Chuaria annularis Zheng, Wang Guixiang, 1984, ed., pl.10, fig.15b; pl.13, fig.3.

Material. About one hundred specimens.

Description. Megascopic vesicle circular or subcircular in outline, originally spheroidal; wall thick, 0.8 - 1*um*, commonly folded, occasionally with concentric wrinkles; well-preserved vesicles displaying smooth, psilate or fine-granular surface texture; most specimens more or less deformed; no excystment structure observed.

Dimensions. The specimens are 0.35 - 2.5mm in diameter. Previously diameters: 0.5 - 5mm (Ford and Breed, 1973), 0.13 - 2.33mm (Hofmann, 1977), 0.3 - 5mm (Duan, 1982) and 0.2 - 7.0mm (Suresh et al., 1983).

Remarks. In northern Anhui, *Chuaria circularis* usually occurs associated with elongate specimens of *Tawuia dalensis* Hofmann. The ratio of length and width between two species displays continuous variation, and the two species are arbitrarily separated.

Recently Vidal and Ford (1985) emended *Chuaria circularis* Walcott based on the acid resistant specimens from the Chuar Group in Arizona. Its emended diagnosis, extremely robust wall with a psilate or chagrinate surface texture, seems to intergrade with that of *Leiosphaeridia* and *Kildinosphaera.* Vidal and Ford (1985) recorded a range 70 - 712*um* in diameter for their specimens. As a form taxon, the size difference of *Chuaria circularis*, because some hand-specimens are more than 5000*um* in diameter, is equal to more than 7000, which is very unusual in one species. The size difference for modern algae or cyanobacteria is generally less than 5000 (Philipose, 1967, cf. Lindgren, 1981).

Processing several samples from *Chuaria*-bearing beds of the Liulaobei Formation demonstrates that most large specimens are more or less broken or fragmented, very hard to be named, some middle size of specimens are usually damaged and samples contain many specimens of *Leiosphaeridia asperata*, *Kildinosphaera chagrinata*, *K. granulata*, *Trachysphaeridium* sp., *Protoleiosphaeridium* sp. and other species, very difficulty to judge which forms belonging to *Chuaria circularis*. The sizes of these specimens are various, dozens of microns to several hundred microns in diameter. In the Pertatataka Formation of the Amadeus Basin, central Australia, some specimens of *Kildinosphaera* are up to 1000*u*m in diameter. Based on recent information, the affinity and taxonomic position of *Chuaria circularis* is not clear and their form variations in reproductive stages have not been fully understood . It would better arbitrarily limit size ranges for *Chuaria circularis* or exclude the specimens from maceration.

Distribution. Upper Sinian Liulaobei Formation, Jiuliqiao, Weiji and Shijia Formations, Lower Cambrian Jingshanzhai and Gouhou Formations, northern Anhui. Previous occurrences were stated in Hofmann (1977, table 1), Hofmann (1985b, fig.3).

Stratigraphic range. Middle Proterozoic to Lower Cambrian.

Genus *Dictyotidium* (Eisenack, 1955) Staplin, 1961

Type species. *Dictyotidium dictyotum* (Eisenack) Eisenack, 1955

Dictyotidium regulare sp. nov.
(pl.IX, figs. C-E; pl.XIX, fig.W)

Etymology. Regularis, L., according to rule.

Holotype. Plate IX, fig.C-D, two focus levels, from the Liulaobei Formation, Huainan Group.

Material. Twenty specimens.

Description. Vesicle circular to subcircular, originally spheroidal; wall very thick, robust, rarely folded, and usually displaying slits on the margin; vesicle ornamented with reticulate meshwork on surface; ridges very low, visible or invisible at periphery; meshwork more or less regular, square or rectangular, varying in size (3 - 8*u*m across lacunar area); surface smooth to psilate; specimens yellow to brown in colour.

Dimensions. Vesicles range 38 - 87*um* in diameter (holotype is 87 x 59*um* in diameter).

Remarks. *D. regulare* sp. nov. differs from *D. birvetense* and *D. priscum* in its square or rectangular meshwork and very low ridges.

Distribution. Upper Sinian Liulaobei Formation and Lower Cambrian Gouhou Formation, northern Anhui.

Stratigraphic range. Late Sinian to Early Cambrian.

Genus *Eoaphanocapsa* Nyberg and Schopf, 1984

Type species. *Eoaphanocapsa oparinii* Nyberg and Schopf, 1984

cf. *Eoaphanocapsa* sp.

(pl.XV, figs.U-V; pl.XX, figs.K-L)

Material. Seven specimens.

Description. Specimens including individuals, twin-like and spheroidal colonies; wall thin, (0.3 - 0.5*um* thick), with a fine-granular surface texture; twin-like vesicles connected as a vegetative fission; colonies enclosed in a sheath membrane and sphaeromorph at outline; sheath membrane single, 0.8 - 1.5*um* thick; cells in colonies tightly packed and distorted; no excystment structures observed.

Dimensions. The solitary specimens are 33 - 50*um* in diameter, twin-like specimens 44 - 48*um*, and specimens in colonies 15 - 30*um*. The spheroidal colonies are 45 - 50*um* in diameter at outline.

Remarks. Present specimens are preserved in shales and relatively large. Its individual cells do not have an external single to multi-layered sheath. The nomenclature herein is tentative.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group and Lower Cambrian

Gouhou Formation, Huaibei Group. *Eoaphanocapsa* Nyberg and Schopf was first described from the Upper Proterozoic Min'yar Formation, South Ural, USSR (Nyberg and Schopf, 1984).

Genus *Favososphaeridium* Timofeev, (1956, 1959) 1966

Type species. *Favososphaeridium scandicum* Timofeev, 1966

Favososphaeridium favosum Timofeev, 1966

(pl.VI, figs.a-c)

Favososphaeridium favosum sp.nov., Timofeev, 1966, p.38-19, pl.8, fig.2.

? *Favososphaeridium favosum* Tim., Timofeev, 1969, p.22, pl.4, fig.9.

Favososphaeridium favosum Tim., Timofeev, 1973, pl.13, fig.11.

Favososphaeridium favosum Tim., Vidal, 1976, p.19-20, fig.9:A-F.

Favososphaeridium wongshanense Yan sp. nov., Yin, 1984, pl.16, fig.6a-6b.

Material. Seven specimens.

Description. Vesicles circular or subcircular; surface ornamented with irregular honeycomb-like meshwork; wall moderately thick, rarely folded, occasionally displaying deformed slits around the margin; occasionally a relatively circular opening observed (about 7*um* in diameter); specimens yellow or yellow-brown in colour.

Dimensions. Vesicles are 21-33*um* in diameter. Previous measurement: 33 - 144*um* in diameter (Vidal, 1976).

Remarks. *F. favosum* was described by Timofeev (1966), and the holotype was an illustration. Timofeev (1969) published a specimen (pl.4, fig.9) that was ill-preserved, and did not show the meshwork structure. In this paper the species is after Vidal's description and specimens (Vidal, 1976).

F. wongshanense Yan sp. nov. was published without description (Yan, 1984). The meshwork structure on the specimen resembles *F. favosum.*

Distribution. Upper Sinian Liulaobei, Jiayuan and Wangshan Formations. Previously recorded from the upper Visingsö Beds, Sweden, and other occurrence from the Soviet Union and other places were documented by Vidal (1976).

Stratigraphic range. Sinian to Middle Cambrian.

Genus *Gloeodiniopsis* Schopf, 1968 emend. Knoll and Golubic, 1979

Type species. *Gloeodiniopsis lamellosa* Schopf, 1968 emend. Knoll and Golubic, 1979

Gloeodiniopsis cf. *lamellosa* Schopf, 1968 emend. Knoll and Golubic, 1979

(pl.XXI, fig.M)

Material. Four specimens.

Description. Specimens preserved in a sheath; spheroidal cells having a tendency to form a tetrahedral tetrad or with irregular arrangement; colonies enclosed by a thin membrane; wall about 0.3 - 0.8*um* thick, smooth or psilate; specimens yellow to brown in colour.

Dimensions. Cells are 4 - 6*um* in diameter and diameters for groups 12 - 16*um*.

Remarks. Present specimens usually display four cells in cubic pack and enclosed in a sheath membrane, similar to *Eotetrahedrion princeps* Schopf and Blacic, 1971. Knoll and Golubic (1979) studied the variation in form of chrococcoids from the Bitter Springs Formation and suggested that the genera *Bigeminoccoccus*, *Eozygion*, *Eotetrahedrion* and *Caryosphaeroides* were synonyms of *Gloeodiniopsis* Schopf emend.. The present specimens have been observed displaying form variations and are tentatively named as a confer species.

Distribution. Lower Cambrian Gouhou Formation, Huaibei Group.

Genus *Kildinosphaera* Vidal, 1983

Type species. *Kildinosphaera chagrinata* Vidal, 1983

Remarks. The genus *Kildinella* Shepeleva et Timofeev, 1963. ex Timofeev, 1966 is invalid because its type species, *Kildinella hyperboreica* Timofeev, 1966 has been transferred to *Leiosphaeridia asperata* (Naumova) Lindgren, 1982 (Lindgren, 1981, 1982). Vidal (in Vidal and Siedlecka, 1983) erected the new genus *Kildinosphaera* to include some taxa previously assigned to *Kildinella.*

Kildinosphaera, according to Vidal (in Vidal and Siedlecka, 1983), is characterized by a "median split' and the sculpture patterns (chagrinate, granulate, verrucate, striate). The "median split" is possibly an aperture of the kind that occurs at certain reproductive stages (Lindgren, 1981), and is important feature in morphological identification.

In fossils forms, the "median split" is very difficult to distinguish from the deformed slits caused by diagenetic deformation; for example, *Protoleiosphaeridium densum* (Timofeev), because it has very robust wall, always displays slits around margin. Even when mounting a slide, some slits possibly appear as a result of the pressure under the cover glass.

A "median split" sometimes can be observed in *Leiosphaeridia asperata.* One specimen (pl.XX, fig.A) has a smooth surface texture and a slit in the middle of the vesicle; another specimen (pl.XV, fig.K) has lost some part of the wall, showing a pseudo-slit on the surface. In the Liulaobei Formation, more than one thousand specimens of *Kildinosphaera* have been recorded, and few of them have a possible "median split". In addition, the holotype of the type species (Vidal, 1976, fig.10-A) does not display a "median split". Thus, the surface sculptures are probably characteristic features for *Kildinosphaera.*

The observation of the surface sculptures may be empirical. Three species, *K.*

chagrinata, *K. granulata* and *K. verrucata*, display their surface textures of gradually coarser, from fine-granular, granular to bulbous verrucae. *Leiosphaeridia asperata* has a smooth surface texture.

Colonies of *Kildinosphaera* are spheroidal aggregates of some packed vesicles or irregularly loose arrangement. *Leiosphaeridia* has similar colony forms.

Size varies in *Kildinosphaera.* In the Liulaobei Formation some vesicles of *Kildinosphaera* are more than 200*u*m in diameter. Some large specimens found in the Upper Proterozoic Pertatataka Formation in the Amadeus Basin, central Australia are more than 800*u*m in diameter, several fragments seem up to 1000*u*m in diameter. The vesicles in colonies generally are smaller than those of solitary specimens.

The wrinkles on the surface display diverse patterns which are considered to be the result of diagenetic deformation.

Kildinosphaera chagrinata Vidal, 1983
(pl.VII, figs.I-L, pl.XX, figs.C, F)

Kildinella sinica Timofeev, 1966, Vidal, 1974, p.6, pl.1, fig.8, 10.

Kildinella cf. *sinica* Timofeev, 1966, Vidal, 1976, p.21-22, fig.10-A.

Kildinella hyperboreica Timofeev, 1966, Vidal, 1976, p.20-21, fig.10, B, C.

Kildinella sinica Timofeev, 1966, Vidal, 1979, p.22, pl.5, fig.1.

Kildinella chagrinata Vidal, sp. nov., Vidal and Siedlecka, 1983, p.55-57, fig.4: A-B.

Kildinosphaera chagrinata Vidal, 1983, Vidal and Ford, 1985, p.360-361, fig.3C-F.

Kildinella sinica Timofeev, 1966, Yin leiming, 1985, p.17, pl.II, fig.14-16.

Kildinella cycloptyca Yin, 1980, Yin Leiming, 1985, p.16-17, pl.1, fig.25; pl.II, fig.22.

Leiopsophosphaera effusus Shep., Yin Chongyu, 1985, pl.1, fig.12.

Teophipolia rugosa sp. nov. Yin Chongyu, 1985, p.108, pl.2, figs.17-18.

Teophipolia tenera sp. nov. Yin Chongyu, 1985, p.108, pl.2, fig.19.

Teophipolia biacris sp. nov. Yin Chongyu, 1985, p.108-109, pl.2, fig.20.

Zonosphaeridium cf. *mite* Sin, Yin Chongyu, 1985, pl.3, fig.8.

Nucellosphaeridium hyalinum sp. nov. Yin Chongyu, 1985, p.107, pl.3, fig. 9-10.

Nucellosphaeridium fengyangense sp. nov., Yin Chongyu, 1985, p.107, pl.3, figs.11-12.

Material. More than 500 specimens.

Description. Vesicle circular to subcircular in outline, originally spheroidal; wall moderately thick, shagreen or finely granular, commonly folded; few specimens with a slit-like aperture; colony spheroidal aggregates which are usually disaggregated in an irregular arrangement; specimens yellow to dark-brown in colour.

Dimensions. The solitary specimens are 19 - 210*u*m in diameter, and regular spheroidal aggregates 66*u*m - 82*u*m. The cells in spheroidal colonies are 9.5 - 13*u*m in diameter. Previous measurements were 25.5 - 177*u*m in diameter from the Chuar and Uinta Mountain Groups; 25 - 70*u*m from northern Norway; 42 -72*u*m from the Eleonore Bay Group in eastern Greenland (Vidal, 1979; Vidal, 1981b; Vidal and Siedlecka, 1983; Vidal and Ford, 1985).

Remarks. *K. chagrinata* is common in the upper Sinian Liulaobei Formation and Lower Cambrian Gouhou Formation. Its morphology of solitary specimens and colony formation resembles those of *Leiosphaeridia asperata*, differing in its fine-granular surface texture. The granular wall seems to be more robust than that of *L. asperata*. The cells in aggregates of *K. chagrinata* are psilate to fine-granular, and tightly packed in the colony. Similar colonies have been reported from the Awatubi Member of Kwagunt Formation, Chuar Group. Vidal and Ford (1985) named them (Fig.6. A-B) as *Satka* *colonialica* Jankauskas, 1979, but their chagrinate and fine-granular surface display no difference from *Kildinosphaera chagrinata.*

Distribution. Upper Sinian Liulaobei, Shijia and Zhaowei Formations, and the Lower Cambrian Gouhou and Jingshanzhai Formations. Previously recorded occurrences were assigned to *Kildinella sinica* or *K.* cf. *sinica* Timofeev, from the Visingsö Beds, southern Sweden (Vidal, 1974, 1976); the Upper Riphean Limestone Dolomite 'Series' of the Eleonore Bay Group , East Greenland (Vidal, 1979b); the Smalfjord Tillite, Dakkovarre, Ekkeroy, Golneselv, Andersby and Klubbnes Formations (Vidal, 1981b); the early Late Proterozoic (Upper Riphean) Vadsö Group in East Finnmark and northern Norway; the Batsfjord Formation of the Barents Sea Group in Varanger Peninsula in northern Norway, and the Kwagunt and Red Pine Formations of the Chuar and Uinta Mountain Groups, USA (Vidal and Ford, 1985). Abundant specimens have been observed from the early Late Proterozoic Bitter Springs Formation, Ediacarian Pertatataka Formation and Middle Cambrian Tempe Formation in the Amadeus Basin, central Australia (Chapter IV).

Stratigraphic range. Late Proterozoic to Cambrian.

Kildinosphaera granulata Vidal, 1983
(pl.VIII, figs.A-F; pl.XX, figs.E, G)

Kildinella sp., Vidal, 1981b, p.25-26, fig.11: A-H.

Kildinosphaera granulata Vidal sp. nov., Vidal and Siedlecka, 1983, p.57-59, fig.5: H-J.

Material. More than 200 specimens.

Description. Vesicle circular to subcircular in outline, originally spheroidal; wall thick, robust, granular, commonly folded; no excystment structure observed; colonies spheroidal or irregular loose aggregates.

Dimensions. Vesicles are 24 - 215*um* in diameter; the surface granulae are about 0.3 - 0.6*um* across; and the diameters for cells in colonies are 10-13*um*. Previous diameters were 45 - 60*um* (Vidal and Siedlecka, 1983).

Remarks. *K. granulata* differs from *K. chagrinata* in its more robust wall and granular surface texture.

Distribution. Upper Sinian Liulaobei Formation, Shijia Formation, Zhaowei Formation and the Lower Cambrian Gouhou Formation. Previously recorded from the Klubbnes Formation and Andersby Formation of the Vadsö Group in East Finnmark (Vidal, 1981b); the Annijokka Member of the Lower Batsfjord Formation, Barents Sea Group (Vidal and Siedlecka, 1983). Abundant specimens have been observed from the early Late Proterozoic Bitter Springs Formation, Ediacarian Pertatataka Formation and Middle Cambrian Tempe Formation in the Amadeus Basin, central Australia (Chapter IV).

Stratigraphic range. Late Proterozoic to Cambrian.

Kildinosphaera verrucata Vidal, 1983
(pl.VIII, figs.G-J; pl.XIII, fig.F; pl.XX, figs.H-I)

Kildinella sp., Vidal, 1981b, p.26-30, fig.13: A-D.

Kildinosphaera verrucata Vidal sp. nov., Vidal and Siedlecka, p.62, fig.5:C.

Kildinosphaera verrucata Vidal, Vidal and Ford, 1985, p.363-364, fig.4:A.

Material. More than 30 specimens.

Description. Vesicle circular to subcircular in outline, originally spheroidal; wall thick, very robust, folded, and ornamented with verruculose texture; bulbous verrucae 1 -1.5*um* across; colony irregularly loose arrangement; no excystment feature observed.

Dimensions. Vesicles are 18 - 95*um* in diameter (including vesicles in colonies). Previously diameters were 142 - 250*um* (Vidal and Ford, 1985) and 40 - 135*um* (Vidal and Siedlecka, 1983).

Remarks. *K. verrucata* differs from *K. granulata* and *K. chagrinata* in its bulbous verruculose surface ornamentation. This species resembles some specimens of *Trachysphaeridium*, such as *T. rugosum* Sin (Yin Chongyu, 1985, pl.1, fig.14) and *T. rudu* Sin et Liu (Yin Chongyu, 1985, pl.1, fig.17). *Kildinosphaera* is more or less intergrade with *Trachysphaeridium.*

Distribution. Upper Sinian Liulaobei Formation and Lower Cambrian Gouhou Formation. Previously recorded from the Klubbnes, Andersby and Ekkeroy Formations, Vadsö Group in East Finnmark, northern Norway (Vidal, 1981b); the Awatubi Member of Kwagunt Formation, Chuar Group, northern Arizona (Vidal and Ford, 1985). Some specimens have been observed from the early Late Proterozoic Bitter Springs Formation, Ediacarian Pertatataka Formation and Middle Cambrian Tempe Formation in the Amadeus Basin, central Australia (Chapter IV).

Stratigraphic range. Late Proterozoic to Cambrian.

Lathribiosa gen. nov.

Type species. *Lathribiosa annularis* gen. et sp. nov.

Etymology. Lathrios, Gr., secret or hidden; bios, Gr., life.

Diagnosis. Annulated tube; external and internal wall structures differentiated; tube tapering to a circular opening (proboscis?).

Remarks. Present material is acid-resistant and collected from the shales of the Liulaobei Formation. Their annulation tube structure is very particular, obviously differs from that of *Oscillatoriopsis*. The annulations are probably connected by membrane(?) and support an empty tube. The structure seems to be like somewhat of worm-like animals rather than of algae.

The new genus is characterized by its possible proboscis-like structure at one end. The structure is tapering from the thicker tube, and its end is open.

The tubes seem too tiny to be of animal origin (50-100*um* in diameter of the tube). However similar structures have been found in some megascopic worm-like metazoan fossils in the Jiuliqiao Formation, about four hundred meters thick above the present sampling locality, named as *Pararenicola huaiyuanensis* Wang. The observation of the modern worm *Nematode* from Hamelin Pool, Shark Bay of Western Australia demonstrates many specimens ranging 30-60*um* (discussion with Dr. J. Bauld). The affinity is left much room to discuss.

Siphonophycus costatus Jankauskas, 1980 is suggested to have similar annulation structure (cf. Jankauskas, 1982). It is tentatively transferred to the genus *Lathribiosa.*

Lathribiosa annularis gen. et sp. nov.
(pl.XIV, fig.A-H)

Etymology. annularis, Latin, of a ring.

Holotype. Plate XIV, fig.A, from the Liulaobei Formation, Huainan Group, slide 83A204-2, (17 x 116).

Paratypes. Plate XIV, fig.D, and fig.F, both from the Liulaobei Formation, Huainan Group, fig.D, slide 83A204-12, (17 x 112.5); fig.F, slide 82AL05-1, (6.5 x 102.3).

Material. Fifteen fragments.

Description. Annulated tubes with a proboscis-like structure at one end; annulations soft and flexible, 1 - 4*um* thick, connected by membrane(?); external wall coarse and internal wall relatively smooth or psilate; tube empty, tapering continuously to the end of the proboscis-like structure; apix of the "proboscis" smooth and thickened; other end structure of the tube unclear; specimens yellow to brown in colour.

Dimensions. Tubes are 45 - 100*um* in diameter (holotype 59*um* in diameter). The diameter of proboscis-like structure is 27*um* for holotype and 54*um* for paratype fig.D.

Remarks. *L. annularis* gen. et sp. nov. differs from *Oscillatoriopsis* by its thick annulated empty tube with differentiated external and internal structures and its proboscis-like structure.

The new species is tentatively suggested as an taxon of unknown affinity, possibly worm-like metazoan. The difficulty is that no complete specimen has been observed and their size is relatively tiny. More information would add to explain their affinities.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group, northern Anhui.

Stratigraphic range. Upper Sinian.

Genus *Leiofusa* Eisenack, 1938

Type species. *Leiofusa fusiformis* (Eisenack) Eisenack, 1938

Leiofusa bicornuta Sin and Liu, 1973
(pl.IX, figs.H-K)

Leiofusa bicornuta Sin et Liu sp. nov., Sin and Liu, 1973, pl.IV, fig.8-9.

Leiofusa bicornuta, Yin. Ch, 1985, pl.III, fig.29.

Material. 26 specimens.

Description. Vesicle fusiform, elliptical or elongate; surface smooth or psilate, occasionally folded; each end rapidly tapering to a spine; spines sharp or slightly blunt at the apices, length equal or unequal; no opening recorded; vesicles yellow-brown or dark-brown in colour.

Dimensions. The fusiform vesicles are 10 - 43*um* at long axis and 5 - 11*um* at short axis, the spines are 2 - 10*um* long. Sin and Lin (1973) recorded 17 - 25*um* long for spines and 32 - 60*um* at the length of the overall shape.

Remarks. The fusiform specimens display simple structure: the smooth surface, occasionally folded, and two short spines. *L. bicornuta* differs from the other species in its spines sharpened rapidly to the points.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group, and the Zhaowei Formation, Huaibei Group, northern Anhui. Previously reported from the Hongshuizhuang Formation, Jixian system in Jixian County, northeastern China (Sin and Liu, 1973). One specimen has been found from the Middle Cambrian Tempe Formation in the Amadeus Basin, central Australia.

Stratigraphic range. Jixianian (1000 - 1400Ma) to Cambrian.

Leiofusa sp.
(pl.XIX, figs.J, K)

Material. Four specimens.

Description. Fusiform vesicles tapering to sharp angles at the ends; wall flexible and folded; surface psilate to fine-granular; specimens yellow to brown in colour.

Dimensions. The vesicles are 45 - 63*u*m long and 23 - 28*u*m wide, ratio (length:width) = 2 - 2.5.

Distribution. Lower Cambrian Gouhou Formation, Huaibei Group.

Genus *Leiomarginata*? Naumova, 1960
Leiomarginata? *simplex* Naumova, 1960
(pl.X, fig.L-M; pl.XIX, fig.c

Leiomarginata simplex Naum., Naumova, 1960, p.114, pl.3, fig.9.

Leiomarginata simplex, Kirjanov, 1968, pl.V, fig.8-9.

Leiomarginata simplex Naumova, Volkova, 1968, p.26, pl.IV, fig.20-25, pl.X, fig.7; pl.XI, fig.10.

?*Leiomarginata simplex* Naumova, Volkova, 1969, p.232, pl.XLVII, fig.16.

Leiomarginata simplex Naumova, Ogurtsova, 1975, p.87-88, pl.66(?), fig.2.

Leiomarginata simplex Naumova, Volkova et al., 1979, p.25-26, pl.XVIII, fig.10.

Leiomarginata sp., Volkova et al., 1979, p.26, pl.XVIII, fig.11-12.

Material. More than twenty specimens.

Description. Vesicles circular or subcircular in outline; wall thick, occasionally folded; surface texture psilate or shagreen; margin of the vesicle surrounded by a thickened ring and the ring commonly with a stable width; no openings observed; specimens yellow to yellow-brown in colour.

Dimensions. Specimens are 13 - 25*um* in diameter and ring width 2 - 4*um* wide. Previous records: about 25*um* in diameter and about 2.5*um* wide for Naumova's illustration (Naumova, 1968), and 21 - 25*um* in diameter (Volkova, 1969).

Remarks. The species was first published by Naumova (1960, p.114), but no description, no holotype, only one illustration. It is against the international code of botanical nomenclature. Because no further information has been collected from Naumova's other paper and this species was widely accepted in the papers of Soviet geologists, the species is described as a questionable taxon.

Leiomarginata is morphologically similar to *Zonosphaeridium* Timofeev (1956) 1959.

Distribution. Upper Sinian Liulaobei Formation and Lower Cambrian Gouhou Formation. Previously recorded from the Lower Cambrian Lontova Horizon (Leningrad, Estonia, Latvia, Lithuania, Byelorussia, Ukraine, Moscow Basin, Poland), Tommotian Stage, Kessyusa Formation (Siberian Platform), Talsy Horizon (Leningrad, Estonia, Latvia, Ukraine) (Volkova et al., 1979). Some specimens have been found from the Bitter Springs Formation in the Amadeus Basin, central Australia.

Stratigraphic range. Late Proterozoic to Early Cambrian.

Genus *Leiosphaeridia* Eisenack, 1958 emend. Downie and Sarjeant, 1963

Type species. *Leiosphaeridia baltica* Eisenack, 1958

Leiosphaeridia asperata (Naumova) Lindgren, 1982

(pl.VII, figs.A-H; pl.X, fig.P; pl.XI, fig.N;
pl.XIII, fig.E; pl.XV, fig.K; pl.XX, figs.A-B. D)

Trachytriletes asperatus, Naumova, 1950, p.178, pl.1, fig.7.

Trachytriletes asperatus, Timofeev, 1959, p.100, pl.10, fig.4.

Kildinella hyperboreica sp. nov., Timofeev, 1966, p.29, pl.5, fig.3.

Polyedrosphaeridium bullatum sp. nov., Timofeev, 1966, p.44, pl.5, fig.9.

Leiosphaeridia ochroleuca Tim., Timofeev, 1966, p.35, pl.VI, fig.3.

Leiosphaeridia of type A, Volkova, 1969, pl.XLVI, fig.4-6,8-15, pl.XLVIII, fig.1-9,11-13, pl.XLIX, fig.1-3, pl.LI, fig.2-5.

Kildinella hyperboreica Tim. Timofeev, 1969, p.11, pl.XVII, fig.3; pl.XXXII, fig.8.

Polyedrosphaeridium bullatum Tim., Timofeev, 1969, p.26, pl.5, fig.6; pl.32, fig.5.

Kildinella hyperboreica Tim., Timofeev, 1973, pl.9, fig.5.

Kildinella hyperboreica Tim., Vidal, 1974, p.6, pl.1, fig.7.

Kildinella hyperboreica Tim., Vidal, 1976, p.20-21, fig.10, B-C.

Kildinella hyperboreica Tim., Vidal, 1979, p.21, pl.5, fig.b.

Kildinella hyperboreica Tim., Vidal, 1981b, p.30-31, fig.15: A-D.

Leiosphaeridia asperata (Naumova) Lindgren, N. comb., Lindgren, 1982, p.41-42, fig.1, 2.

Leiosphaeridia asperata (Naumova) Lindgren, Vidal and Siedlecka, 1983, p.62-63, fig.5:D.

Leiosphaeridia asperata (Naumova) Lindgren, Vidal and Ford, 1985 p.365-367, fig.5:A-B.

? *Chuaria circularis* Walcott emend. Vidal and Ford, Vidal and Ford, 1985, p.357-359, fig.3:A.

Leiopsophosphaera pelucidus Shep., Yin Chongyu, 1985, pl.1, fig.8.

Macroptycha biplicata var. gigantea (var. nov.), Yin Chongyu, 1985, p.108, pl.3, fig.25.

Macroptycha biplicata Tim., Yin Chongyu, 1985, pl.3, fig.26.

Material. More than 2000 specimens.

Description. Vesicle circular to subcircular in outline, originally spheroidal; wall moderately thick, smooth or psilate, single or double, commonly folded; occasionally with a darker spot in the centre; no excystment structures observed; colonies spheroidal aggregates or irregular loose arrangement; vesicles in colonies usually small; specimens yellow to brown in colour.

Dimensions. The specimens are 16 - 180*u*m in diameter for solitary vesicles, and 13 - 38*u*m for vesicles in colonies. Previous measurements were 10-48*u*m in diameter for solitary specimens (N=601), 28-45*u*m in diameter for specimens in colonies, and regular colonies (coenobia) were about 150-260*u*m in diameter at outline (Lindgren, 1982). Other documents: 27-100*u*m in diameter (Vidal and Ford, 1985), 40-77*u*m in diameter for *Kildinella hyperboreica* from the Visingsö Beds (Vidal, 1974, 1976), 15-70*u*m in diameter (Vidal, 1981b) and 35-62*u*m in diameter (Vidal, 1979) for *K. hyperboreica.*

The largest solitary vesicle in my observation is from the Bitter Springs Formation in the Amadeus Basin, central Australia, and it is more than 300*u*m in diameter.

Discussion. *L. asperata* is a common species in the Late Proterozoic. Its structure is very simple, no distinguishing features, but smooth surface texture and deformed wrinkles. These simple vesicles could be procaryotes or eucaryotes, unicellular or multicellular. Observation of the modern green algae, *Ulva lacluca* v. *rigida* suggests its multicellular vegetative groups could form simple smooth vesicles after they died. After mounted a slide some specimens display different wrinkles (pl.III, figs.F, H).

The wrinkles are diagenetic deformation on flexible wall. Their patterns are depended on the compression in the diagenesis, and the diagenetic characters are not reliable for identification. The larger boat-shaped wrinkles, interpreted as prolonged chambers of *Macroptycha* (Timofeev, 1973), is probably a misunderstanding (pl.VII, fig.D).

The relic of cell inclusion sometimes consist of a darker spot in the centre (pl.XX, fig.B) with a circular or irregular shape. The darker spot was considered as an nucleus origin (Timofeev, 1963). Some procaryotes have been observed to form a darker spot in experiments (Knoll and Barghoorn, 1975). The observation of modern green alga *Enteromorpha lingulata* is suggested the darker area in the eucaryotic algae degradation includes nucleus and other organs.

Remarks. *Leiosphaeridia asperata* differs from *Kildinosphaera chagrinata* Vidal, 1983 in its smooth surface texture.

Leiopsophosphaera pelucidus Shep., *Macroptycha biplicata* Tim., and *M. biplicata* var. *gigantea* Yin Ch. 1985 are identified by its wrinkling forms and size difference, ranging within the diagnosis of *L. asperata*. On the other hand, *Leiopsophosphaera* and *Macroptycha* were not validly published (Lindgren, 1981, 1982).

One SEM photograph (Vidal and Ford, 1985, fig.3:A) was suggested as *Chuaria circularis* Walcott. Its smooth and wrinkling surface textures are similar to that of *L. asperata*. The specimens are about 300*u*m in diameter and extremely robust. According to Lindgren (1981), the size is recorded to range 8 - 440*u*m in *Leiosphaeridia*.

Distribution. Upper Sinian Liulaobei, Shijia, Zhaowei, and Jiayuan Formations, and the Lower Cambrian Gouhou and Jingshanzhai Formations. Previous occurrences were documented by Lindgren (1982) and Vidal et Ford (1985). Abundant specimens have been observed from the early Late Proterozoic Bitter Springs Formation, Ediacarian Pertatataka Formation and Middle Cambrian Tempe Formation in the Amadeus Basin, central Australia (Chapter IV).

Stratigraphic range. Proterozoic to Palaeozoic.

Lophosphaeridium (Timofeev, 1959) Downie, 1963

Type species. *Lophosphaeridium rarum* Timofeev, 1959; by subsequent designation of Downie (1963).

Lophosphaeridium tuberosum sp. nov.

(pl. VI, figs. A-N, pl. XIX, fig. N)

Etymology. tuberosum, Latin, full of lumps: tubercles, protuberances or others.

Holotype. Plate VI, figs.A-C, three focus levels, from the Liulaobei Formation, Huainan Group, slide 82AL02-4, (8.7 x 109.3).

Paratypes. Plate VI, figs.D-F, three focus levels from the Liulaobei Formation, Huainan Group, slide 82AL02-2, (6 x 111); plate XIX, fig.N, from the Gouhou Formation, Huaibei Group, slide 83A289-2, (20.3 x 97.8).

Material. More than forty specimens.

Description. Vesicle circular or subcircular in outline, originally spheroidal; wall robust, rarely folded, occasionally split; surface with relatively big tubercles; tubercles rounded, solid, widened at the base, 0.5 - 2.1 *um* across, and 0.3 - 0.8 *um* long; 25 - 70 tubercles observed on the surface; some vesicles with a circular opening (2 - 4*um* in diameter); occasionally a central darker spot observed; specimens yellow to brown in colour, commonly tubercles darker on the vesicles.

Dimensions. The specimens are 12 - 20*um* in diameter (holotype 15*um* in diameter).

Remarks. Timofeev (1959) erected *Lophosphaeridium*, but he did not selected a type species. It was not valid until Downie (1963) emended this genus. *Lophosphaeridium* differs from other genera with similar morphology in its tuberculose sculpture. Some of previous specimens of *Lophosphaeridium* did not display distinct difference from *Leiosphaeridia*. A complex Leiospheroidal transference among *Protoleiosphaeridium*, *Leiosphaeridia* and *Lophosphaeridium* was stated by Lindgren (1981).

L. tuberosum sp. nov. is characterized by its relatively big tubercles and a circular opening, which differs from *L. tentativum* Volkova, *L. truncatum* Volkova and other species with similar morphology.

Distribution. Upper Sinian Liulaobei and Zhaowei Formations and the Lower Cambrian Gouhou Formation. Some specimens have been observed from the Bitter Springs Formation in the Amadeus Basin, central Australia.

Stratigraphic range. Late Proterozoic to Early Cambrian.

Lophosphaeridium sp.

(pl.VI, figs.O-P)

Material. Four specimens.

Description. Circular to subcircular vesicles ornamented with sparse tubercles; tubercles relatively big (0.5 - 2*um*); wall thin, flexible and folded; surface psilate to fine-granular; no convincing opening observed; specimens yellow to brown in colour.

Dimensions. Vesicle diameters are 27 - 58*um*.

Remarks. The uncertain taxon differs from *L. tuberosum* sp. nov. in its thin, flexible wall and large size.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group and Zhaowei Formation, Huaibei Group.

Genus *Micrhystridium* Deflandre, 1937

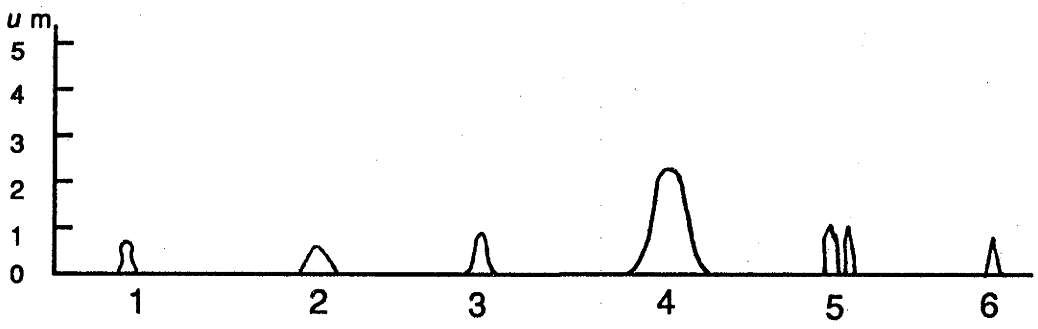
Type species. *Micrhystridium inconspicuum* Deflandre, 1937, p.80 = *Hystrichosphaera inconspicua* Deflandre, 1935, p.233, pl.9, fig.11-12.

Remarks. *Micrhystridium* is a common taxon in the Phanerozoic and some species have been recorded ranging into the Late Proterozoic (Volkova, 1969; Wang Fuxing, 1985; Yin Leiming, 1986a). The vesicles in this genus are commonly small, and subtle differences and variability among them generally can not be described confidently (Downie, 1982). Its diagnosis has been emended several times.

Staplin (1961) emended *Micrhystridium*, and removed its upper size restriction (20*u*m), and he considered that *Micrhystridium* differed from *Baltisphaeridium* in its processes freely communicating with the vesicle interior. He erected a new genus *Multiplicisphaeridium* to include those specimens with differentiated spines. As for those forms with distinct ridges defining polygonal areas are placed in *Dictyotidium* (Staplin, 1961). In 1965, Staplin et al. supplied more information to *Micrhystridium*, and considered the wall structure of *Micrhystridium* was not differentiated between the spines and vesicle (Staplin et al., 1965, p.180). Sarjeant (1967, p.203) disagreed this point and stated that Jurassic and Cretaceous *Micrhystridium* did have a double-layered wall, but he did not give an example. In his paper, Sarjeant (1967) also emended the diagnosis and he considered 20*u*m-diameter limited was important.

Downie and Sarjeant (1963) expressed their disagreements on Staplin's emended diagnosis. In their emended diagnosis, they maintained less than 20*u*m for mean and modal diameter for *Micrhystridium*. They considered that the genera, *Micrhystridium* and *Baltisphaeridium*, presented two natural size modes at 20*u*m - diameter (Downie et Sarjeant, 1963, p.84), but Loeblich (1969) considered that the size limit of 20*u*m for *Micrhystridium* was of little value biologically.

Lister (1970) summarized previous emendations and proposed a compromise emended



1. *Micrhystridium brevicornum* 2. *M. circulapertum.*
3. *M. oligum.* 4. *M* cf. *oligum.* 5. *M. qoardratapertum.*
6. *M. spinosum.*

Text-fig. II-16. Processes of *Micrhystridium;* lateral view.

diagnosis for *Micrhystridium*. He used less than 20*um* for modal diameter of vesicle and considered that the processes communicated freely with vesicle cavity and an inner wall, if present, was highly appressed to the outer wall. He emphasized that double-walled micrhystrids did not evolve until the Mesozoic.

Present specimens assigned to *Micrhystridium* are recorded from the Late Sinian Liulaobei, Zhaowei and Jiayuan Formations and Lower Cambrian Gouhou Formation. The specimens do show different openings, double-layered wall and most specimens larger than 20*um*-diameter. The information may provide more evidence to re-organized its diagnosis. Based on present information, Staplin's emended diagnosis in 1961 is approved in this paper.

Six form specie have been identified, of them, one uncertain, one conferring and two new species (Text-figure II-16).

Micrhystridium brevicornum Jankauskas, 1976
(pl.XIX, figs.E-G)

Micrhystridium brevicornum sp. nov., Jankauskas, 1976, p.189-190, pl.XXV, fig.9, 12.

Micrhystridium brevicornum Jankauskas, Volkova et al., 1979, p.18-19, pl.IX, fig.21-24.

Micrhystridium brevicornum Jankauskas, Downie, 1982, p.260, fig.6:P.

Material. Six specimens.

Description. Circular or subcircular vesicles with short spines; spines sparse, hollow, homomorphic, 0.5 - 2.0*um* long, blunt or rounded at the tip and slightly widen at the base, process number 28 - 45 seen at outline; no regular opening observed; specimens yellow-brown to dark-brown in colour.

Dimensions. Vesicle diameters are 21 - 37*um*. Previous diameters: 15 - 18*um* (Volkova et al., 1979), and 18*um* in diameter (Downie, 1982).

Remarks. Present specimens are more than 20*u*m in diameter, larger than type specimens. As a form taxon, the vesicle with short, sparse spines is considered as the characteristic feature for *M. brevicornum*. Size difference is not important biologically for identification.

Distribution. Lower Cambrian Gouhou Formation, Huaibei Group in northern Anhui. Previously recorded from the Lower Cambrian Vergale Horizon (Lithuania); Lower? Cambrian Izhora Formation (Leningrad); Lower Cambrian Bastion Formation, Greenland; Lower Cambrian shales, Norway; Lower Cambrian Fucoid Beds, Scotland and Gog Formation, Alberta (Downie, 1982).

Stratigraphic range. Lower Cambrian.

Micrhystridium circulapertum sp. nov.
(pl.V, figs.L-O; pl.XIX, figs.U-V)

Etymology. Name is derived from the vesicles occasionally with a circular opening.

Holotype. Pl.V, figs.L-M, two focus levels. The specimen is recorded from the Liulaobei Formation, Huainan Group in northern Anhui. Slide 83A204-2, (16.4 x 112).

Material. Twenty-seven specimens.

Description. Vesicle circular or subcircular in outline, originally spheroidal; wall thick and robust, rarely folded, and occasionally split around margin; spines short (1-2.5*u*m), hollow, blunt or obtuse at the tips and widened at the base, 1-4*u*m across at the bases, number 30 - 51 seen at outline; process hollow, communicating freely into the vesicle cavity; occasionally a circular opening observed; specimens yellow-brown to dark-brown in colour.

Dimensions. Specimens are 22 - 35*u*m in diameter (holotype 27*u*m in diameter).

Remarks. The new species differs from other species with similar morphology in its short spine with very wide bases and occasionally having a circular opening.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group and Lower Cambrian Gouhou Formation, Huaibei Group in northern Anhui. One specimen has been found in the early Late Proterozoic Bitter Springs Formation in the Amadeus Basin (Chapter IV).

Stratigraphic range. Upper Proterozoic to Lower Cambrian.

Micrhystridium oligum Jankauskas, 1976
(pl.V, figs.X-Y; pl.XV, fig.L)

Micrhystridium oligum sp. nov., Jankauskas and Posti, 1976, p.147, pl.1, fig.10, 13, 15, 16, 20.

Micrhystridium oligum Jankauskas, Volkova, 1979, p.21, pl.IX, fig.8-10.

Material. Six specimens.

Description. Vesicles circular or subcircular in outline, originally spheroidal; wall thick, psilate, and folded; spines thick, relatively sparse, numbered 21 - 45 seen at outline, rounded or blunt at the tip, narrow or slightly widened at the bases, 1 - 3*um* long, 0.8 - 1.3*um* across at the bases; specimens yellow to brown in colour.

Dimensions. Specimens are 14 - 32*um* in diameter. Previous record was 8 - 11*um* in diameter (Volkova et al., 1979).

Remarks. Downie (1982) illustrated some species in the genus *Micrhystridium*. In his illustration, *M. oligum*, *M. ellaensis* and *M. ordensis* are all possessing the spines with blunt tips and narrow bases, and differing in their sparse or dense arrangement. The distribution of the spines on the present specimens suggests they resemble *M. oligum*.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group and Zhaowei Formation, Huaibei Group. Previously recorded from the Lower Cambrian Rausve Horizon in Lithuania (Jankauskas, 1976).

Stratigraphic range. Upper Sinian to Lower Cambrian.

Micrhystridium cf. *oligum* Jankauskas, 1976
(pl.V, figs.V-W; pl.VI, fig.T)

Material. Eight specimens.

Description. Circular or subcircular vesicles ornamented with very thick spine; spines variable on the vesicles, blunt or rounded at the tips, slightly widened at the base, and 1 - 4*um* long and 1.5 - 4*um* wide; processes sparse arrangement, number 17 - 33 seen at outline; no openings observed; specimens brown to dark-brown in colour.

Dimensions. Vesicle diameters are 25 - 47*um*.

Remarks. The specimens conferred to *M. oligum* have relatively big size and very thick spines. Their sparse arrangement and some thin spinose forms resemble *M. oligum*.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group, northern Anhui.

Micrhystridium quadratapertum sp. nov.
(pl.V, figs.A-K)

Etymology. Name is from the vesicle occasionally presenting an irregular square opening.

Holotype. Plate V, figures A-D, four focus levels, collected from the Liulaobei Formation, Huainan Group. Slide 83A204-3, (7.4 x 103.4).

Paratype. Plate V, figure F, recorded from the Liulaobei Formation, Huainan Group, slide 83A204-12, (13.7 x 110).

Material. More than forty specimens.

Description. Vesicles circular to subcircular in outline, originally spheroidal; wall thick, psilate, rarely folded and occasionally split; spines dense, hollow, homomorphic, relatively short, sword-like, slight widen at the base, and rapidly-sharpened at the apices; spine length 1 - 4.5*um*, number 55 - 72 seen at outline; occasionally an irregular square opening observed; specimens yellow to brown in colour.

Dimensions. Vesicle diameters are 23 - 35*um* (holotype 26*um* in diameter).

Remarks. *M. quadratapertum* sp. nov. differs from other species of *Micrhystridium* in its short sword-like spines.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group, northern Anhui.

Stratigraphic range. Upper Sinian.

Micrhystridium spinosum Volkova, 1969
(pl.V, figs.S-U)

Micrhystridium spinosum sp. nov., Volkova, 1969, p.229, pl.L, fig.14-16.

Micrhystridium spinosum Volkova, Gardiner et Vanguestain, 1971, p.190, pl.I, fig.9-10.

Micrhystridium spinosum Volkova, Volkova et al., 1979, p.21-22, pl.IX, fig.25.

Micrhystridium spinosum Volkova, Downie, 1982, p.262, fig.7:f.

Material. Three specimens.

Description. Vesicles circular to subcircular in outline, originally spheroidal; wall thick, psilate, folded or split; spines relatively dense, short, hollow, homomorphic, wide at the bases and sharp at the apices; spine 1 - 3*um* long and number about 35 seen at outline; specimens yellow to brown in colour.

Dimensions. Vesicle diameters 22 - 26*um*. Previous records were 7 - 13*um* (Volkova, 1969) and 10 - 16*um* in diameters (Downie, 1982).

Remarks. Present specimens are relatively larger, and their spines resemble those of the type specimens.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group. Previously recorded from the Lower Cambrian Vergale Horizon (Latvia, Ukraine, Poland), Rausve Horizon (Latvia, Ukraine, Poland); Middle Cambrian Thulla Formation, Bray Group (Ireland), Middle Cambrian Kibartai Horizon (Latvia, Poland), Lower Cambrian Fucoid Beds (Scotland), Bastion Formation (Greenland) (Volkova et al., 1979; Downie, 1982).

Stratigraphic range. Upper Sinian to Middle Cambrian.

Micrhystridium sp.
(pl.VI, figs.Q-S)

Description. Unnamed taxon of *Micrhystridium* consisting of double-walls; inner body empty, circular or subcircular; internal and external walls separated; spines only ornamented on the external wall; process base widened, and blunt or slightly sharp at the tips; spines about 30 seen at periphery and 1 - 2*um* in length; vesicles 19 - 21*um* in diameter.

Discussion. The specimen (fig.Q) lost half part of the external wall, exposing its inner spheroidal body. This feature is very rare to observed. Double-walled specimens in *Micrhystridium* may provide more information for the diagnosis of the genus.

Genus *Octoedryxium* Rudavskaja, 1973

Type species. *Octoedryxium truncatum* (Rudavskaja) Vidal, 1976

Octoedryxium truncatum (Rudavskaja) Vidal, 1976
(pl.VI, figs.U-Z)

Octoedryxium truncatum Rudavskaja, gen. et sp. nov., Rudavskaja, 1973 p.7, pl.1, fig.1-3.

Tetraedrixium tyrassum sp. nov., Timofeev, 1973, p.17, pl.1, fig.8; pl.43, fig.2-4.

Tetraedrixium bernaschevium sp. nov., Timofeev, 1973, p.17, pl.1, fig.9; pl.43, fig.5.

Octaedrixium simmetricum sp. nov., Timofeev, 1973, pl.1, fig.11; pl.43, fig.6-12.

Octaedrixium dentatum sp. nov., Timofeev, 1973, p.18, pl.1, fig.12; pl.20, fig.6-7.

Octaedrixium intrarium sp. nov., Timofeev, 1973, p.18-19, pl.1, fig.10; pl.43, fig.13-14.

Octaedrixium sp., Timofeev, 1973, pl.2, fig.4.

Quadratimorpha ordinata Sin et Liu, sp. nov., Sin et Liu, 1972, pl.4, fig.10-12.

Quadratimorpha ordinata Sin et Liu, gen. et sp. nov., Sin et Liu, 1973, p.60, pl.4, fig.10-12.

Octoedryxium truncatum (Rudavskaja, 1973), n. comb., Vidal, 1976, p.22-25, fig.11:A-P.

Octoedryxium truncatum (Rudavskaja), Timofeev et al., 1976, p.49, pl.19, fig.2-5.

Octoedryxium truncatum (Rudavskaja) Vidal, 1979, p.22, pl.2, fig.f-g.

Octoedryxium truncatum (Rudavskaja) Vidal, Vidal et Knoll, 1982, fig.2:E-F.

Octoedryxium truncatum (Rudavskaja) Vidal, Vidal et Siedlecka, 1983, p.63, fig.7:E-G.

Material. Seven specimens.

Description. Octahedral or square-like vesicles with smooth or psilate surface texture; diagonal ridges observed; wall spongy or porous, rarely folded, occasionally with a slit-like aperture; corners of the square sharp or blunt; specimens yellow to dark-brown in colour.

Dimensions. The sides of the square are 10 - 22*um*. Previous measurements: 15 - 80*um* (Vidal, 1976), and 20 - 40*um* (Vidal et Siedlecka 1983).

Distribution. Upper Sinian Liulaobei and Zhaowei Formation in northern Anhui.

Previous occurrences were recorded by Vidal (1976) and Vidal et Siedlecka (1983). The species *Q. ordinata* is reported by Sin et Liu (1973) from the Hongshuizhuang (Hunghsuichuang) Formation in Jixian County, northern China, previously misunderstood as upper-middle Sinian and recently its age was dated at about 1100 - 1200 Ma (Wang Yuelun et al., 1980).

Abundant *O. truncatum* (Rudavskaja) has been found from the Ediacarian Pertatataka Formation in the Amadeus Basin, central Australia.

Stratigraphic range. Middle Proterozoic to Lower Cambrian.

Ovulum Jankauskas, 1975

Type species. *Ovulum saccatum* Jankauskas, 1975

Ovulum saccatum Jankauskas, 1975

(pl.XIX, figs.H-I, P, R)

Ovulum saccatum sp. nov., Jankauskas, 1975, p.96-97, pl.XI, fig.1-15, 23.

Ovulum saccatum Jank., Volkova et al., 1979, p.39, pl.XI, fig.21-27.

Material. Fifteen specimens.

Description. Ovate or elliptical vesicles ornamented with smooth or fine-granular surface texture; wall commonly folded, occasionally folds along the margin consisting of a thickened ring; vesicles rounded at one pole and open at the other; opening relatively big; margin of the opening sometimes ornamented with the frill, displaying a crescent-like structure; specimens yellow to dark-brown in colour.

Dimensions. Specimens are 13 - 35*um* at long axis, and 7.5 - 17*um* at short axis; the diameter of openings ranges 5 - 11*um*. Previous measurements were recorded 5 - 16*um* and 3 - 9*um* for axes respectively (Jankauskas, 1975).

Remarks. Present specimens are larger than the type specimens of the Soviet Union. The larger specimens usually have a large opening, and it is possible the opening increases with the microorganism.

O. saccatum differs from chitinozoan-like microfossils in lacking a neck structure.

Distribution. Lower Cambrian Gouhou Formation, Huaibei Group in the Huaibei region. Previous occurrences were recorded from the Lower Cambrian Vergale Horizon (Latvia, Lithuania, Ukraine), Rausve Horizon (Estonia, Latvia, Lithuania, Ukraine); the Lower? Cambrian Izhora Formation in Leningrad region, the Middle Cambrian Kibartu Horizon (Liepaja) (Volkova et al., 1979).

Stratigraphic range. Lower to Middle Cambrian.

Genus *Paleasphaeridium* Yin Ch., 1985

Type species. *Paleasphaeridium zonale* Yin Ch., 1985.

Translated Diagnosis. Colonies consisting of a group of spheroidal vesicles connected by a thin membrane; membrane translucent and single-layered; vesicles with a coarse surface texture; a thickened ring commonly around margin; vesicles 22 - 36*u*m in diameter.

Remarks. The genus is similar to *Synsphaeridium* and *Leiosphaeridia* in the forms of solitary specimens and irregular colony formation, but differs in its colony connected by a membrane sheath.

Paleasphaeridium zonale Yin Ch., 1985

(pl.XIII, figs.A-D)

Paleasphaeridium zonale gen. et sp. nov., Yin Chongyu, 1985, p.109, pl.4, fig.2.

Material. More than twenty colonies.

Description. Irregular formation of the colonies consisting of circular or subcircular vesicles and surrounded by a single-layered sheath membrane; vesicles with psilate to fine granular surface texture; wall commonly folded, usually forming a thickened ring around the margin of vesicle, ring 0.5 - 2.5*um* wide; membrane translucent, very thin; specimens yellow to yellow-brown in colour.

Dimensions. The vesicles are 12 - 20*um* in diameters. Previous measurements were 22 - 36*um* in diameter for vesicles, and 4 - 6*um* wide for the thickened ring.

Remarks. The solitary vesicle of *P. zonale* resembles that of *L. asperata* (Naumova) in its wrinkles, smooth surface texture and occasionally a darker spot present in the centre, but the colonies of *P. zonale* is connected by a single-layered sheath membrane. Yin Chongyu (1985) emphasized its thickened ring structure, but this ring is more or less diagenetically deformed.

Distribution. Present and previous specimens are all recorded from the upper Sinian Liulaobei Formation, Huainan Group, northern Anhui. Some specimens have been observed from the Middle Cambrian Tempe Formation in the Amadeus Basin, central Australia (Chapter IV).

Stratigraphic range. Upper Sinian to Cambrian.

Genus *Protoleiosphaeridium* (Timofeev, 1959) Timofeev, 1960

Type species. *Protoleiosphaeridium conglutinatum* (Tim.) Timofeev, 1960 = *Protoleiosphaeridium conglutinatum* Timofeev, 1959 [p. 26, pl.1, fig.6; pl.13, fig.1; pl.15 (cont.),fig.1; pl.16, fig.1; pl.17, fig.1; pl.18, fig.2; pl.18 (cont.), fig.1; pl.19, fig.1; pl.19 (cont.), fig.2] (cf. Loeblich and Tappan, 1976).

Discussion. Timofeev (1959) invalidly described the genus *Protoleiosphaeridium* because no type species had been indicated, but subsequently was validated by Timofeev (1960) with *P. conglutinatum* (Timofeev, 1959) Timofeev, 1960 as lectotype species. However, Timofeev (1966) divided this genus into two new genera *Protosphaeridium* and *Synsphaeridium* (non. *Synsphaeridium* Eisenack, 1965), and he transferred *Protoleiosphaeridium conglutinatum* Tim. emend. as the type species of *Synsphaeridium*. As this was already the type species of *Protoleiosphaeridium* (Tim.) Timofeev, 1960 the name for *Synsphaeridium* is illegitimate (Loeblich and Tappan, 1976). Timofeev (1966) also erected a new species *Protosphaeridium densum* as the type species of the new genus *Protosphaeridium*, and he stated that this genus equalled to *Protoleiosphaeridium* Timofeev, 1959. As the description of *Protosphaeridium* was said to equal *Protoleiosphaeridium* and did not explicitly exclude the type species of *Protoleiosphaeridium*, *Protosphaeridium* is illegitimate and must be rejected as a superfluous name for *Protoleiosphaeridium* (Tim.) Timofeev, 1960 (Loeblich and Tappan, 1976). Loeblich and Tappan (1976) considered the genera *Protosphaeridium*, *Synsphaeridium*, as well as *Prototrachysphaeridium* Timofeev, 1964 were the synonyms of *Protoleiosphaeridium*. Yin Leiming and Li (1978) published similar opinion.

Protoleiosphaeridium Timofeev 1960 contains spheroids with small size (less than 50*um* in diameter) and smooth to shagreen surface structure. Downie and Sarjeant (1963) considered *Protoleiosphaeridium* were congeneric with the genus *Leiosphaeridia*, and this taxonomic change has been rejected by Staplin et al. (1965), but recently accepted by Lindgren (1981, 1982); however, in his recent paper, Downie (1981) described the genus *Protoleiosphaeridium* himself.

For the complicated usage of the two genera in the publications and they have been suggested to describe same kind of specimens, in this paper I tentatively accept *Protoleiosphaeridium* as valid genus to include those leiospheres with smooth, shagreen, spongy or other kind of surface textures which can differ from that of *Leiosphaeridia*. Part of the species previously referred to *Protosphaeridium* has been transferred to the genus *Protoleiosphaeridium*.

Genus *Turuchanica* Rudavskaja, 1964 consists of those specimens with robust wall and display slits on margin. The slits, especially those not so deep, are probably caused by diagenetic deformation. This genus, at least part of the specimens, is probably congeneric with *Protoleiosphaeridium*.

Genus *Liulaobeinella* Yan, 1982 is characterized by its vesicles half thickened. In my observation many specimens of *Protoleiosphaeridium densum* are lost one-fourth part of the wall, displaying one half lighter and the other half darker. Similar vesicles can be found in *Leiosphaeridia* (pl.X, fig.P). Part of the specimens in the genus *Liulaobeinella* have been transferred to *Protoleiosphaeridium.*

Synsphaeridium Eisenack (1965) is tentatively accepted in this paper to include those spheroidal vesicles which are grouped together without order.

Protoleiosphaeridium densum (Timofeev, 1966)
comb. correct.

(pl.X, figs.A-F; pl.XXI, figs.H-K)

Protosphaeridium densum sp. nov., Timofeev, 1966, p.21, pl.IV, fig.5; pl.XLIV, fig.2.

Turuchanica ternata sp. nov., Timofeev, 1966, p.45, pl.IX, fig.8.

Protosphaeridium densum Timofeev, Timofeev, 1969, p.8, pl.1, fig.4.

Turuchanica alara Rud., Timofeev, 1969, pl.IV, fig.5.

Turuchanica ternata Tim., Timofeev, 1969, p.19, pl.IV, fig.6; pl.VIII, fig.9; pl.X, fig.13; pl.XI, fig.12; pl.XII, fig.14.

Protosphaeridium densum Tim., Sin et Liu, 1973, p.14, pl.VII, fig.3; pl.VIII, fig.7; pl.XI, fig.9-10.

Protosphaeridium densum Tim., Timofeev, 1974, pl.XIV, fig.1; pl.XV, fig.1; pl.XVI, fig.16.

Turuchanica ternata Tim., Timofeev, 1974, pl.XV, fig.5; pl.XVII, fig.16; pl.XX, fig.19.

Liulaobeinella tenera Yan, gen. et sp. nov., Yan, 1982, p.84, pl.1, fig.56-58.

Liulaobeinella densa Yan, gen. et sp. nov., Yan, 1982, p.84, pl.1, fig.60-62.

Liulaobeinella minor Yan, gen. et sp. nov., Yan, 1982, p.84-85, pl.1, fig.64-66.

Liulaobeinella rarijugata Yan, gen. et sp. nov., Yan, 1982, p.85, pl.1, fig.63.

Leiopsophosphaera densa (Tim.) Sin et Liu, Yan, 1982, pl.1, fig.6-9.

Turuchanica alara Rud., Yan, 1982, pl.2, fig.16.

Turuchanica ternata Tim., Yan, 1982, pl.2, fig.16.

Protoleiosphaeridium densum Timofeev, 1966, Yin Leiming, 1983, pl.11, fig.1,9.

Leiopsophosphaera solida (Liu et Sin) Sin et Liu, Yin Chongyu, 1985, pl.1, fig.10.

Leiopsophosphaera crassa Sin, Yin Chongyu, 1985, pl.1, fig.11.

Turuchanica ternata Tim., Yin Chongyu, 1985, pl.3, fig.17.

Material. More than 500 specimens.

Emended diagnosis. Form taxon with smooth or psilate surface texture and extremely robust wall; suffering from diagenetic deformation the vesicles commonly split around margin.

Description. Vesicles circular to subcircular in outline, originally spheroidal; wall very thick (0.5 - 1.2*um*), extremely robust, single, smooth to psilate, usually with very thin folds and commonly split around the margin; inner side of the wall fine-granular; slits sometimes reaching to vesicle centre, most of them very short and some similar to "median splits"; some vesicles losing one-fourth part of wall, displaying one half lighter and the other half darker; no excystment structure observed; specimens yellow-brown or dark brown in colour.

Dimensions. Vesicles are 12 - 73*um* in diameter. Previous records: 15 - 35*um* in diameter (Timofeev, 1966), and 15 - 80*um* in diameter (Timofeev, 1969). *Turuchanica* Rud., according to Timofeev (1969), ranging 15 - 150*um* in diameter. *Turuchanica ternata* Tim. was 50 - 80*um* (Timofeev, 1966). *Liulaobeinella* Yan was 9 - 30*um* at long axis (Yan, 1982).

Remarks. *P. densum* (Timofeev, 1966) is a common taxon in the Proterozoic. It differs from *L. asperata* by its extremely robust vesicles and relatively thick wall, and differs from *P. laccatum* by lacking velutinous surface texture and usually displaying some slits around the vesicle margin. Timofeev (1966) considered *P. densum* and *P. laccatum* had same structure, the feature to identify the two species was size difference, and he defined *P. densum* ranging 15 - 35*u*m and *P. laccatum* 35 - 60*u*m in diameter.

P. laccatum Timofeev, 1966, based on Vidal's description (Vidal, 1976), has velutinous surface texture, and thus its wall is relatively flexible. Observation suggests that *P. laccatum* does not display slits on the vesicle margin.

Most slits of *P. densum* may be diagenetically deformed. Because *P. densum* has a extremely robust wall, its wall may be splits rather than be folded when under the pressure. *Turuchanica* Rud. and *Liulaobeinella* Yan are defined on these diagenetic slit features. Several hundred specimens observed do not show any reliable slit structures similar to those of modern alga *Micrasterias*.

Distribution. Upper Sinian Liulaobei, Shijia, Zhaowei and Jiayuan Formations, and Lower Cambrian Jingshanzhai and Gouhou Formations. Sin et Liu (1973) recorded *P. densum* from the Changchengian Chuanlinggou Formation (1800Ma) and Qingbeikouan Xiamaling Formation. *P. densum* and *Turuchanica ternata* are widely distributed in the Proterozoic of the Soviet Union (Timofeev, 1966, 1969).

Stratigraphic range. Proterozoic to Palaeozoic.

Protoleiosphaeridium flexuosum (Timofeev, 1966) comb.
(pl.X, figs.J-K, Q-R; pl.XXI, fig.L)

Protosphaeridium flexuosum sp. nov., Timofeev, 1966, pl22, pl.IV, fig.7.

Protosphaeridium flexuosum Tim., Timofeev, 1969, p.8, pl.1, fig.6.

Protosphaeridium cf. *flexuosum* Tim., Vidal, 1976, p.25, fig.12:A-P.

Material. More than 400 specimens.

Description. Vesicles circular to subcircular in outline, originally spheroidal; wall spongy, shagreen or porous, rarely folded; vesicles commonly with a circular or irregular circular opening; colonies arranging without order; specimens yellow to brown in colour.

Dimensions. Vesicles are 19 - 73*u*m in diameter. Previous diameters were 25 - 60*u*m (Timofeev, 1966) and 5 - 60*u*m (Timofeev, 1969) for *Protosphaeridium. flexuosum*, and 22 - 30*u*m for *Protosphaeridium.* cf. *flexuosum* Tim. (Vidal, 1976).

Remarks. *P. flexuosum* differs from other species of *Protoleiosphaeridium* by its spongy vesicles.

Vidal (1976) observed some spheroidal protuberances and an opening on the vesicle under scanning electron microscope, which had not been described in original diagnosis of Timofeev (1966), and he named his specimens as *Protosphaeridium.* cf. *flexuosum* Timofeev. Generally the opening of the vesicles occurs in reproductive stages, those specimens without openings represent some vegetative period. The function of protuberances has not been understood. For the present material, the spongy wall is considered to be a diagnostic feature for *P. flexuosum*.

Distribution. Upper Sinian Liulaobei, Shijia and Zhaowei Formations, and the Lower Cambrian Gouhou Formation. Previous occurrences were recorded by Vidal (1976) for *Protosphaeridium* cf. *flexuosum*.

Stratigraphic range. Proterozoic to Middle Cambrian.

Protoleiosphaeridium laccatum (Timofeev, 1966), comb.
(pl.XXI, figs.F-G)

Protosphaeridium laccatum Timofeev, 1966, Vidal, 1976, p.25-26, fig.13:A-C, F.

Previous synonymy - see Vidal (1976, p.25).

Material. About seventy specimens.

Description. Vesicles circular or oval in outline, originally spheroidal; wall thick, smooth or psilate, velutinous appearance; slits, folds and openings rarely observed; specimens yellow to dark-brown in colour.

Dimensions. Specimens are 25 - 40*um* in diameter. Previous measurements were 20 - 68*um* in diameter (Vidal, 1976).

Remarks. Vidal (1976) reported 20861 specimens to *Protosphaeridium laccatum* from the Visingsö Beds, and some specimens up to 1500 to 2000*um*. The specimens in this paper are less abundant and relatively smaller size. The velutinous surface texture serves to distinguish *P. laccatum* from the other specimens with similar morphology.

Distribution. Upper Sinian Liulaobei and Shijia Formations and the Lower Cambrian Gouhou Formation. Previous occurrences were recorded by Vidal (1976) for *Protosphaeridium laccatum.*

Stratigraphic range. Proterozoic to Ordovician.

Genus *Pterospermopsimorpha* Timofeev, (1962, 1963) 1966

Type species. *Pterospermopsimorpha pileiformis* Timofeev, 1966

Pterospermopsimorpha binata Timofeev, 1966

(pl.IX, figs.A-B)

Pterospermopsimorpha binata sp. nov., Timofeev, 1966, p.33-34, pl.V, fig.11.

Pterospermopsimorpha binata Tim., Timofeev, 1969, p.46, pl.III, fig.6.

? *Pterospermopsis asperata* Yan sp. nov., Yan, 1982, p.86, pl.II, fig.17.

Material. Four specimens.

Description. Vesicle subcircular or oval in outline; a central darker inner body surrounded by an outer lighter membrane; inner body robust, relatively large, not folded, no convincing openings, and with a smooth surface texture; outer membrane translucent, psilate to fine-granular, more or less deformed; specimens yellow to brown in colour.

Dimensions. Specimens are 35 - 70*u*m in diameter for inner darker bodies and 5 - 16*u*m wide for outer lighter membrane. Previous measurements: 50 - 90*u*m in diameter (Timofeev, 1966, 1969) and 9 x 17*u*m for the inner dark body and 5 - 8*u*m wide for the outer lighter membrane (Yan Yongkui, 1982).

Remarks. Timofeev (1966) erected this species with one picture and he republished this picture in his another paper (1969). The present specimens are similar to the type specimen.

Yan (1982) described a new species, *Pterospermopsis asperata*. This species was characterized by an elliptical inner darker body and a coarse outer lighter layer, and no significant difference from *P. binata*. The genus *Pterospermopsis* W. Wetzel (W. Wetzel, 1952) was considered to be invalid because the holotype of its type species was a badly damaged specimen (Eisenack, 1972; cf. Volkova et al., 1979).

P. concentrica (Sin et Liu) Vidal, 1976 differs from the present species by its outer lighter layer having a porous appearance and many stripes radiating from the inner darker body (Vidal, 1976).

Distribution. Upper Sinian Liulaobei Formation , Huainan Group, northern Anhui. Previously recorded from the Chuanlinggou Formation, northern China (Timofeev, 1966, 1969).

Stratigraphic range. Proterozoic.

Pterospermopsimorpha spongia sp. nov.

(pl.IX, figs.M-S)

Etymology. Name is derived from its external lighter spongy wall.

Holotype. Plate IX, figs.M-N, two focus levels, from the Liulaobei Formation, Huainan Group, slide 82AL11-5, (9.4 x 114).

Material. More than thirty specimens.

Description. Vesicle circular to oval in outline, consisting of a inner darker body and lighter surrounding wall; inner darker body spheroidal to elliptical, empty and with a smooth surface texture; outer lighter wall spongy or porous; a 'median split' occasionally observed on the external surface (about 5*um* long and 1*um* wide); specimens yellow to yellow-brown in colour.

Dimensions. The inner dark bodies are 15 - 28*um* in diameter (holotype, 11 x 25*um*), and 3 - 11*um* wide for surrounding wall. The diameters for vesicles at outline are 24 - 37*um*.

Remarks. The new taxon differs from other species of *Pterospermopsimorpha* in its surrounding lighter spongy wall.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group, northern Anhui. Some specimens have been observed from the Upper Proterozoic Bitter Springs and Pertatataka Formations in the Amadeus Basin, central Australia.

Stratigraphic range. Late Proterozoic.

Genus *Pyritosphaera* Love, 1957

Type species. *Pyritosphaera barbaria* Love, 1957

Pyritosphaera Love, 1957, p433.

Pyritella Love, 1957, p434.

Microconcentrica Naumova, 1960(?).

Bavlinella Shepeleva, 1962.

Sphaerocongregus Moorman, 1974.

Diagnosis (Modified from Love). spheroidal aggregates of several to numerous tightly packed spheroidal or sub-spheroidal cells and coated occasionally; colonies irregular forms or linear arrangement.

Discussion. Love (1957) erected the genus *Pyritosphaera* and found it had a close genetic association with pyrite grains in the Lower Carboniferrous Oil Shale Group in Scotland, but he noted that the pyritospheres had a specific gravity of 3.8-4.0 (normal pyrite grains: 4.8-5.1) and they were coated. He confirmed this discovery in his further researches (Love, 1965, 1978).

Coated pyritospheres probably are organic origin, especially after dealing with nitric acid. The outer coating is very thin and easy to be damaged. In my observation, it is difficult to find a complete surrounding membrane, particularly for these specimens with 'honeycomb'-shaped surface meshwork. It is well-known that organic aggregates could be damaged, modified or replaced by pyrite and other minerals, but a real pyrite grain does not have a outer surrounding membrane. A specimen which contains pyrite composition and lacks outer surrounding membrane could be a pyrite grain or a organic aggregate replaced by pyrite and lose its outer surrounding membrane in laboratory preparation. Use of heavy liquid of specific gravity less than 2.5 to floating organic matter in laboratory, very few pyrite grains could be observed in samples.

Love (1957) described *Pyritosphaera* as a spheroid ornamented with 'spines', which may be damaged specimens. In his holotype, no such 'spines' have been observed.

Duchesne (1963, cf. Volkova, 1974) found three forms of *Pyritosphaera barbaria* from the Cambrian deposits of the Bayehon Valley, and he considered them as microorganisms.

The life-cycle of the genus has been studied (Moorman, 1974). The pyritosphere rich beds, in my collections from China and Australia, have been found to contain abundant specimens like that of *Pyritella* Love, 1957. This occurrence has been well interpreted by Knoll et al. (1981). As the description of the form variations, *Pyritella* is a junior synonym of *Pyritosphaera*, probably one form in life cycle.

The genus *Bavlinella* was erected by Shepeleva (1962) and emended by Vidal (1976). This genus is characterized by its spheroidal aggregate of numerous tightly packed spheroidal cells. Volkova (1974) considered *Bavlinella faveolata(-us)* Shepeleva was a synonym of *Pyritosphaera barbaria* Love, however she suggested they were not independent organisms, but modified bodies of acritarchs or other plant microfossils. Muir (1977) expressed similar opinion. Anywhere Vidal (1977) discussed this questions in his correspondence.

The genus *Sphaerocongregus* Moorman, 1974, which consists of a group of mono- and pluri- cellular structure. Vidal (1976) considered it was congeneric with the genus *Bavlinella.*

The genus *Microconcentrica* Naum. (type species, *M. atava* Naum.) was possibly first published in 1960, and Naumova (1960) stated this genus contained vesicles with a rounded or oval outline, thin or thick wall, a smooth, shagreen or fine-warty surface texture being covered by a concentric arrangement of semicircular cells, and vesicles 10-30*um* in diameter. Naumova presented a illustration for *Microconcentrica orbiculata* Naum., which is similar to the specimens of *Pyritella* and *Sphaerocongregus variabilis* Moorman, 1974. Thus *Microconcentrica* is probably a synonym of *Pyritosphaera.*

Pyritosphaera barbaria Love, 1957
(pl.XIII, fig.g; pl.XV, figs.A-H; pl.XIX, figs.Q, T)

Pyritosphaera barbaria gen. et sp. nov., Love, 1957, p.433, pl.XXXIII, fig. 3-5.

Pyritella polygonalis gen. et sp. nov., Love, 1957, p.434, pl.XXXIII, fig. 6-7.

? *Microconcentrica orbiculata* Naum., Naumova, 1960, pl.3, fig.13.

Bavlinella faveolatus gen. et sp. nov., Schepeleva, 1962, p.170, fig.1.

Bavlinella faveolatus Schepeleva, Volkova, 1968, pl.19, fig.13.

Bavlinella faveolatus Schepeleva, Timofeev, 1969, p.17, pl.III, fig.10,

Microsphaera faveolata Sin gen. et sp. nov., Sin et Liu, 1973, pl.13, fig.7, Form A, Manum, 1967, p.48-49, pl.1, fig.1-5.

Sphaerocongregus variabilis n. sp., Moorman, 1974, p.535, pl.1, 2,3, text-figure, 3.

Favososphaera conglobata Burmann, 1972, Konzalova, 1974, p.43, pl.3, fig.4-5.

Favososphaera sola Burmann, 1972, Konzalova, 1974, p.44, pl.3, fig.1-3.

Bavlinella faveolatus Schepeleva (Schepeleva, 1962) nom. correct., Vidal, 1976, p.17-18, fig.7:A-C.

Bavlinella faveolatus (Schepeleva, 1962) Vidal, Vidal, 1976b, fig.2:M-O.

Bavlinella faveolata (Shepeleva, 1962) Vidal, 1976, Vidal, 1981b, p.23.

Pyritosphaera barbaria Love, 1957, Love, 1979, fig.1, 1-6.

Pyritella polygonalis Love, 1957, Love, 1979, fig.1, 7-8.

Bavlinella faveolata (Shepeleva) Vidal, 1976, Knoll et al., 1981, pl. A-R.

Microconcentrica atava Naum., Yin Chongyu, 1985, pl.2, fig.9.

Microconcentrica aff. *induplicata* Liu et Sin, Yin Chongyu, 1985, pl.2, fig.9.

Material. More than one hundred specimens (also more than one thousand specimens have been obtained from the Lower Cambrian Qiongzhusi Formation in eastern Yunnan, southern China, in Chapter III).

Description. Specimens spheroidal or subspheroidal aggregates of numerous tightly packed cells; cells spheroidal, subspheroidal or irregular, and 1-10*um* in diameter; occasionally aggregates enclosed by a thin external membrane; spheroidal aggregates sometimes to form irregular colonies; cells in chain-like colonies closely connected in parallel arrangement, with equal or unequal sizes; cell wall thin, occasionally folded, with a smooth to psilate surface texture; specimens observed yellow to dark-brown in colour.

Dimensions. Spheroidal aggregates are 14 - 45*um* in diameter. Previously diameters: 2-35*um* (*P. barbaria*) and 20-50*um* (*Pyritella polygonalis*) (Love, 1957), 13-15*um* (Vidal, 1976), 5 - 20*um* (Moorman, 1974), 15 - 25*um* (Timofeev, 1969), and 10 - 30*um* (Naumova, 1960). Duchesne (1963, cf. Volkova, 1974) recorded three forms: isolated individuals (20-70*um*), "colonies" (100-250*um*) and mixed forms (25-250*um*). All three forms have been observed from the Lower Cambrian Qiongzhusi Formation in eastern Yunnan, southern China.

The chain-like specimens are 132 - 150*um* long and 15 - 17*um* wide. Previous measurements were 105*um* long and 10.4*um* wide (Moorman, 1974).

Remarks. Moorman (1974) erected the new species *Sphaerocongregus variabilis* and reconstructed its form variation as a growth cycle. All forms in her text-figure 3 have been found in the Liulaobei Formation. Vidal (1976) only accepted part of Moorman's spheroidal aggregates (pl.1, fig.1-4, 7-9) as valid members of *Bavlinella* and he rejected some large specimens. In the Liulaobei Formation, the specimens display gradual variation in sizes, probably supporting Moorman's growth cycle.

Distribution. Upper Sinian Liulaobei, Zhaowei and Shijia Formations and Lower Cambrian Gouhou Formation in northern Anhui. Abundant specimens have been found in the Lower Cambrian Qiongzhusi Formation, Chengjiang County, Yunnan Province. Previously recorded from the Lower Carboniferrous Oil Shales Group, Scotland (Love, 1957), Lower Proterozoic Mount Iso Shale, Queensland, Australia (Love, 1965), Upper Precambrian Mineral Fork Formation near Salt Lake City, Utah (Knoll et al., 1981); the Stappogiedde Formation Mortensnes Tillite, Grasdal, Dakkovarre and Stangenes Formations of East Finnmark (Vidal, 1981b); the Eleonore Bay and Tillite Groups in East Greenland (Vidal, 1976b); the Visingsö Beds (Vidal, 1976); the uppermost Proterozoic

Hector Formation, Alberta, Canada (Moorman, 1974); and other occurrences are documented by Vidal (1976).

Stratigraphic range. Proterozoic to Phanerozoic.

Genus *Sinianella* (Yin. L., 1980) emend.

Type species. *Sinianella uniplicata* (Yin. L., 1980) emend.

New genus contains two species: *Sinianella uniplicata* (Yin. L., 1980) emend., and *S. scabrata* sp. nov..

Previous diagnosis (after Yin Leiming, 1980). Calyx-like in outline, of which one end is sharp, and the other is stem-shaped. Both lateral sides protruded outward. Surface texture psilate or slightly coarse. A darker and boat-like area observed on the vesicle. Specimens are brown to black.

Emended diagnosis. Vesicle bottle-shaped with a single prominent process drawn out at one pole and semi-circular or rounded at the other; process rounded or truncated, and open at the apix; colony linear and interlocking arrangement.

Remarks. *Sinianella* is characterized by its single prominent process open at the apix and linear colony structure.

Unlike *Leiosphaeridia* and *Kildinosphaera*, the colonies of *Sinianella* are linear arrangement. The colonies display every two cells contacting each other, and prominent processes are functionally connected with the others. Generally two cells are connected with interlocking or front-to-back order. The prominent processes in the colonies are usually small.

Yin Leiming (1980) erected *Sinianella* based on its stem-like process and a darker and boat-like area on the vesicle. The process may not be interpreted as "stem" for some processes are very small, and not functionally adhere to the ground or other organisms. The form-taxon probably was a group of planktonic micro-organisms. The functions of the processes are possibly connecting and communicating. As for darker and boat-like area, because of ill quality of the photographs, it is possibly a wrinkle. In his text-figures (Yin Leiming, 1980), the vesicle with a darker area seems to be a broken specimen, losing some part of the wall. This feature is quite common in the Liulaobei Formation, some specimens in preparation are lost some part of the wall, displaying some area darker and the other lighter.

The genus *Pirea* Vavrdova 1972 was originally designed as overall broadly bottle-shaped with single process drawn-out from vesicle, but the process with rounded distally, probably not open outside. No colony structures of *Pirea* have been described.

Sinianella uniplicata (Yin, L., 1980) emend.
(pl.XI, figs.A, C-F, H-I, K-M; pl.XXI, fig.E)

Sinianella uniplicata Yin, gen. et sp. nov., Yin Leiming, 1980, pl.I, fig.37, 38, text-fig.4.

Lectotype. Plate XI, fig.A, slide 85A202-1, (11.2 x 116.5), collected from the Liulaobei Formation, at Bagongshan section, Shouxian County in the Huainan region.

Paratypes. Plate XI, Fig.F, slide 82AL05-1, (10.5 x 105.5); plate XI, fig.K, slide 82AL05-2, (10 x 113.8). Both specimens are collected from the Liulaobei Formation at the Bagongshan section, Shouxian County in the Huainan region.

Material. More than 500 specimens.

Emended diagnosis. Vesicle bottle-shaped with a single prominent process at one end and its colony linear arrangement; wall thin, with a smooth or psilate surface texture.

Description. Vesicles bottle-shaped, elliptical or elongate in outline; wall thin, smooth or psilate, commonly folded; wrinkles irregular arrangement and most of them parallel to longitudinal axis; a prominent process drawn out from the vesicle, and the process semi-circular, blunt or truncate shape at the apix; semi-circular process usually small, 2 - 8*um* long and 4 - 8*um* wide, and truncate processes relatively large, 4 - 10*um* long and 6 - 12*um* wide; truncate processes obviously open and some blunt processes having a tendency to open at the tips; other apix rounded.

Colony consisting of two to dozens of specimens (some colonies contains more than 60 vesicles); vesicles in colonies usually small; processes 2 - 4*um* long, 3 - 5*um* wide, functionally connecting with adjacent vesicles; colonies linearly interlocking arrangement.

Dimensions. The solitary specimens are 15 - 90*um* wide and 18 - 235*um* long (lectotype, 55*um* wide, 116*um* long). The specimens in colonies are 11 - 25*um* wide and 13 - 35*um* long (paratype, plate XI, fig.F., 11.6*um* wide, 20*um* long). The length of the colony is up to 400 - 500*um*.

The measurements recorded by Yin Leiming (1980) were: processes: 4.5 - 7.5*um* wide and 1.5 - 5*um* long; vesicle: 24 - 65*um* long and 15 - 42*um* wide.

Remarks. The species was first described by Yin Leiming (1980), and he provided two figures, with one holotype and the other paratype, but both specimens were ill-preserved, and no surface textures are observed. In his text-fig.4, Yin Leiming (1980) published three illustrations with irregular margin and a darker area on surface, which are doubted being damaged. Thus in this description a lectotype is proposed.

Distribution. Sinian Diaoyutai Formation, Xihe Group in Anshan, Liaoning, north-eastern China (Yin leiming, 1980), upper Sinian Liulaobei Formation, Huainan Group in the Huainan region; upper Sinian Shijia, Jiayuan, Zhaowei Formations and Lower Cambrian Gouhou Formation, Huaibei Group in the Huaibei region, central eastern China. Some specimens have been observed from the Bitter Springs Formation in the Amadeus Basin, central Australia.

Stratigraphic range. Upper Proterozoic to Lower Cambrian.

Sinianella scabrata sp. nov.

(pl.XI, figs.B, G, J; pl.XXI, figs.A-D)

Unnamed specimen. Damassa and Knoll, 1986, Fig.5:A, E.

Etymology. Scaber, Latin, rough, scabrous.

Material. More than 80 specimens.

Holotype. Plate XXI, fig.A., slide 85A256-4, (2 x 110), from the Gouhou Formation, Huaibei Group in Suxian County of the Huaibei region.

Paratype. Plate XI, fig.G., slide 82AL11-15, (2 x113.6), from the Liulaobei Formation, Huainan Group in the Huainan region.

Description. Vesicles bottle-shaped, elliptical or elongate in outline; wall thick, robust, folded and ornamented with granular or verruculose surface texture; a single prominent process drawn out from the vesicle; process rounded, or truncate shape; truncate processes obviously open at the apix; some processes very long, like a neck structure; other apix of the vesicles rounded; specimens yellow to dark-brown in colour; colonies linear or interlocking arrangement; vesicles in colony commonly small.

Dimensions. The solitary vesicles are 18 - 65*um* wide and 21 - 175*um* long (holotype: 48*um* wide, 64*um* long). processes 3 - 15*um* wide and 3 - 25*um* long (holotype, 12.4*um* wide and 7.75*um* long). The specimens in colonies are 12 - 24*um* wide and 15 - 34*um* long.

Remarks. *S. scabrata* sp. nov. is distinguished from the *S. uniplicata* (Yin, L., 1980) in its scabrous surface texture.

One specimen, plate XI, fig.I, has a long process at the one apix and a sharp point at the other, and its surface wrinkles show spiral structure. This specimen is temporarily assigned to *S. scabrata* sp. nov.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group in the Huainan region; Lower Cambrian Gouhou Formation, Huaibei Group in Suxian County of the Huaibei region. Ediacarian Arcoona Quartzite Member, the Tent Hill Formation, Stuart Shelf, South Australia (Damassa and Knoll,1986). Some specimens have been observed from the Bitter Springs Formation in the Amadeus Basin.

Stratigraphic range. Upper Proterozoic to Lower Cambrian.

Genus *Stictosphaeridium* Timofeev (1962, 1963) 1966

Type species. *Stictosphaeridium sinapticuliferum* Timofeev, 1966

Stictosphaeridium sp.

(pl.X, figs.N-O; pl.XX, fig.M)

Material. More than three hundred specimens.

Description. Vesicles circular or subcircular in outline, originally spheroidal; wall very thin, translucent, highly flexible, commonly folded; wrinkles irregular, concentric, or branched; surface smooth, psilate to granular, more or less diagenetically damaged; no openings observed; specimens white-yellow to yellow in colour.

Dimensions. Vesicle diameters are 25 - 90*u*m.

Remarks. The specimens of the uncertain taxon have similar morphology to those of *Leiosphaeridia* and *Trachysphaeridium*, except their translucent wall. The specimens observed are more or less diagenetically damaged. *Stictosphaeridium* sp. is a collective group in this study.

Distribution. Upper Sinian Liulaobei, Shijia, Zhaowei, Jiayuan Formations, and Lower Cambrian Gouhou Formation. The collective taxon is possibly not significant for stratigraphic correlation.

Genus *Synsphaeridium* Eisenack, 1965

Type species. *Synsphaeridium gotlandicum* Eisenack, 1965

Synsphaeridium sp.
(pl.XIII, fig.J)

Remarks. *Synsphaeridium* was established by Eisenack (1965) to contain spheroidal vesicles which are assembled as colonies without order.

The genus is intergrade with many other genera, such as *Leiosphaeridia* and *Kildinosphaera*, which also contain irregular colonies. Irregular arrangement of vesicles is demonstrated little value biologically.

Synsphaeridium sp. in this study is temporarily used as a rag-bag species to include those irregular clusters are not confidently identified.

Genus *Tawuia* Hofmann, 1979

Type species. *Tawuia dalensis* Hofmann, 1979

Tawuia dalensis Hofmann, 1979
(pl.IV, figs.A, D-I)

Synonymy. See Hofmann, 1985, p.334-336.

Fengyangella doedica Zheng (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.8, fig.5.

Conicina obtusus Zheng (gen. et sp. nov.), Wang Guixiang, 1984, pl.8, fig.6.

Shouhsienia longa Xing et Zheng, Wang Guixiang, 1984, ed., pl.8, fig.7.

? *Cylindraceusa brevis* Yang (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.8, fig.11.

Nephroformia liulaobeiensis Zheng, Wang Guixiang, 1984, ed., pl.8, fig.10, 12.

Pumilibaxa huaiheiana Zheng, Wang Guixiang, 1984, ed., pl.9, fig.1, 3, 5-7, 9, 12, 16; pl.13, fig.6, 12a.

Linguiformis laeric Zheng (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.9, fig.2, 4, 11, 14.

Bipatinella cervicalis Zheng (gen. et sp. nov.) Wang Guixiang, 1984, ed., pl.9, fig.10.

Claviforma brevia Zheng (gen. et sp. nov.), Wang Guixiang, 1984, pl.9, fig.13.

Pumilibaxa huaiheina Zheng, Wang Guixiang, 1984, ed., pl.9, fig.15a.

Baculiformis crassis Yan (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.9, fig.17.

Tawuia docdica Zheng (sp. nov.), Wang Guixiang, 1984, ed., pl.10, fig.6, 9.

Cylindraceusa longa Yan (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.10, fig.7.

Liulaobeia mesacosta Zhou (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.10, fig.8.

Tawuia hippocrepica Zheng (sp. nov.), Wang Guixiang, 1984, ed., pl.10, fig.10.

Pumilibaxa longa Yan, Wang Guixiang, 1984, ed., pl.10, fig.12; pl.12, fig.15; pl.13, fig.8.

Claviformis brevis Zheng (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.10, fig.13.

Tawuia sinensis Duan, Wang Guixiang, 1984, ed., pl.10, fig.14; pl.11, fig.3, 9, 10; pl.13, fig.11.

? *Bagongshanella striolata* Zheng (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.10, fig.16.

Sinenia sp., Wang Guixiang, 1984, ed., pl.10, fig.3.

Sinenia liulaobeiensis Yan et Zheng (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.11, fig.1.

Tawuia cf. *dalensis* Hofmann, Wang Guixiang, 1984, ed., pl.11, fig.6.

Tawuia striatia Zheng, Wang Guixiang, 1984, ed., pl.11, fig.7.

Pumilibaxa amorginata Yan (sp. nov.), Wang Guixiang, 1984, ed., pl.11, fig.8; pl.13, fig.10.

Ephippiodeusa typicula Yan (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.11, fig.12.

? *Valvaphysa mamarginata* Yan (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.12, fig.1, 3.

Acriformia simplex Yan (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.12, fig.4.

Tawuia cf. *sinensis* Duan, Wang Guixiang, 1984, ed., pl.12, fig.11, 14; pl.13, fig.14.

Nephroformia regularis Yan (sp. nov.), Wang Guixiang, 1984, ed., pl.12, fig.16.

Fusiphysa simplex Yan (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.13, fig.7.

Tawuia minuta Yan (sp. nov.), Wang Guixiang, 1984, ed., pl.13, fig.9.

Langania gigantus Yan (gen. et sp. nov.), Wang Guixiang, 1984, ed., pl.13, fig.13.

Material. About twenty specimens.

Description. Megascopic vesicles elongate form in outline, straight to highly bent, terminated with rounded or semi-circular ends; specimens more or less damaged, with smooth to granular surface texture, occasionally folded; some vesicles slightly tapering from one end to the other; no excystment structure observed.

Dimensions. The specimens are 3.5 - 11mm long and 1 - 2.5mm wide, ratio (length:width) are 1.8 - 6. Previous measurements from Hofmann (1985a, text fig.3): 1 - 8.5mm wide (mean width = 3.42mm), mean length = 25.44mm (the longest is 15.2cm), the major ratio (length:width) between 2 and 5.

Remarks. The synonymy of *T. dalensis* is all from the monograph on the Upper Proterozoic in northern Anhui and Jiangsu (Wang Guixiang, editor, 1984). The new genera and species are published without description.

The identification between *T. dalensis* and *C. circularis* is empirical and mostly based on their length:width ratio. The relation of two species has been discussed by Hofmann (1985a, p.337-342).

Distribution. Upper Sinian Liulaobei, Jiuliqiao, Weiji and Shijia Formations, Lower Cambrian Jingshanzhai and Gouhou Formations, northern Anhui and Jiangsu Provinces. Some specimens are found from the upper Sinian Jiucheng Member of the Dengying Formation in Chengjiang County, Yunnan Province, southern China. Previously recorded from the Little Dal Group, Mackenzie Mountains, northwestern Canada (Hofmann and Aitken, 1979).

Stratigraphic range. Middle Proterozoic to Lower Cambrian.

Genus *Trachysphaeridium* Timofeev (1956) 1959

Type species. *Trachysphaeridium attenuatum* Timofeev, 1959

Trachysphaeridium cf. *laminaritum*
(Timofeev, 1966) Vidal, 1976

(pl.X, figs.G-H; pl.XX, fig.J)

Trachysphaeridium laminaritum sp. nov., Timofeev, 1966, p.36, pl.VII, fig.3.

Trachysphaeridium laminaritum Tim., Timofeev, 1969, p.20, pl.4, fig.7.

Trachysphaeridium laminaritum Tim., Timofeev, 1973, pl.15, fig.6; pl.27, fig.6.

Trachysphaeridium laminaritum Tim., Timofeev, 1974, pl.XXII, fig.9.

Trachysphaeridium laminaritum Tim., Vidal, 1974, p.8, pl.1, fig.17.

Trachysphaeridium laminaritum Tim., Vidal, 1976, p.35-36, fig.20:A-B, D-H.

Trachysphaeridium laminaritum Tim., Vidal, 1976, Vidal and Ford, 1985, p.373-375, fig.8:A-C.

Material. More than two hundred specimens.

Description. Vesicle circular or subcircular, originally spheroidal; wall thick, occasionally folded or split; surface with a granular or verruculose texture; lacunar areas among the processes forming concavities displaying more-or-less alveolar-like appearance; occasionally a circular opening observed; specimens yellow to brown in colour.

Dimensions. Specimens are 25 - 72*um* in diameter. The previous measurements were 41 - 57*um* and 38 - 80*um* in diameter for *Trachysphaeridium laminaritum* (Vidal, 1976; Vidal and Ford, 1985).

Remark. Precent specimens are more or less damaged, and various in surface texture; some of them display somewhat alveolar-like texture, but not confidently referred to *T. laminaritum*.

Distribution. Upper Sinian Liulaobei, Shijia, Zhaowei Formations, and Lower Cambrian Gouhou Formation. Previously recorded from the Kwagunt Formation and Red Pine Shale of the Uinta Mountain Group (Vidal and Ford, 1985), Visingsö Beds (Vidal, 1974), Vadsö Group (Vidal, 1981b), and findings in the Soviet Union were stated by Vidal (1976).

Stratigraphic range. Late Proterozoic to Early Cambrian.

Trachysphaeridium laufeldi Vidal, 1976
(pl.X, fig.I)

Trachysphaeridium laufeldi sp. nov., Vidal, 1976, p.36-38, fig.21:A-N.

Trachysphaeridium laufeldi Vidal, Vidal, 1976b, fig.2:A.

Trachysphaeridium laufeldi Vidal, Vidal and Ford, 1985, p.375-376, fig.7:A, B, D, F.

Material. Two specimens.

Description. Circular or subcircular vesicles with numerous small conical spines; spiny protuberance observed; no excystment structures observed; specimens brown to dark-brown in colour.

Dimensions. Vesicle diameters are 35 - 55*u*m. Previous measurements were 28 - 49.5*u*m and 42 - 50*u*m in diameter (Vidal, 1976; Vidal and Ford, 1985).

Remarks. *T. laufeldi* differs from *T. laminaritum* (Tim.) by its numerous small conical spines.

Distribution. Upper Sinian Liulaobei Formation. Previously recorded from the Kwagunt Formation, Chuar Group; the Mount Watson Formation and Red Pine Shale, Uinta Mountain Group; the Visingsö Beds; the Eleonore Bay Group, East Greenland; the Andersby Formation, Vadsö Group, Finnmark (Vidal, 1976, 1976b, 1981; Vidal and Ford, 1985).

Stratigraphic range. Late Proterozoic.

Genus *Volkovia* Downie, 1982

Type species. *Volkovia dentifera* (Volkovia) Downie, 1982.

Remarks. Downie (1982) erected the genus for the specimens bearing a single prominent spine at one pole and an operculum or opening at the other. *Deunffia* Downie has no polar operculum or opening. Downie (1982) also suggested this genus is one of the Lower and Middle Cambrian oomorph taxon.

Volkovia flagellata (Jankauskas) Downie, 1982
(pl.XIX, fig.B)

Deunffia flagellata Jankauskas sp. nov., Jankauskas, 1975, pl.XI, fig.47-50, 55.

Volkovia flagellata comb. nov. (= *Deunffia flagellata* Jankauskas, 1975), Downie, 1981, p.265.

Material. Two specimens.

Description. Ovate vesicle with at one apix a short prominent spine and an opening at the other; spine truncated; opening slightly constricted on the margin; wall psilate to fine-granular and folded; a lighter membrane surrounding the inner darker vesicle; surrounding membrane 1 - 2*um* thick; vesicle yellow or yellow-brown in colour.

Dimensions. The vesicles are 22 - 30*um* at long axis, 13 - 17*um* at short axis, 1.5 - 2*um* long for the spine and 4 - 6*um* wide for the opening. Previously recorded measurements were 3 - 4*um* at length, 5 - 8*um* at width and spine up to 3*um* long (Jankauskas, 1975).

Remarks. Present specimens are larger than the type specimens from USSR and one specimen (pl.XIX, fig.B) displays a double wall, which is possibly due to the cell's shrinkage. Some species, for example, *Leiosphaeridia asperata*, usually display single wall, but in the Liulaobei Formation, some of them show double walls.

Distribution. Lower Cambrian Gouhou Formation, Huaibei Group in northern Anhui, China. Previously recorded from the Lower Cambrian Vergale and Rausve Horizons in Baltic region (Jankauskas, 1975).

Stratigraphic range. Lower Cambrian.

2.6.2. Filamentous Microfossils

The Proterozoic and Cambrian shales from the Huainan and Huaibei Groups in northern Anhui and Jiangsu Provinces contain beautifully preserved filamentous microfossils, including *Archaeotrichion*, *Eomycetopsis*, *Heliconema*, *Oscillatoriopsis*, *Palaeolyngbya* and *Siphonophycus*. The filaments are identified as follows.

1. Filaments tightly spiraled................................*Heliconema.*

1. Filaments not spiraled...2.

2. Filaments with septa..3.

2. Filaments without septa..4.

3. Filaments with external sheath.......................*Palaeolyngbya.*

3. Filaments without external sheath...............*Oscillatoriopsis.*

4. Width of filaments less than or equal to 1.5*um*.*Archaeotrichion.*

4. Width of filaments 2 - 9.5*um*.........................*Eomycetopsis.*

4. Width of filaments more than 10*um*...............*Siphonophycus.*

The difficulty in this table is to distinguish *Eomycetopsis* from *Archaeotrichion* and *Siphonophycus*. All three genera are deformed tubes, generally interwoven to form mats, no septa, no special ornamentation on surface or special inclusion within tubes, only display their width differences. The width of the filaments in my observation ranges 0.5*um* to more than 60*um*, some fragments even much wider. In fossil mats some very thin filaments (less than 1*um*) entangle the wider filaments (about 5*um*). Based on previous descriptions (Schopf, 1968), the width differences are arbitrarily defined. Generally when a tube is deformed, its width will increase 57% of its diameter in lateral view, thus the diameters of three genera in cubic tubes are less than 1*um* for *Archaeotrichion*, 1.3 - 6*um* for *Eomycetopsis* and more than 6.3*um* for *Siphonophycus*.

Archaeotrichion, based on its small diameter and nonseptate nature, was suggested as bacterial affinity (Schopf, 1968). In present material, *Archaeotrichion contortum* consists of mats, sometimes is interwoven with *Eomycetopsis*. The preservation possibly suggests the two genera have a close affinity. *Eomycetopsis* is considered as a species in Oscillatoriacean, Cyanophyta (Hofmann, 1976; Knoll and Golubic, 1979).

All filaments studied probably belong to cyanobacteria. Diver and Peat (1979) erected a subgroup Nematomorphitae to include filamentous microfossils. Following description is still in alphabetical order.

Archaeotrichion Schopf, 1968

Type species. *Archaeotrichion contortum* Schopf, 1968

Archaeotrichion contortum Schopf, 1968
(pl.XVII, figs.F, K-N; pl.XVIII, fig.G)

Archaeotrichion contortum Schopf, sp. nov., Schopf, 1968, p.686, pl.86, fig.1-2.

Material. More than one hundred specimens.

Description. Tubular filaments very thin, nonseptate and apparently unbranched; solitary filaments straight or sinuous, stable width in one thallus, and with a smooth surface texture; mats irregularly interwoven; filaments generally truncated and no end structure observed; specimens yellow to dark-brown in colour.

Dimensions. The filaments are less than or equal to 1.5*um* wide and up to several hundred microns long. The measurements of type species were less than 1*um*, commonly 1/2 - 2/3 *um* in diameter, and up to 110*um* long (Schopf, 1968).

Remarks. *Archaeotrichion* is similar to *Eomycetopsis* in the formation of solitary filament and mat structure and differs in its narrower width. The picture (pl.XVIII, fig.M) displays the filaments of *Eomycetopsis* interwoven by very thin filaments of *Archaeotrichion*. Transitional forms exist between the two genera.

Distribution. Upper Sinian Liulaobei and Shijia Formations, northern Anhui. The holotype was recorded from the Bitter Springs Formation, Amadeus Basin, central Australia (Schopf, 1968).

Genus *Eomycetopsis* Schopf, 1968 emend. Knoll and Golubic, 1979

Type species. *Eomycetopsis robusta* Schopf, 1968 emend. Knoll and Golubic, 1979

Eomycetopsis parallela sp. nov.

(pl.XVII, figs.A-E)

Etymology. Parallelus, Latin, side by side equidistantly.

Holotype. Plate XVII, fig.A, from the Liulaobei Formation, Huainan Group, slide 85A202-1, (3.5x105).

Paratype. Plate XVII, fig.B, from the Liulaobei Formation, Huainan Group, slide 85A202-3, (13.6x111.5).

Material. More than thirty specimens.

Description. Filaments deformed tubes, parallel arrangement, unbranched, closely packed to form thick filamentous colony; filaments psilate to fine-granular surface texture, straight or sinuous, 'S', 'C', or 'U'-shaped at the outline; filaments displaying a rounded or semi-circular apix, and truncated at the other; specimens yellow to dark-brown in colour.

Dimensions. The filaments are 3-6.2*u*m wide, colonies 9.5 - 25*u*m wide, and up to one hundred microns long.

Remarks. New species differs from other specimens of *Eomycetopsis* in its filaments parallel arrangement and a rounded apix.

The filaments of *E. parallela* sp. nov. are regularly arranged, generally as colonies. The colony forms are probably growth pattern, rounded apices showing their growing direction. Because they are photosynthetic organisms the direction of growth is probably upward.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group, northern Anhui.

Eomycetopsis robusta Schopf, 1968 emend.
Knoll and Golubic, 1979
(pl.XVII, figs.G-I; pl.XXI, figs.N-Q)

Synonymy, see Mendelson and Schopf, 1982, p.59.

Eomycetopsis robusta Schopf, Strother, Knoll and Barghoorn, 1983, p.30, pl.1, fig.9.

Eomycetopsis robusta Schopf, 1968, emend. Knoll and Golubic, 1979, Knoll , 1984, p.145, fig.4:E, F, I.

Eomycetopsis robusta Schopf, 1968 emend. Knoll and Golubic, 1979, Nyberg and Schopf, 1984, p.751, fig.4, 8, 10A.

Material. More than one hundred specimens.

Description. Tubular filaments unbranched, nonseptate, straight, commonly sinuous; commonly interwoven as mats; filaments smooth to fine-granular surface texture; no end structure and inclusions observed; specimens yellow to brown in colour.

Dimensions. The filaments are 2 - 7.8*um* in width and with a major width 3 - 5*um*. Some filaments are up to several hundred microns long. Schopf (1968) measured 2.8 - 4.2*um* in diameter for *E. robusta* and 2.1 - 3.4*um* in diameter for *E. filiformis*. The measurements of 2.2 - 4.4*um* in diameter were recorded in emended diagnosis (Knoll and Golubic, 1979).

Remarks. Present filaments have a width range of 2 - 7.8*um* for deformed tubes and their diameters should be equal to 1.3 - 5*um*. Many filaments in mats observed display different width, some thin ones are difficult to be distinguished from *Archaeotrichion*.

Distribution. Upper Sinian Liulaobei, Shijia, Zhaowei, Jiayuan Formations and Lower Cambrian Gouhou and Jingshanzhai Formations. The holotype of *E. robusta* was recorded from the Bitter Springs Formation, Amadeus Basin, central Australia (Schopf, 1968). The species have been found widely distributed in the Proterozoic.

Eomycetopsis spiralata sp. nov.
(pl.XVII, fig.J; pl.XVIII, fig.H)

Etymology. The name is derived from the filaments displaying spiral forms.

Holotype. Plate XVII, fig.J, from the Zhaowei Formation, Huaibei Group, northern Jiangsu, slide 83A083-2, (6.7x109.3).

Material. Four specimens.

Description. Spiral filaments with deformed tubes, unbranched, nonseptate, smooth to fine-granular on surface; wall thin; spiral commonly consisting of one filament, forming 3 - 10 circles (holotype is three and a half circles); no end structures of the filaments observed; specimens yellow to yellow-brown in colour.

Dimensions. The filaments are 2.2 - 2.8*u*m in width (1.4 - 1.8*u*m in diameter), the holotype is 2.6*u*m in width (1.66*u*m in diameter). The circles of spiral are 14.5 - 44*u*m in diameter (holotype is 14.5 in diameter).

Remarks. The spiral forms of *E. spiralata* sp. nov. are similar to that of *Obruchevella*, but present spiral are not regular, each circle has a slightly different diameter, some spirals are biased to the centre, even crossing the circles. The spiral forms are possibly a growth pattern of *Eomycetopsis*. *Obruchevella* is a spring-like form.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group, northern Anhui, and the Zhaowei Formation, Huaibei Group, northern Jiangsu. Some specimens have been found from the Middle Cambrian Tempe Formation in the Amadeus Basin, central Australia.

Genus *Heliconema* Schopf, 1968

Type species. *Heliconema australiensis* Schopf, 1968

Heliconema? sp.
(pl.XVIII, fig.F)

Material. Two filaments.

Description. Tubular filaments deformed, non septate, unbranched and coiled as spiral; surface smooth to fine-granular; filaments solitary preserved; end structure truncated; specimens yellow brown.

Dimensions. The filaments are 2 - 3.3*u*m wide. The distance between adjacent spiral is 4.5*u*m.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group, Huainan region.

Genus *Oscillatoriopsis* Schopf, 1968

Type species. *Oscillatoriopsis obtusa* Schopf, 1968

Oscillatoriopsis spp.
(pl.XIV, fig.I; pl.XVIII, figs.I, K, L)

Material. More than twenty fragments.

Description. Three filamentous forms of *Oscillatoriopsis* observed; Form I (pl.XIV, fig.I): the cells 17 - 20*u*m wide and 1 - 1.5*u*m long; Form II (pl.XVIII, fig.I): the cells 8 - 11*u*m wide and 8 - 10 *u*m long, with very thick septa; Form III (pl.XVIII, fig.K): the cells 6 - 10*u*m wide and 8 - 11*u*m long, with thin septa; all filaments unbranched, no encompassing sheath, with smooth to fine-granular surface texture; no end structures observed.

Remarks. Schopf (1968) erected the genus *Oscillatoriopsis* to include those filaments with septa, unbranched, obtuse-rounded terminal and sheath absent. The solitary specimens from the Bitter Springs Formation were up to 150*u*m long, and the medial cells 3.0 - 3.7*u*m long and 3.4 - 4.2*u*m wide. Present filaments display size differences.

Distribution. Upper Sinian Liulaobei Formation.

Genus *Palaeolyngbya* Schopf, 1968

Type species. *Palaeolyngbya barghoorniana* Schopf, 1968

Palaeolyngbya barghoorniana Schopf, 1968
(pl.XVIII, figs.A-C)

Palaeolyngbya barghoorniana Schopf, sp. nov., Schopf, 1968, p.665-666, pl.77, fig.1-5.

Material. Four specimens.

Description. Tubular solitary filaments multicellular, unbranched and more or less diagenetically deformed; filaments covered with nonlamellated sheath; sheath incomplete, very thin, about 1*u*m thick; surface psilate to fine-granular; trichomes straight or sinuous, some 'U'-shaped; terminal obtuse-rounded; medial cells tightly arranged and no partially septation observed; trichomes brown in colour.

Dimensions. The solitary filaments are up to 150*u*m long, and medial cells are 2 - 3*u*m long, 10 -15*u*m wide and its terminal cells are commonly 3 - 4*u*m long. The filaments from the Bitter Springs Formation were 50*u*m long, and the medial cells 2.6 - 3.1*u*m long, 8.3 - 10.9*u*m wide (Schopf, 1968).

Remarks. Schopf (1968) observed partial septation which were incomplete subdivide apical cells of filaments. The partial septation, according to Schopf (1968), are the normal means of cell division resulting in vegetative growth. Because of ill preservation, the partial septations are not observed in the present filaments.

Distribution. Upper Sinian Liulaobei Formation, Huainan Group in Huainan region. The holotype was described from the Bitter Springs Formation in the Amadeus Basin, central Australia.

Genus *Siphonophycus* Schopf, 1968

Type species. *Siphonophycus kestron* Schopf, 1968

Siphonophycus sp.

(pl.XIV, fig.J; pl.XVIII, figs.D, E, J, N)

Material. More than fifty specimens.

Description. Tubular filaments non-septated, unbranched, and more or less damaged; filaments with psilate to granular surface texture; commonly filaments solitary, straight to slightly bent, occasionally several filaments interwoven to form mats; no end structures observed; specimens yellow to brown in colour.

Dimensions. The filaments are 10 - 60*u*m wide. The measurements for *Siphonophycus kestron* Schopf were 8.3 - 15*u*m wide (Schopf, 1968).

Remarks. *Siphonophycus* has been emended by Schopf (in Awramik et al., 1983), and its emended diagnosis seems no important difference from its previous description. Recently Zhang Zhongying (1986) emended this genus based on mat structure: "gathered in bundles or densely interwoven", but few mats are observed from the shales in this study. Zhang Zhongying (1986) also considered no distinctive morphological difference between *Siphonophycus* and *Eomycetopsis* except their widths and he proposed a size limit (not more than 5*u*m) on average filament diameter to divide the two genera.

Distribution. Upper Sinian Liulaobei Formation and Lower Cambrian Gouhou Formation.

Chapter 3

SINIAN AND LOWER CAMBRIAN FLORAS ON THE SOUTH CHINA PLATFORM

3.1. INTRODUCTION

The Upper Proterozoic is well developed and widely distributed in China. Grabau (1922) used the name "Sinian" for the sequences which overlie metamorphic basement and underlie the rocks which contain trilobites and shelly fossils. Many achievements in Sinian investigation have been made since Lee and Zhao (1924) described the Sinian sequences in the Yangtze Gorges. During the past decade, many investigators have studied the palaeontology, geochemistry, depositional environment, glaciation, paleomagnetism and isotopic dates in this sequence (Zhao Ziqiang et al., 1980; Cao Ruiji et al., 1978; Yin Leiming and Li Zaiping, 1978; Wang Yuelun et al., 1980; Ma Guogan et al., 1980, 1984; Xue Yaosong et al., 1984).

Isotopic dates for the Sinian have been produced at the Yichang Institute of Geology and Mineral Resources, Yunnan Institute of Geology, the Australian National University and other places. The granites unconformably underlying the Liantuo Formation, the lowest part of the Sinian, have been dated at 842 Ma, 875 Ma, and 880 Ma (U-Th-Pb method), 860±50 Ma by U-Pb method on zircons, and 819±54 Ma by Rb-Sr methods (Ma Guogan et al., 1980). The date on zircons in the phosphatic rocks of the Liantuo Formation is 748±12 Ma (U-Pb) and the dates on the uppermost siltstone of the Doushantuo Formation are 700±5 and 691±29 Ma ($^{87}Sr/^{86}Sr$ - $^{87}Rb/^{86}Sr$) (Ma Guogan et al., 1984). The Proterozoic/Cambrian transition is dated at 609±50 Ma, 612±36 Ma, 603±32 Ma by the Rb-Sr method on detrital rocks (Ma Guogan et al., 1980) and 614±18

Ma, 602±15 Ma using illites (Zhang, Compston and Page, 1982). 602±15 Ma is regarded as a minimum estimate for the age of the Proterozoic - Cambrian boundary (Zhang, Compston and Page, 1982). The ages suggested for the Sinian System range from 800 Ma to 600 Ma and the upper Sinian from 700 Ma to 600 Ma (Zhao Ziqiang et al. , 1980).

Animal fossils are poorly recorded from the Sinian sequence on the South China Platform. Soft-bodied metazoans include *Paracharnia dengyingensis* (Ding and Chen 1981) Sun, 1986, *Sabellidites* sp., *Micronemaites formosus* Sin et Liu, and *Saarina* sp. (Zhao Ziqiang et al., 1980; Ding et al., 1981; Sun Weiguo, 1986). Of them, *P. dengyingensis* is frond-like form, similar to some forms from the Ediacara Fauna, and may provide the evidence for biostratigraphic correlation.

The Sinian mega-algal flora on the South China Platform contains *Vendotaenia didymos* (Cao et Zhao 1978) comb. nov., *Tawuia dalensis*, *Chuaria* sp., *Tyrasotaenia* sp., *Daltaenia* sp., *Longfengshania*? sp., and other forms. Some mega-algal fossils have been considered to be of stratigraphical significance (Gnilovskaya, 1979), but my recent collection of the mega-algal fossils from the Lower Cambrian Qiongzhusi Formation suggests many Sinian (or Vendian) fossils persist into the Cambrian (discuss later in this chapter).

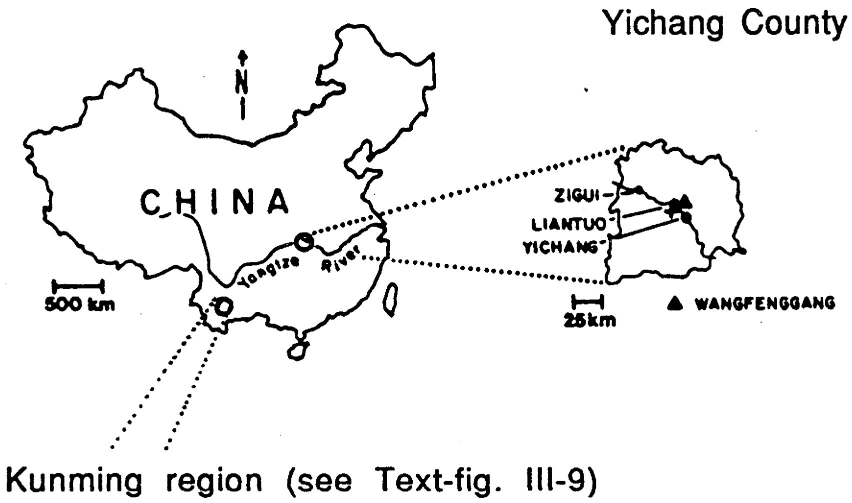
Microfossils on the South China Platform have been investigated since the last decade. Yin Leiming and Li (1978) described a number of microfossils in acid macerates from the Sinian, consisting of 26 genera and up to 81 species, and 11 new genera and 18 new species from chert thin sections. Zhao Ziqiang et al. (1980) reported 27 genera and more than 50 species in acid macerates. It is well known that acritarch classification is in a state of flux. Many taxa have been amended or considered to be invalid. Of the genera from the Sinian, *Leiosophosphaera* Naumova, 1960, *Macroptycha* Timofeev, 1976 are congeneric with *Leiosphaeridia* Eisenack, 1958 (Lindgreen, 1981, 1982), *Pseudozonosphaera* Sin and Liu, 1973 with *Trachysphaeridium* Timofeev, (1956) 1959 (Vidal, 1976) and *Quadratimorpha* Sin and Liu 1973 with *Octoedryxium* Rudavskaja, 1973 (Vidal, 1976). Some other genera, *Archaeohystrichosphaeridium* Timofeev, 1959, *Dictyosphaera* Sin and Liu, 1973, *Brochalaminaria* Ouyang, Yin and Lin, 1974, *Microconcentrica* Naumova, 1960, *Lignum* Sin, 1962, *Polyporata* Sin and Liu, 1973, *Nucellosphaeridium* Timofeev, 1963, and *Asperatopsophosphaera* Shepelava, 1963 are questioned. More than seventy percent of the reported species in the Sinian System on the South China Platform need confirming. There is much to be done. *Micrhystridium* sp. and *Favososphaeridium* sp. have been observed from the upper Sinian and may be used to correlate with the Vendian assemblages of the Soviet Union.

Microfossils in chert sections from the upper Sinian Doushantuo and Dengying Formations are abundant and diverse. A number of species have been described, including *Baltisphaeridium, Comasphaeridium,* and other lavishly spinose acritarchs (Yin Leiming and Li, 1978; Wang Fuxing et al. 1983; Zhang Zhongying, 1984; Awramik et al., 1985; Yin L., 1986). Recently Wang Fuxing (1985) proposed a microfossil assemblage based on the discovery in thin sections from the upper Sinian, including *Baltisphaeridium* sp., *Micrhystridium* sp., *M. ampliatum* Wang, 1985, *Lophosphaeridium* sp., and other spheroidal forms.

Phosphorites in the upper Sinian contain abundant well-preserved microfossils (Tang Tianfu et al., 1978; Chen Meng'e and Liu, 1985; Zhang Yun, 1987). Chen Meng'e and Liu described two new genera including three species. One genus *Meghystrichosphaeridium* is ornamented with conical spines and its diameter ranges from 200-800*u*m. These superbly preserved microfossils will enrich our understanding of the Sinian biota.

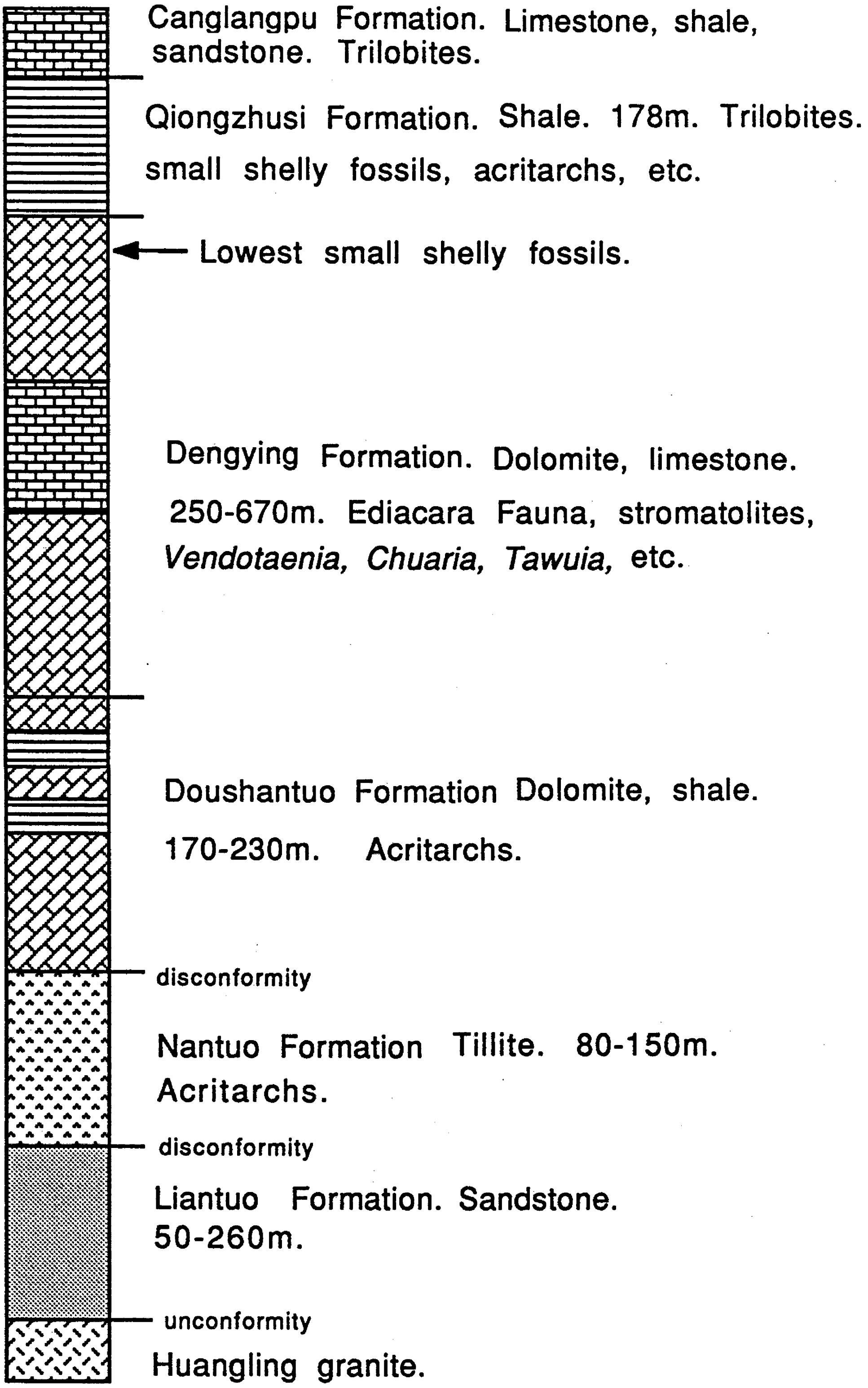
Lower Cambrian microfossils on the South China Platform occur abundantly from the Qiongzhusi Formation. Xing Yusheng (in Luo Huilin et al., 1984) reported *Baltisphaeridium*, *Scaphospinosa, Micrhystridium*, and another dozen species from this formation; he considered that the microfossils in the Qiongzhusi Formation indicated an important geological evidence in the Proterozoic - Cambrian transition. Unfortunately his specimens are badly preserved. In my observation, the Qiongzhusi assemblage contains abundant *Skiagia*, which may include some specimens previously referred to *Baltisphaeridium* (Xing Yusheng, in Luo Huilin et al., 1984).

Samples in this study were mainly collected from the Yangtze Gorges and eastern

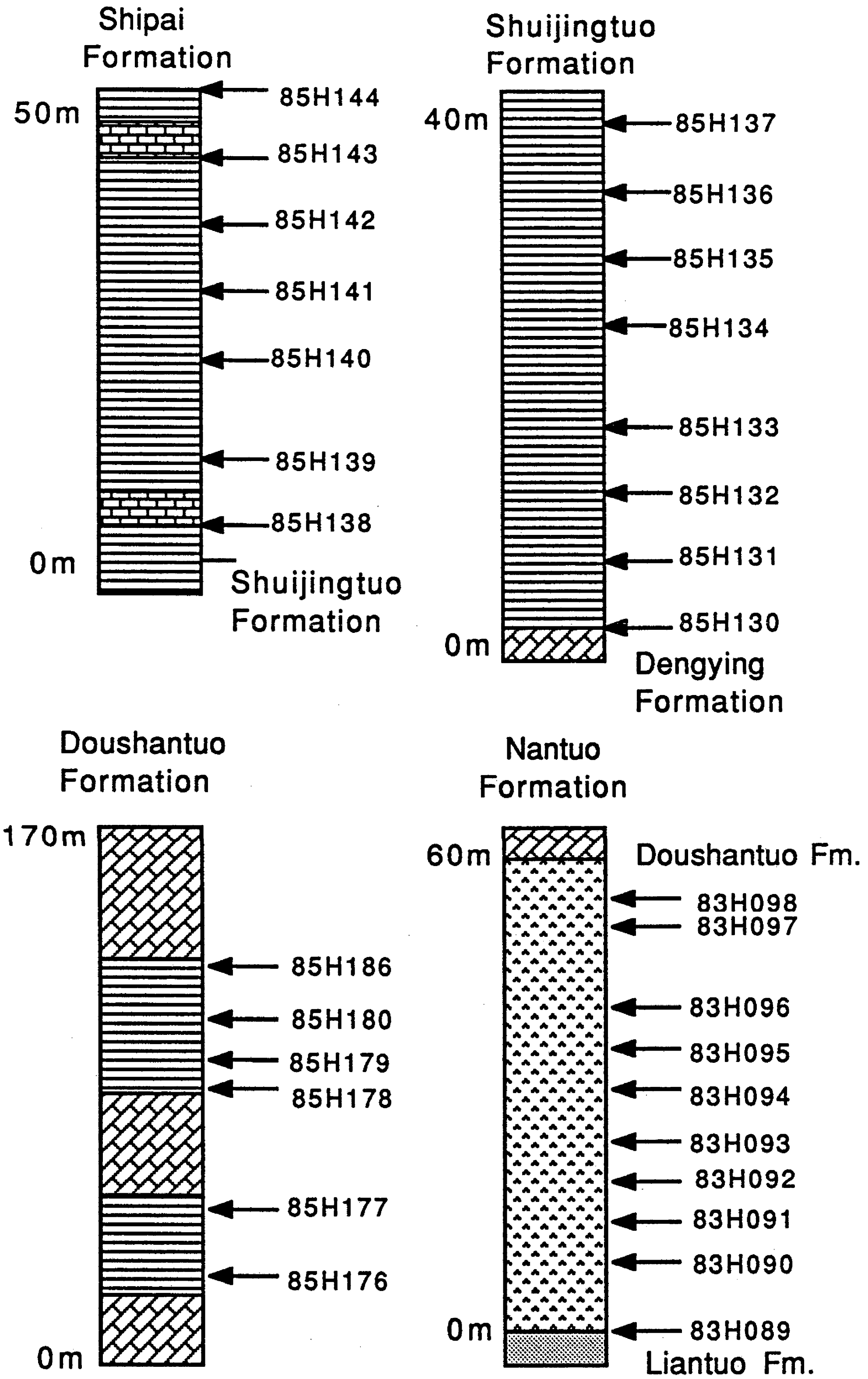


Text-fig. III-1. Index maps showing sample locations (modified from Awramik et al., 1985).

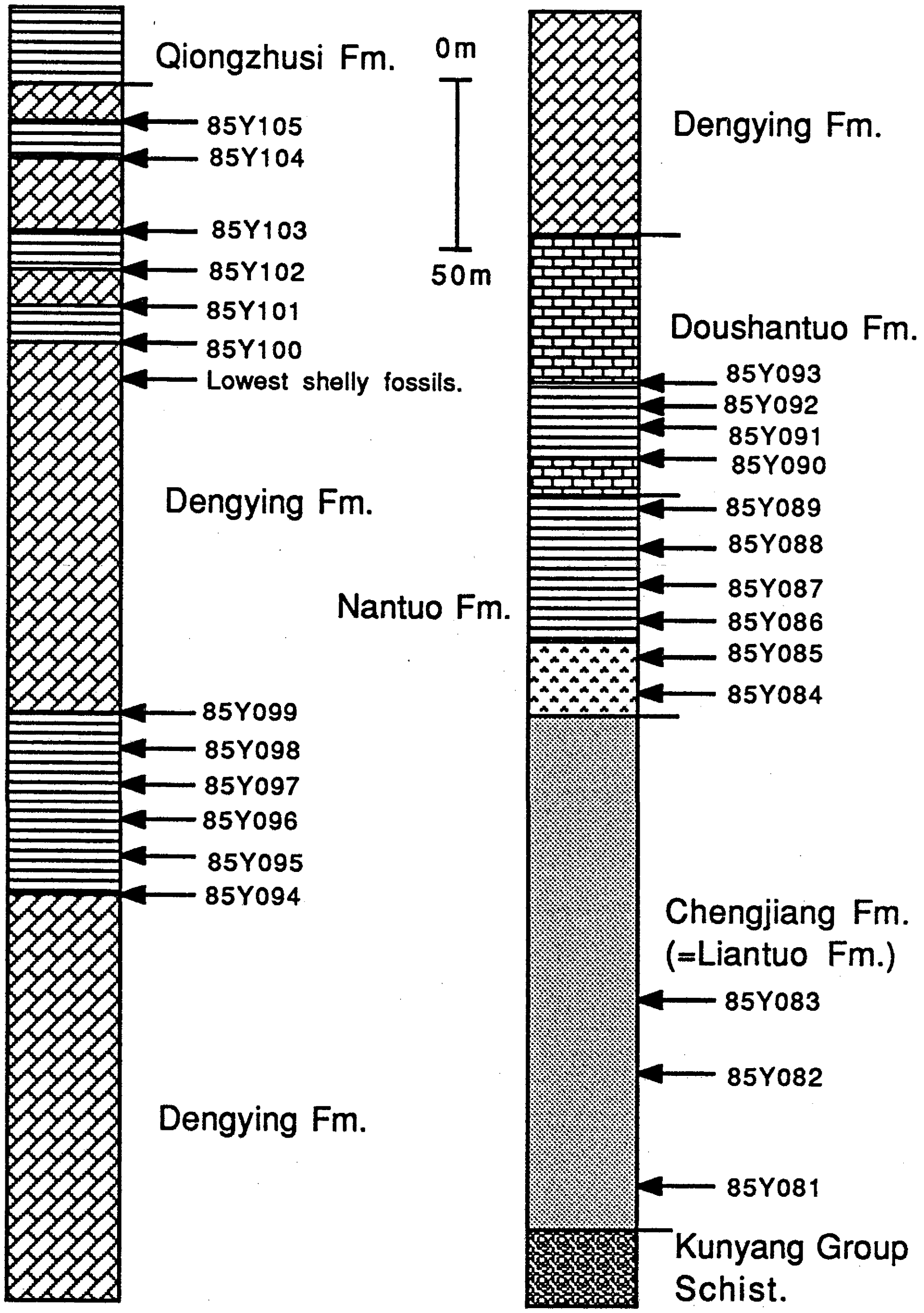
Yunnan (Text-figure III-1). A stratigraphic column of Sinian and Lower Cambrian sequences is shown in Text-figure III-2. More than one hundred samples were processed for microfossil investigation (Text-figure III-3, Text-figure III-4, Text-figure III-10, 11, 12).



Text-fig. III-2 Generalized stratigraphic column of the Sinian and Lower Cambrian sequences on the South China Platform.



Text-fig. III-3. Geological log of sampling sequences at the Wangfenggan and Huangshandong sections in the Liantuo region of the Yangtze Gorges, Hubei Province, central China. Sample levels are indicated by arrows.



Text-fig. III-4. Geological log of the Sinian sequence at the Wangjiawan section, Jinglin, eastern Yunnan, southern China. Sample levels are indicated by arrows.

3.2. MEGA-ALGAL FLORA ON THE SOUTH CHINA PLATFORM

Investigation of the Proterozoic mega-algal fossils started a century ago. Perhaps most valuable pioneering work was undertaken by Walcott who named a formal taxon *Chuaria circularis* for these carbonaceous discs collected from the Chuar Group of the Grand Canyon in Arizona (Walcott, 1899). For more than half a century, these disc-like remains have been referred to different groups and until a decade ago they were commonly accepted as an algal origin (Ford and Breed, 1973).

Reports of the mega-algal fossils have been widely scattered through the literature and about 17 genera and less than 20 species have been considered to be valid (Hofmann, 1985b). A tentative stratigraphic correlation of the fossils has been proposed recently. Hofmann (1985b) discussed the significance of 700-1100 Ma old *Chuaria* - *Tawuia* assemblage, and further investigation suggested the assemblage might occur between 700 Ma and 900 Ma (Sun Weiguo et al., 1986; Sun Weiguo, 1987). After studying vendotaenides from the East European Platform, Gnilovskaya (1979) recognized three floras in the Late Vendian and Early Cambrian: Redkino, Upper Valdai and Late Valdai-Early Baltic flora.

From recent publications, the reliable and possibly the lowest mega-algal fossil level reported so far may be referred to those from the Middle Proterozoic Changchengian Gaoyuzhuang Formation in Jixian, Tianjin, northern China (Du Rulin et al., 1986). A new genus *Sangshuania* was erected to include two species *S. sangshuanensis* Du (spiral-shaped, very similar to *Grypania spiralis* Walter et al. 1976) and *S. linearis* Du (meander-shaped). The organic ribbons are 1-2mm wide and more than 100mm long. The Gaoyuzhuang Formation has been considered older than 1400 Ma (Chen Jinbiao et al., 1980). The formation contains one bed of Pb-Zn rich dolomite and isotopic dating for the bed gave an average of 1434Ma (five dates, Pb-Pb, cf. Du Rulin et al., 1986). The fossil bed is slightly below the Pb-Zn rich bed and therefore its age can be considered to be older than 1434Ma (Du Rulin et al., 1986).

Another group of the Middle Proterozoic mega-algal fossils is from the Greyson Shale of the Belt Supergroup in Montana. The specimens were first collected and described by

Walcott (1899) and restudied by Walter, Oehler and Oehler (1976). The assemblage contains six categories: long, narrow interwined, unbranched ribbons *Proterotania montana, P. neihartensis*; lanceolate *Lanceoforma striata*; spiral-shaped *Grypania spiralis*; curved ribbons *Helminthoidichnites*? *meekii* and unnamed branching filaments. Walter et al. (1976) considered that most of them were megascopic eucaryotic algae and probably related to the brown, red, or green algae. The Greyson Shale is considered to have been deposited about 1300 Ma ago (Walter et al., 1976).

Most abundant mega-algal fossils in the late Middle Proterozoic are reported from the Little Dal Group, Mackenzie Mountains, northeastern Canada. Hofmann (in Hofmann and Aitken, 1979) first named *Tawuia dalensis* from the "basinal sequence" of the group, and in 1985 he reported more megascopic fossils, including lateral branching *Daltaenia mackenziensis* and oval disc with a stalk-like appendage *Longfengshania stipitata*. Nearly ten species are described from the group and the assemblage includes the *Chuaria - Tawuia* association. The Little Dal Group has been dated at 1000-700 Ma (Hofmann, 1985a).

In China a bed of latest Middle Proterozoic or early Late Proterozoic (900-850 Ma) mega-algal fossils has been found in the lower part of the Jing'eryu Formation, Qingbaikou System in the Yanshan Range of Hebei Province, northern China (Du Rulin, 1982; Du Rulin and Tian, 1985). The bed contains the *Chuaria - Tawuia* assemblage, *Tyrasotaenia* and abundant *Longfengshania* (including four species). This mega-algal assemblage is similar to that of the Little Dal Group.

Upper Vendian mega-algal fossils are widely reported through the East-European Platform. Gnilovskaya (1979) described three floras based on vendotaenid distribution. The first flora is from the Redkino Formation of the lower part of the Valdai series and consists of the bushy *Eoholynia* Gnilovskaya - vendotaenides with a cordlike thallus, possibly fungi *Caudina* Gnilovskaya, colonial alga *Orbisiana* Sokolov, *Leiothrichoides* Hermann and *Helminthoidichnites* Walcott (Gnilovskaya, 1979); the second flora is mainly from the upper part of the Valdai series and consists predominantly of *Vendotaenia antiqua* which is widely distributed in the East European Platform; and the third is from the Late Valdai and Early Cambrian and is dominated by *Tyrasotaenia* (Gnilovskaya, 1979). More than ten forms, mainly vendotaenides, are reported in the Upper Vendian of the East European Platform. On the South China Platform similar floras have been reported, but in northern China, the mega-algal floras are different. In the southern margin of the North China Platform the upper Sinian Liulaobei, Jiuliqiao, and Shijia Formations and Lower Cambrian Gouhou Formation contain abundant *Chuaria*, *Tawuia*, and some *Tyrasotaenia*; *Vendotaenia* is less abundant.

The Sinian flora on the South China Platform is occurs in the upper Doushantuo Formation, and the Shibantan (=the Jiucheng Member) and Baiyunshao Members of the Dengying Formation. The flora is characterized by abundant vendotaenides.

Zhu Weiqing and Chen (1984) described one species, *Enteromophites, siniansis* from the black shales of the upper Doushantuo Formation in the Yangtze Gorges. The species displays many branched thalli and a holdfast structure, with a length about 17mm. They considered the form could be compared with some modern green algae.

Vendotaenia didymas (Cao et Zhao, 1978) comb. nov. was first described from the type Sinian section in the Yangtze Gorges (Cao Ruiji and Zhao, 1978). The species is characterized by the variation in the width of thalli in one specimen, commonly tapering or restricting at the ends. *Vendotaenia antiqua* has a stable width within one specimen. In the black limestone of the Shibantan Member of the Dengying Formation in the Yangtze Gorges, dozens of layers yield *Vendotaenia didymas* and generally they are in mass occurrence. Vendotaenid beds are also found in the Jiucheng Member, Yuhucun Formation at the Baimashan section near Chengjiang, Yunnan and the middle part of the Dengying Formation at the Wangjiawan section, Jinning, Yunnan (Cao Renguan et al., 1980). The vendotaenid beds in the upper Sinian are considered to occur at equivalent stratigraphic levels.

Two specimens of *Tawuia dalensis* have been collected from the Jiucheng Member (the Yuhucun Formation) at the Baimashan section near Chengjiang County of eastern Yunnan Province. One is straight and the other tightly bent. Some tawuid-shaped specimens have been reported from the Meishucun section, Jinning (Xing Yusheng, in Luo Huilin et al., 1984).

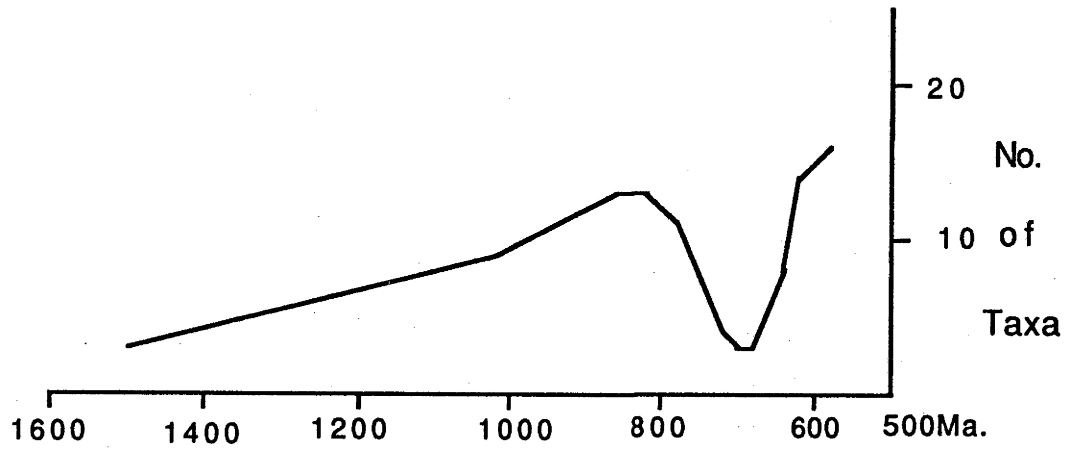
Some tyrasotaenides are found with *Tawuia dalensis* in the upper Sinian. These specimens are longer and wider than *Tyrasotaenia podolica* Gnilovskaya, and have tapering ends. Several broken specimens with a stalk-like appendage have been referred to *Longfengshania*, unfortunately they are small and badly preserved.

The Baiyunshao Member of the Yuhucun Formation at the Baimashan section contains one layer of the mega-algal fossils *Daltaenia* cf. *mackenziensis*. The ribbons have lateral branching.

The upper Sinian flora resembles the upper Valdai flora (second assemblage). Both of them contain abundant vendotaenides. However, the upper Sinian flora is diverse, consisting of *Enteromophites*, *Tawuia*, *Chuaria* and *Daltaenia*, but lacking *Aataenia* Gnilovskaya, *Leiothrichoides* Hermann and *Sarmenta* Gnilovskaya.

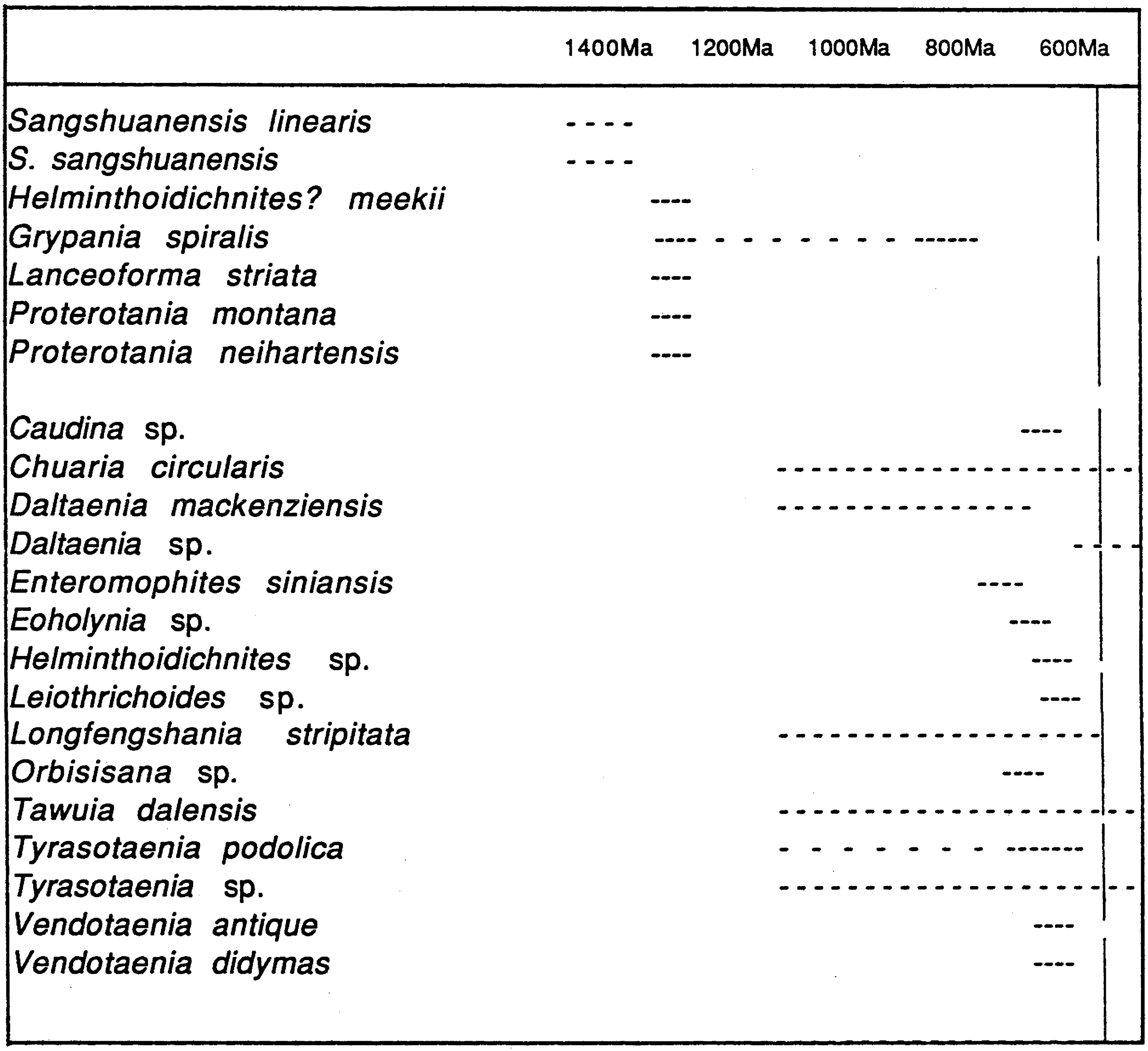
Unlike the poor preservation of the Lower Cambrian flora in the East-European Platform, abundant mega-algal fossils have been found in the Lower Cambrian Yu'anshan Member (the Qiongzhusi Formation) at the Maotianshan section near Chengjiang County. The member contains the "Chengjiang Fauna", which includes abundant soft-bodied fossils *Naroia*, medusa, sabellidites, the trilobites *Yunnanocephalus* and *Eoredlichia*, brachiopods and many other species (Zhang Wentang and Hou, 1985). In association with the fauna, more than four meters of a shale rich in mega-algal fossils are exposed. Preliminary investigation suggests the bed contains *Vendotaenia*, *Tyrasotaenia*, *Daltaenia* and some other forms. Most of the forms have been recorded from the Sinian and it seems that the Lower Cambrian flora is probably inherited from the Upper Proterozoic without significant change.

The review of Proterozoic mega-algal fossils indicates that a few species occur in several localities in the early or middle of the Middle Proterozoic and diversity increases in the late Middle Proterozoic or the early Late Proterozoic; the diversity and abundance decreases at the time of the Late Proterozoic glaciation; late Late Proterozoic mega-algal fossils are diverse from the upper Sinian (or Upper Valdai series) and continue to flourish in the Lower Cambrian; and most Lower Cambrian fossils are similar to those of the upper Sinian (Text-figure III-5, 6).



Text-fig. III-5. Diversity changes for the Middle Proterozoic and Early Cambrian megascopic algal fossils. The diversity displays slow increase of the number in the Middle Proterozoic, sharp decrease during the Late Proterozoic glaciations and rapid increase in the Ediacarian.

No convincing animal samples have been collected from the Upper Proterozoic pre-glacial strata so far. Late Late Proterozoic (or Ediacarian) metazoans are widely distributed in the world and some of them are considered to be planktonic. On the South China Platform the Ediacara fauna *Paracharnia dengyingensis* (Ding and Chen) occurs in the same level (Shibantan Member) with *Vendotaenia didymas* (Cao et Zhao). Small shelly fossils, trace fossils, trilobites, and other groups dramatically increase in the Early Cambrian. The abundance and diversity of the mega-algal organisms which began in the late Sinian would have provided a food supply for the numerous animals in the Early Cambrian.



Text-fig. III-6. Stratigraphic range of the Proterozoic and Lower Cambrian mega-algal fossils. The symbol ---- indicates the occurrence.

3.3. MICROFOSSILS FROM THE NANTUO FORMATION

The tillite of the Nantuo Formation was first reported as Cambrian by Willis and Blackwelder (1907). In 1924 Lee and his co-worker investigated the sequences in the Yangtze Gorges and recognized the tillite as belonging to the Sinian.

The tillite is about sixty meters thick at the Wangfenggang section in the Yangtze Gorges. It disconformably underlies the dolomites of the Doushantuo Formation and overlies the sandstones of the Liantuo Formation, and can be subdivided into five beds based mainly on colour. Isotopic ages of 700-740 Ma have been recorded for the Nantuo Formations (Zhao Ziqiang et al., 1980; Ma Guogan et al., 1984).

In the Yangtze Gorges the Nantuo Formation is probably a continental deposit. No well-preserved bedding or varved structures are exposed. Striated stones from sand to boulder size are mixed with clay without sorting, especially in the lower part. Sometimes "nailhead" striations can be seen on the stone surfaces. A number of thin shell-like coatings on the larger stones (as clay or calcareous "egg shells") are observed, and this has been considered to be a result of constant change between colder and warmer weather during moving (Zhao Ziqiang et al., 1980; Wang Yuelun et al., 1981).

One bed of shales and sandstones is exposed in the middle of the tillites at the Wangfenggang section and the bed can be traced for 2km. The shales and sandstones are 0-2m thick and well-bedded. Organic matter from the bed is badly preserved and fragmented.

The microfossils reported previously from Nantuo Formation are poorly preserved (Zhao Ziqiang et al., 1980). Only several long ranging microfossils (*Trachysphaeridium* sp., *Trematosphaeridium* sp. and *Leiosphaeridia* sp.) have been found. The microfossils in this study are satisfactory. Ten large samples (150 to 200g.) from the Wangfenggang section have been processed. Five produced microfossils, and three of them yielded relatively abundant individuals (Text-figure III-7). The assemblage is relatively diverse, more than ten forms having been identified, two of which are new. Some specimens are well-preserved, but most of them are strongly carbonized and do not display surface textures. This may indicate, using the scale for colour index (Staplin, 1977), that the rocks have been subjected to temperatures of 100-250°C.

Three specimens of *Vandalosphaeridium varangeri* Vidal have been found in the tillite. This species contains short, un-branched processes which support an outer transparent membrane, and has been recorded from the Lower Vendian Ekkeroy, Dakkovarre and Grasdal Formations in the east Finnmark, northern Norway, and Dundas and Nassarssuk Formations, Thule Group in northwestern Greenland (Vidal, 1981b). Its discovery in the lower Sinian Nantuo Formation indicates that it is a wide- spread species in the Late Proterozoic.

Favososphaeridium is characterized by its surface honeycomb-like meshwork. The Nantuo Formation yielded relatively abundant specimens of this form-taxon. In sample 83H091, more than 30% of all specimens were ornamented with this kind of meshwork, and some have a large circular opening. Unfortunately the specimens are more or less deformed. Other species in the genus, such as *Favososphaeridium favosum* Timofeev range from the Vendian to Cambrian in the Atlantic region, the Soviet Union and northern China (Timofeev, 1966; Vidal, 1976). *Favososphaeridium* sp. is only recorded from the Nantuo Formation in this study.

Pyritosphaera barbaria Love, 1957 (=*Bavlinella faveolata* (Shepeleva) Vidal), a purported endoporulating cyanobacterium, was reported to dominate the microfossil assemblage in the Tillite Group in Greenland (Vidal, 1976b). This form-taxon represents the colonial cysts of the reproductive stage (Moorman, 1974, Zhang Zhongying, 1982, Vidal and Ford, 1985). Zhang Zhongying (1982) discussed his rejection of the view that *Sphaerocongregus variabilis* was conspecific with *Bavlinella faveolata.* The specimens from the Nantuo Formation are a spheroidal aggregate of numerous tightly packed spheroidal cells, and no different from those preserved in cherts. The taxon has been found to range over long periods (Love, 1963; Vidal et al., 1983). Care is called for since some pyrite framboids may produce a similar structure (Love, 1957; Volkova, 1974).

The tillite contains some distinctive microfossils. One form is vase-shaped resembling *Melanocyrillium*, but its surface is ornamented with an irregular reticulate meshwork similar to that of *Dictyotidium*. Another form has a single prominent process at one end and resembles *Sinianella*, but it differs from *S. uniplicata* (Yin L.) and *S. scabrata* in its spongy wall.

Spheroidal microfossils dominate the assemblage the Nantuo Formation, including *Kildinosphaera granulata, Leiosphaeridia* sp., *Trachysphaeridium laminaritum* (Tim.), *Trachysphaeridium* sp., *Stictosphaeridium* sp. and *Protoleiosphaeridium* sp.. Some large dark vesicles are more than 600*u*m in diameter, but these vesicles are generally carbonized and no surface texture has been observed. Most spheroids range over long periods.

Vase-shaped microfossils with a smooth surface texture have been found. They are considered to be heterotrophic plankters. Similar microfossils are widely recorded from the Late Proterozoic (Bloeser, 1985; Knoll and Vidal, 1981).

The upper part of the glaciogenic shale of the Nantuo Formation at the Wangjiawan section, eastern Yunnan yields less diverse microfossils. Most organic matter has been fragmented, only a few vesicles with many small conical spines referable to *Trachysphaeridium* cf. *laufeldi* have been recorded. The severe environment would have restricted the diversity, and only a few species survived in it.

In summary, the microfossil assemblage from the Nantuo Formation is dominated by common Late Proterozoic spheroids; even though some distinctive taxa, such as *Vandalosphaeridium varangeri*, have been recorded, the assemblage cannot be used confidently for stratigraphic correlation.

Sample No. Name of Species	83H089	83H091	83H093	83H094	83H096
Dictyotidium sp.	1	18			
Favososphaeridium sp.	2	43			
Leiosphaeridia asperata				1	10
Protoleiosphaeridium densum		14	5	34	13
P. flexuosum	2	1		14	11
Pyritosphaera barbaria		10		2	4
Sinianella sp.				5	18
Stictosphaeridium sp.		2			1
Trachysphaeridium sp.	5	10	1	2	30
T. cf. *laminaritum*		4	5	82	86
Trematosphaeridium sp.				2	2
Vandalosphaeridium varangeri		2			
Vase-shaped microfossils		1		22	30
Siphonophycus? sp.		3			

Text-fig. III-7. Microfossils from the lower Sinian Nantuo Formation. Distribution of individuals among species is numered.

3.4. UPPER SINIAN MICROFOSSIL ASSEMBLAGES

3.4.1. Stratigraphy

The upper Sinian is well exposed in southern China and includes the lower Doushantuo Formation and the upper Dengying Formation. In 1982 the Meishucun section was proposed as the Chinese candidate for the global stratotype section for the Proterozoic - Cambrian boundary, since abundant shelly fossils (ninety genera and more than one hundred species) have been found in the upper Dengying Formation and fossil zonations have been well established across the Proterozoic - Cambrian transition. The Yuhucun Formation is used for the mainly dolomitic sections in eastern Yunnan and correlated with the Denying Formation (Xing Yusheng and Luo, 1984; Luo Huilin, 1981).

The upper Sinian may have been deposited in a shallow marine environment (Zhao Ziqiang et al., 1980). The dolomites of the Doushantuo Formation in the Yangtze Gorges disconformably overlies the Nantuo Formation. Irregular slump structures and gypsum pseudomorphs have been observed in the lower part of the dolomites (Zhao Ziqiang et al., 1980). The higher part of the sequence has predominantly parallel beds, rich in bedded cherts and chert nodules. It seems that the lowest part of the Doushantuo Formation was deposited in very shallow water, and the upper part in a relatively deeper marine environment. On the basis of a study of stable isotopic composition of the carbonates, Lambert et al. (1987) considered that the dark-coloured strata of the Doushantuo Formation have been formed in restricted marine environments and the thin basal dolomite bed has been involved in non-marine waters. The top bed of the formation contains siliceous ooid structures (Zhao Ziqiang et al., 1980). At the Wangjiawan section in eastern Yunnan, the rocks of the Doushantuo Formation mainly consist of parallel beds of carbonates and sandy shales. Intraclastic limestone has been observed and may indicate a littoral environment.

The Dengying Formation consists only of carbonates more than 600m thick in the

Yangtze Gorges. The rocks in the lowest (Hamajing) member contain oolites and cross-bedding, indicating a shallow turbulent environment. The second (Shibantan) member consists of parallel-bedded black limestones, yielding abundant algal filaments of *Vendotaenia didymas*. Some beds are laminated. It is considered the member has been deposited in a subtidal, low energy environment. This member in eastern Yunnan consists of shales, named the Jiucheng Member. The dolomites of a third (Baimatuo) member contain fenestrae and desiccation cracks and may have been deposited in an arid, periodically exposed environment. The upper part of the Dengying Formation, including the Xiaowaitoushan, Zhongyicun and Dahai Members, consists mainly of phosphorites, and is rich in small shelly fossils. Phosphorite is probably restricted mainly to the continental shelf sediments, in areas of warm water, low rate of detrital sedimentation, and slightly reducing conditions (Bromley, 1967). It is suggested the phosphorites in the upper Dengying Formation were deposited in a similar, shallow shelf environment. Abundant microfossils, particularly filamentous microfossils, have been found in the phosphorites, and this may support the suggestion of a shallow water origin (Zhu Shixing et al., 1984). The Dengying Formation underlies the shale of the Lower Cambrian Qiongzhusi or Shuijingtuo Formations on the South China Platform.

3.4.2. Doushantuo Assemblage

The Doushantuo Formation consists of dolomites, shales and limestones. Some cherts have been found. The microfossils obtained from the shales by maceration are poorly preserved and display low diversity. The black and grey shales have been demonstrated by Lambert (personal communication) to have been exposed to a temperature reaching the oil window, and post-diagenetic thermal process may have destroyed many organic forms in the soft shales, because abundant well-preserved microfossils have been recorded from interbedded cherts.

About thirty shaly samples from the Doushantuo Formation in the Yangtze Gorges, and four from eastern Yunnan have been processed, and only three of them contain ill-preserved specimens, including *Triangumorpha* sp., *Pyritosphaera barbaria* Love, *Navifusa crassa* (Sin and Liu) , *Kildinosphaera granulata* Vidal, *Protoleiosphaeridium flexuosum* Tim and other unidentified specimens. Among them, *Navifusa crassa* (Sin and Liu) is abundant in the Dengying Formation and is also recorded from the Lower Cambrian; other species are considered to have long ranges, and are without significance for stratigraphic correlation.

Cao Renguan et al. (1980) reported about twenty species (in maceration) from the Doushantuo Formation at the Wangjiawan section, Jinning, Yunnan, but most taxa need to be confirmed. Yin Leiming and Li (1978) described more than thirty species from the formation, of these, *Favososphaeridium* and *Micrhystridium* are the important taxa of the upper Sinian assemblage.

Though poorly preserved microfossils have been recorded from shales, the cherts and the phosphorites in the Doushantuo Formation have been found to contain beautifully preserved microfossils which enrich our knowledge of the late Sinian microbiota.

Yin Leiming and Li (1978) described more than ten species in chert sections from the Doushantuo Formation. Included are two large spinose species: *Asterocapsoides sinensis* Yin et Li 1978 is circular in form, 325*um* in diameter, has double walls, and is ornamented with regularly-arranged spines which are about 16*um* long, widened at bases (20-30*um* wide), sharp or obtuse at tips, and about 30 of them can be seen in outline; and *Tianzhushania spinosa* Yin et Li, 1978 has an indented margin in outline, is 450*um* in diameter, the spines have widened bases (15-30*um*), moderate length (30-46*um*) and sharp tips. The two species are found from the Tianzhushan district near Changyang, Yichang of Hubei Province in central China. Some similar spinose specimens referred to *Asterocepsa*? and *Hystrichopsprids* have been found in dolomite sections (Tang Tianfu et al., 1978).

Zhang Zhongying (1984) described one new species *Comasphaeridium magnum* from the Doushantuo Formation in western Hubei Province of central China. The species is 170-267*um* in diameter with dense, thin, hair-like spines 20-37*um* long. He suggested the occurrence of the species was of significance in biostratigraphy.

Awramik et al. (1985) reported a superbly preserved heterogeneous assemblage of bacteria, cyanobacteria, planktonic algae, submillimetre-sized burrows and some problematic forms from the cherts of the Doushantuo Formation in the Yangtze Gorges. Included are the spinose acritarch *Baltisphaeridium* and some large vesicles (400-900*u*m wide and 750-1500*u*m long).

The next assemblage from the cherts of the Doushantuo Formation in the Yangtze Gorges contains more than 19 acritarchs (Yin L., 1985, 1986). In the assemblage some common Proterozoic forms *Leiosphaeridia, Favososphaeridium, Peterospermopsimorpha, Vandalosphaeridium* and *Trematosphaeridium* have been found; also thousands of specimens of *Micrhystridium,* and few large specimens of *Baltisphaeridium maximum* (vesicle diameter 215-345*u*m) and *Comasphaeridium*? (vesicles 197-232*u*m long and 99-113*u*m wide, process length 22-26*u*m) are observed.

Filamentous microfossils in the cherts also display diversity. Zhang Zhongying (1981a, 1981b; 1982, 1984) described *Eomycetopsis robusta,* cf. *Gunflintia minuta, Palaeolyngbya* sp., *Rhicnonema antiquum, Siphonophycus* sp., *Obruchevella minor* and other species. Some beautiful filaments have been reported (fig.3, a, c, d) by Awramik et al. (1985).

Phosphorites of the Doushantuo Formation, like cherts, also yield some superbly preserved microfossils. Chen Meng'e and Liu Kuiwu (1986) described two genera to include three species. *Megasphaera inornata* Chen et Liu is a spheroidal form with smooth surface texture and 500-800*u*m in diameter, and the genus *Mehystrichosphaeridium* has spines: *M. wenganensis*, 200-500*u*m in diameter, spines sparse arrangement, 15-20*u*m long, widened at bases and tapering to the points, and the spines not communicating freely into the vesicle cavity; and *M. chadianensis*, 500-800*u*m in diameter with dense spines to support an outer wall.

Zhang Yun (1987) reported some superbly-preserved multicellular metaphyte fossils from the phosphorites of the Doushantuo Formation at Kaiyang of Guizhou Province. Some phospharized fossil thalli display complex tissue and structures, 0.3 - 5mm in diameter, with a main body and a few branched parts. Also many other complex, multicellular and large specimens have been observed in phosphorites, including some specimens referred to *Papillomembrana* which was first described from the Upper Proterozoic in Norway (Spjednaes, 1963).

Abundant filamentous microfossils also have been found in phosphorites. Zhu Shixing and Wang (1984) described more than ten forms from the Doushantuo Formation at the Kaiyang phosphorite mine in Guizhou Province. Many of them are common in the Upper Proterozoic, such as *Oscillatoriopsis, Palaeolyngbya, Eomycetopsis*, and some others may be new. These filaments may provide evidence to help explain the environment and formation of the phosphorites.

In addition to microfossils, the phosphorites of the Doushantuo Formation contain some stromatolites (Zhu Shixing and Wang, 1984; Zhou Maoji et al., 1984). Some of these contain microfossils.

Reviewing microfossil occurrences in the Doushantuo Formation on the South China Platform, we may reach following conclusions:

1. Shales of the formation contain an assemblage of low diversity, and many microfossils are common in the Upper Proterozoic, including *Micrhystridium, Protoleiosphaeridium, Kildinosphaera, Trachysphaeridium, Trematosphaeridium, Pyritosphaera, Navifusa, Triangumorpha* and *Leiosphaeridia*; post-diagenetic metamorphosis may damage most organic forms.

2. Most diverse assemblages are preserved in cherts and phosphorites. They contain many common Upper Proterozoic forms, in addition to some large spinose species: *Baltisphaeridium maximum* Yin L. 1986, *Asterocapsoides sinensis* Yin et Li, 1978, *Tianzhushania spinosa* Yin et Li, 1978, *Comasphaeridium?* sp., *Comasphaeridium magnum* Zhang, 1984, *Mehystrichosphaeridium wenganensis* Chen et Liu, 1986, *Mehystrichosphaeridium chadianensis* Chen et Liu, 1986, and *Papillomembrana.*

3. Filamentous microfossils are abundant in the cherts and phosphorites.

3.4.3. Dengying Assemblage

The Dengying Formation consists of six members. The upper three members (Xiaowaitoushan, Zhongyicun and Dahai Members) are dolomite and dolomitic phosphorites, and contain small shelly fossils; and the lower three members (Hamajing, Shibantan <=Jiucheng>, and Baimatuo <=Baiyanshao> Members) contain soft-bodied fossils of Ediacara fauna and other late Sinian fossils. The microfossil assemblage of the Dengying Formation crosses the Proterozoic - Cambrian boundary.

The Dengying Formation in the Yangtze Gorges consists of carbonates, and few shaly samples available. In eastern Yunnan the Jiucheng Member contains brown and grey shales 30-40m thick. Eight samples from the Wangjiawan and Baimashan sections were processed in this study, but only one of them (85Y098) yielded relatively abundant microfossils.

Navifusa crassa (Sin et Liu, 1978) is characterized by its rodlike form, rounded ends, smooth surface texture, spongy wall and occasionally an opening at one end. The Dengying Formation contains abundant specimens and the species also has been recorded from the Doushantuo Formation and Lower Cambrian Qiongzhusi Formation on the South China Platform.

Lophosphaeridium tuberosum sp. nov. was first described from the upper Sinian Liulaobei Formation and Lower Cambrian Gouhou Formation. Its relatively small vesicles bear large tubercles and have a circular opening. Several specimens have been recorded from the Dengying Formation, but they do not have circular openings. The species has been found in the Lower Cambrian Qiongzhusi Formation.

Two specimens of *Micrhystridium* have been found in the Dengying Formation. In China micrhystrids have been recorded from the upper Sinian Liulaobei and Doushantuo Formations and many Lower Cambrian sequences. The occurrence of micrhystrids seems to be a characteristic of upper Sinian assemblages.

The Dengying assemblage also consists of other common species persistent in the

Upper Proterozoic, such as *Leiomarginata*? *simplex* Naumova, *Leiosphaeridia asperata* (Naumova) Lindgren, *Kildinosphaera granulata* Vidal, *Protoleiosphaeridium flexuosum* (Timofeev), *Pyritosphaera barbaria* Love, *Trachysphaeridium* sp., *Trematosphaeridium holtedhlii* Timofeev and other spheroidal species. Some common species in the Dengying Formation have been previously recorded by Zhao Ziqiang et al., (1980), Cao Renguan et al. (1980) and Yin L. et Lin (1978).

The cherts of the Dengying Formation contain many well preserved microfossils. Wang Fuxing et al. (1983) described 18 genera and 20 species from phosphatic cherts, including *Micrhystridium, Protoleiosphaeridium, Obruchevella* and other spheroids and filaments. Also some other species have been reported from the cherts of the Dengying Formation (Luo Qiling et al., 1982; Song Xueliang, 1984; Xing Yusheng, in Luo et al., 1984).

Yin Leiming (1986) described about ten forms from chert sections of the Dengying Formation in Zigui district of Hubei Province, including *Micrhystridium, Eoaperturilites* and some curious filaments of *Megathrix* Yin L., 1986. Re-examination of the thin section Hm80-14-3 (Yin Leiming's collection), showed many small acritarchs including at least three forms of *Micrhystridium*, some *Comasphaeridium* and specimens bearing blade-like processes possibly referable to *Goniosphaeridium* or *Liepaina*. More data are needed for further investigation.

Microfossils from the Dengying Formation seem to be less diverse than those from the Doushantuo Formation, and they particularly lack the large spinose acritarchs. Wang Fuxing (1985) considered no significant differences between the microfossil assemblages from the two formations and he proposed an "Assemblage V" to include the microfossils from the upper Sinian.

3.5. DIVERSITY OF EARLY CAMBRIAN MICROFOSSILS

The diversity of microfossils in the Early Cambrian is remarkable. Volkova et al., (1979) listed more than eighty acritarch species in this epoch from the East European Platform. He et al. (1983) and Xing Yusheng (in Luo Huilin et al., 1984) studied the microfossils from the Lower Cambrian sequences in eastern Yunnan and considered the appearance and diversity of *Baltisphaeridium* in the Qiongzhusi Formation would be of biostratigraphic significance and the lower part of the Qiongzhusi stage might have been an important period for the flourishing of microorganisms.

The Proterozoic - Cambrian transition on the South China Platform is continuously exposed, commonly consisting of marine carbonates. Among them, one bed of phosphorites (the Zhongyicun Member) can be traced throughout the platform. Chinese scientists have suggested three levels as candidates for the Proterozoic - Cambrian boundary: China A marks the first appearance of small shelly fossils (Xiaowaitoushan Member); China B defines the base of the zone of the small shelly fossil *Paragloborilus* - *Siphogonuchites*, characterized by a more diversified mineralized fauna (Zhongyicun Member); and China C is defined by a lithological change from a phosphate-rich rock to a black shale (Badaowan Member) (Hsu et al., 1985) (Text-figure III-8). The Qiongzhusi Formation contains the first trilobites and the Lower Cambrian Period on the South China Platform is subdivided into ten trilobite zones (Zhang Wentang and Jell, 1987).

The material studied was collected from five sections across the Proterozoic - Cambrian transition (Text-figure III-9). Two of them from the Tianzhushan and Huangshantong sections (Text-figure III-3) in the Yangtze Gorges, and the other three from the Meishucun (Text-figure III-10), Qiongzhusi sections (Text-figure III-11) and Maotianshan Drill Core (Text-figure III-12). The most interesting samples were collected from the Drill Core which ranges from the upper Canglangpu Formation to the base of the lowest Cambrian Xiaowaitoushan Member.

A remarkable diversity of microfossils (about fifty species) has been found from the Lower Cambrian Yu'anshan Member of the Qiongzhusi Formation on the South China Platform. The most interesting and diverse forms are referred to *Skiagia*. This genus

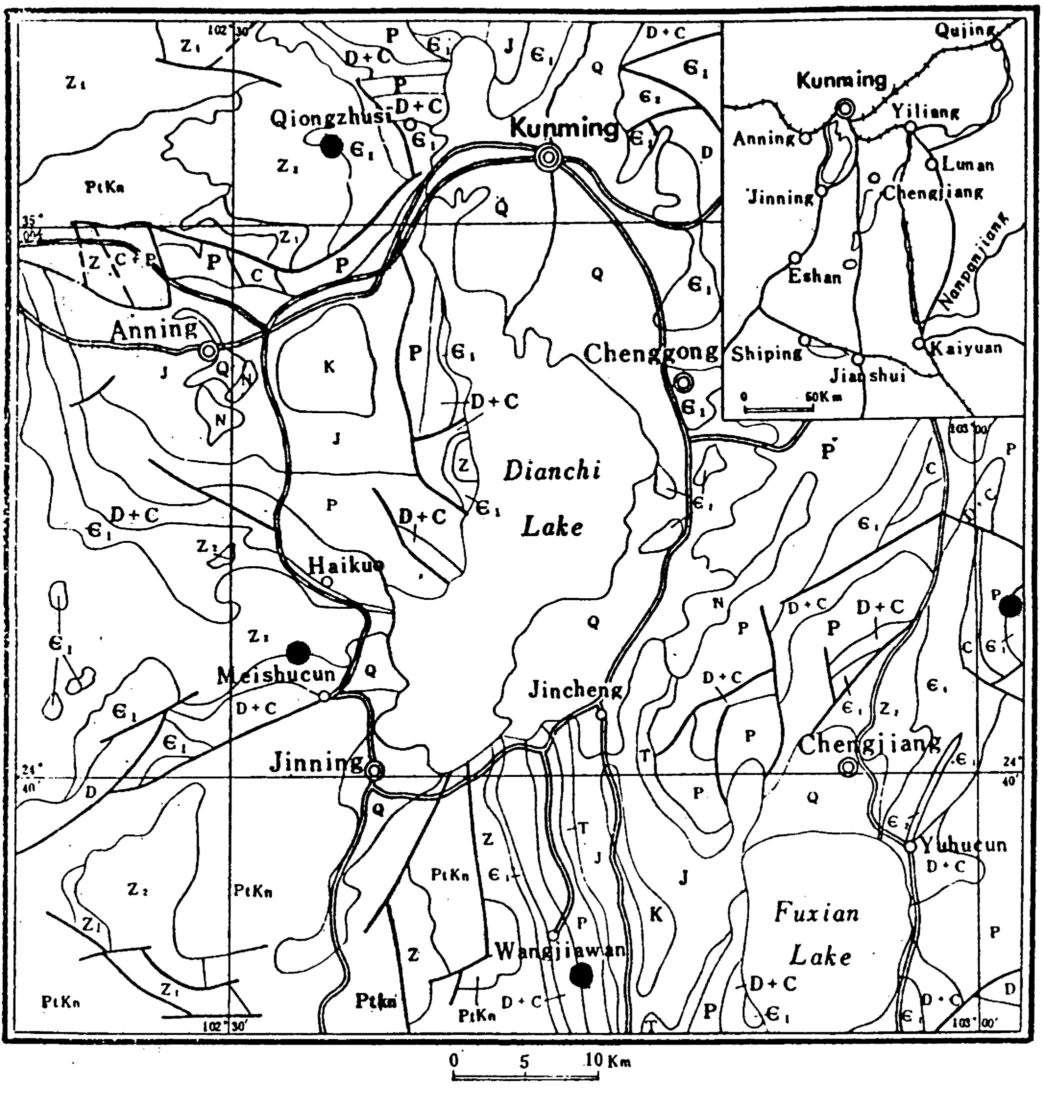
Era	Ass.	Trilobite Zones	Small Shelly Fossil Zones	Other Fossils
Cambrian		*Drepanuroides* Zone *Yunnanaspis-Yiliangella* Zone		
	IV	*Eoredlichia-Wutingaspis* Zone		Brachiopods Archaeocyathids Sabellidites Medusoids
	III	*Parabadiella* Zone ----China C---- ----China B----	*Sinosachites-Eonovitatus* *Paragloborilus--Siphogonuchites* *Circotheca-Anabarites-Protohertzina* Zone	Tracefossils
Sinian		----China A----		Ediacara fauna Vendotaenides
	II			*Chuaria--Tawuia*
	I	(Tillite)		

Text-fig. III-8. Microfossil assemblages in relationship with other fossil occurrences from the Sinian and Lower Cambrian sequence on the South China Platform. Ass.-- Microfossil Assemblages.

includes more than six species and most of them were previously referred to *Baltisphaeridium* (Volkova, 1968, 1969; Fridrichsone, 1971). The species, except *Skiagia ciliosa* (Volkova) which has been found from the Lower to Middle Cambrian, are all distributed in the Lower Cambrian throughout the Soviet Union, Poland, Norway, Sweden, Greenland, Scotland, Wales, England, Belgium, Spitsbergen and China (Volkova et al., 1979; Downie, 1982; Moczydlowska and Vidal, 1986; Knoll and Swett, 1987). The occurrence of a large member of *Skiagia* seems to be characteristic feature of the Lower Cambrian assemblages.

The presence of funnel-shaped processes could be an important biological innovation in phytoplankton. The processes are hollow and widen distally to form a funnel shape without closed tips. In the Yu'anshan Member the processes of *Skiagia* seem to vary through the life cycles; small vesicles have short, thin processes that flare only slightly at the tips and large vesicles have long, thickened processes with funnel-shaped terminations. Some cells in the colonies have processes with slightly thickened tips. It is possible that funnel-shaped processes are developed from these processes with thickened tips or baltisphaerid-like processes, and the development may have taken relatively long period since some specimens have been recorded from the upper Sinian Liulaobei Formation (Vidal and Moczydlowska, 1987) and Ediacarian Pertatataka Formation in the Amadeus Basin (Zang, in this thesis, Chapter IV). However only a few specimens occur in the Upper Proterozoic, and in the Lower Cambrian abundance seems more remarkable, about one thousand specimens of *Skiagia* having been recorded from sample 85Y055 in the Yu'anshan Member, that is more than 80% of the all specimens in the sample.

Baltisphaerid species in the Yu'anshan Member include *Baltisphaeridium cerinum* Volkova, *B*? *dubium* Volkova, *B*. *latviense* Volkova and *Baltisphaeridium* sp.. *B*. *cerinum* Volkova has been recorded from the Lower Cambrian Lükati and Vergale Horizons in the East European Platform, and Lower Cambrian rocks in Sweden, Norway, Belgium, Scotland, Greenland and other places; *B*. *dubium* Volkova recorded from the Lower Cambrian Talsy and Vergale Horizons in the East European Platform; and *B*. *latviense* Volkova recorded from the Middle Cambrian Kilartu Horizon (Latvia) (Volkova, 1968; Volkova et al., 1979; Downie, 1982). The diversity of *Baltisphaeridium* may be another important feature to distinguish the Cambrian assemblages.



Text-fig. III-9. Geological sketch map of the Kunming region, eastern Yunnan on the South China Platform. The symbol ● indicates the sample localities (from Lu Huilin et al., 1985).

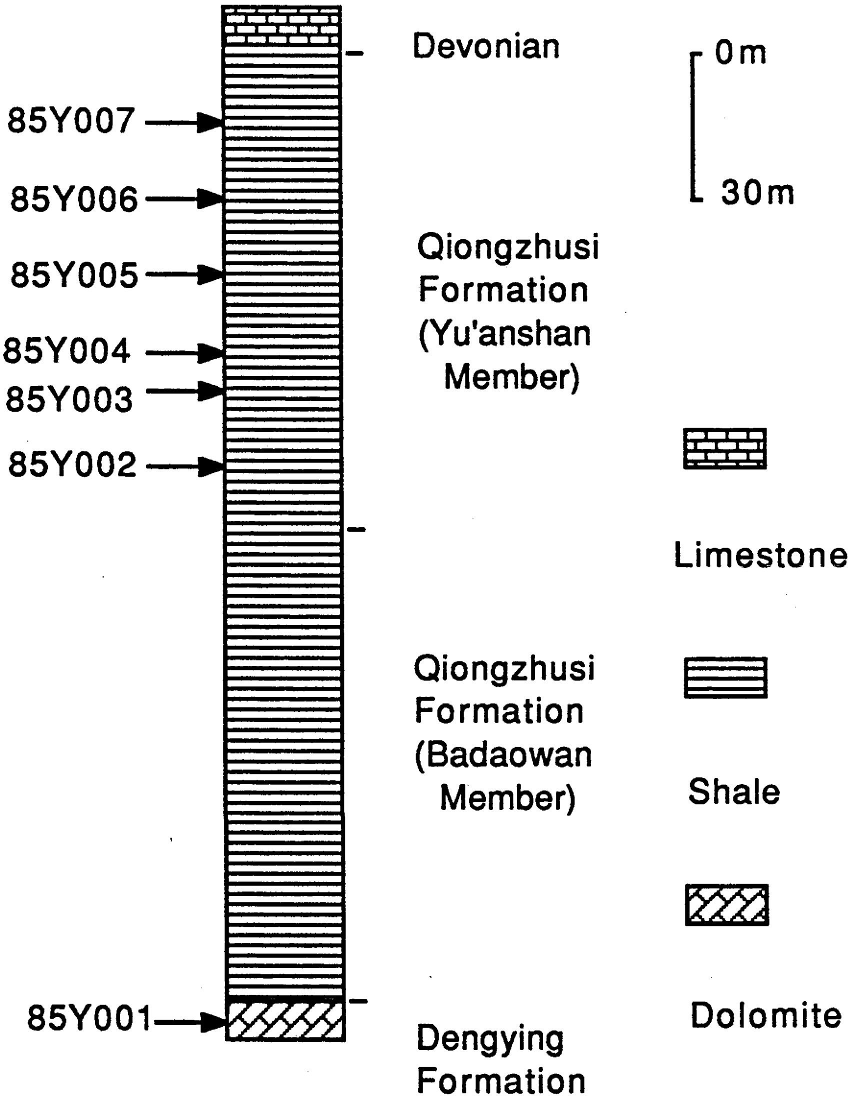
Comasphaeridium strigosum (Jankauskas) Downie is characterized by its dense, thin and flexible hair-like spines; it was previously referred to *Baltisphaeridium*. More than thirty specimens have been found in the Yu'anshan Member. This species has been found in the Lower and Middle Cambrian in the Europe (Jankauskas, 1976; Volkova et al., 1979; Downie, 1982).

Goniosphaeridium differs from *Baltisphaeridium* in its blade-like processes communicating freely into the vesicle cavity. Two forms of the genus have been recorded from the Yu'anshan Member: *Goniosphaeridium* cf. *implicatum* (Fridrichsone) Downie and *Goniosphaeridium* sp. Also one specimen has double walls on its processes (plate XXXIII, fig.E).

Some new species have been described from the Yu'anshan Member in eastern Yunnan. *Liepaina chengjiangensis* sp. nov. differs from *L. plana* Jankauskas et Volkova in its vesicles with granular surface texture, dense processes, indented outline and processes having no webs. *Liepaina plana* has the processes joined by webs and smooth surface texture, and this species has been recorded from the Middle Cambrian Kibartu Horizon in the East European Platform. The other new species is *Ooidium qiongzhusiense* sp. nov., in which the vesicles are ornamented with a granular surface and one pole has separated trabeculae.

The Lower Cambrian microfossil assemblage also contains many important species possibly ranging from the upper Sinian to Lower Cambrian. Four forms of *Micrhystridium* have been found. They are *M. circulapertum* sp. nov., *M. spinosum* Volkova, *M. tornatum* Volkova and *M.* sp.; of them, *M. circulapertum* and *M. spinosum* have been recorded from the upper Sinian Liulaobei Formation and other Lower Cambrian sequences in Europe (Volkova et al., 1979; Downie, 1982), and *M. tornatum* ranges from Vendian to Middle Cambrian (Volkova et al., 1979). *Dictyotidium* cf. *birvetense* Paskeviciene, 1979, *Alliumella baltica* Vanderflit, *Lophosphaeridium tuberosum* sp. nov., and *Archaeodiscina umbonulata* Volkova are generally considered as important forms from the Sinian to Lower Cambrian.

Many common species have been found in the Lower Cambrian assemblage, including



Text-fig. III-10. Geological log of the Lower Cambrian Qiongzhusi Formation at the Meishucun section in JInglin, eastern Yunnan, southern China. Sample levels are indicated by arrows.

Kildinosphaera chagrinata, K. granulata, K. verrucata, Leiosphaeridia asperata, Navifusa crassa, Protoleiosphaeridium densum, P. flexuosum, P. laccatum, P. papyraceum, Pyritosphaera barbaria, Sinianella scabrata, Stictosphaeridium sp., *Synsphaeridium* sp., *Trachysphaeridium* cf. *laminaritum, T. levis,* and *Trematosphaeridium holtedahlii.* Most of those taxa range over long periods, and have no significance for biostratigraphic correlation.

Filamentous microfossils are scattered in the Lower Cambrian samples. Some specimens of *Eomycetopsis robusta* (Schopf) Knoll et Golubic occur in association with *Skiagia.* Filamentous microfossils probably provide some evidence for environmental analysis.

The Qiongzhusi Formation in eastern Yunnan is divided into the lower Badaowan Member and the upper Yu'anshan Member. The Badaowan Member consists of black shales which conformably overlie the Dahai Member of the Dengying Formation. No trilobites have been recorded from this member, and small shelly fossils include hyolithids, hyolithelmithes, monoplacophorans, chancelloriids and other forms (Luo Huilin et al., 1984). Some badly-preserved microfossils have been found, including *Trachysphaeridium, Protoleiosphaeridium, Pyritosphaera* and other fragmented specimens of *Kildinosphaera.* Most specimens are carbonized.

In Maidiping section, Emei, Sichuan of southwestern China, Wang Fuxing and Chen (1987) described more than 25 taxa of acritarchs from the Lower Member of the Jiulaodong Formation of the earliest Cambrian Meishucun Stage. The upper member of the Jiulaodong Formation contains trilobites *Eoredlichia, Wutingaspis, Mianxiandiscus* and other fossils , which can be correlated with the Yu'anshan Member of the Qiongzhusi Formation. The lower member yields small shelly fossils *Ebianotheca, Sinosachites, Circotheca* and *Turcutheca* (Yi Jicheng, 1980), and the fossils suggest the member could be correlated with the Badaowan Member (Wang Fuxing and Chen, 1987). This assemblage contains spinose acritarchs *Baltisphaeridium, Micrhystridium, Coryphidium* and *Acanthodiacrodium.* Wang Fuxing and Chen (1987) suggested that the occurrence of spinose acritarchs such as *Baltisphaeridium* in the lowest Cambrian might raise the possibility of using some acritarchs for determinating the Proterozoic - Cambrian boundary.

The Lower Cambrian Yu'anshan Member (Qiongzhusi Formation) consists of yellow grey shales and conformably underlies the Canglangpu Formation and overlies Badaowan Member in eastern Yunnan. The lower part of the Yu'anshan Member contains the first trilobite *Parabadiella* Zone and the upper part another trilobite *Eoredlichia- Wutingaspis* Zone (=*Yunnanocephalus* Zone). The Chengjiang Fauna occurs in the upper part of the Member (Zhang Wentang and Hou, 1985). Zhang Wentang (in press) considered that *Parabadiella* is the oldest trilobite known anywhere, and the *Eoredlichia - Wutingaspis* Zone could be tentatively correlated with the *Holmia* Zone in eastern Europe. Abundant occurrences of *Skiagia* in the *Eoredlichia - Wutingaspis* Zone in China and the *Holmia* Zone in Europe (Downie, 1982) may support this suggestion.

The microfossil assemblages from the Lower Cambrian on the South China Platform can be divided into three subassemblages, numbered from the base upwards.

Subassemblage 1 (the Badaowan Member) consists of the spinose acritarchs *Baltisphaeridium, Micrhystridium, Coryphidium, Acanthodiacrodium* and the spheroidal forms *Trachysphaeridium, Protoleiosphaeridium, Pyritosphaera, Kildinosphaera* and other common forms.

Subassemblage 2 (the Yu'anshan Member) contains very abundant and diverse microfossils, and the elements include *Skiagia, Baltisphaeridium, Comasphaeridium, Goniosphaeridium, Micrhystridium, Ooidium, Liepaina,* many other spheroids and some filaments. Abundant *Skiagia* characterizes this assemblage.

Subassemblage 3 (the lower part of the Canglangpu Formation) includes some common spheroids of *Leiosphaeridia, Kildinosphaera, Pyritosphaera,* fragmented specimens of *Baltisphaeridium,* and filamentous microfossils.

The microfossils from the black shales of the Badaowan Member are carbonized, and using thermal index (cf. Staplin, 1977) suggests the shales might have been exposed to a temperature about 100-250^{o}C, and the high temperature in post-diagenesis might have damaged microfossil forms. The grey and yellow shales of the Yu'anshan Member consist of calcium carbonate, quartz, mica, small amount of chlorite, and some sandy shales are interbedded in the sequence. A large number of well-preserved trilobites, brachiopods, soft-bodied fossils and other groups have been collected and most species are considered to be benthic animals. A quiet, nearshore and open marine environment is suggested for the well bedded shales in the Yu'anshan Member. The trilobite-rich beds of intraclastic siltstone in the member contain poorly preserved microfossils, and the siltstone may be deposited in inshore shoal environment. The microfossils of the subassemblage 3 were mainly collected from sandy shales of the Canglangpu Formation. Sandy shales are commonly considered not favourable for microfossil preservation. The thick sandstone and interbedded intraclastic silty limestone in the formation may suggest a nearshore shoal water condition.

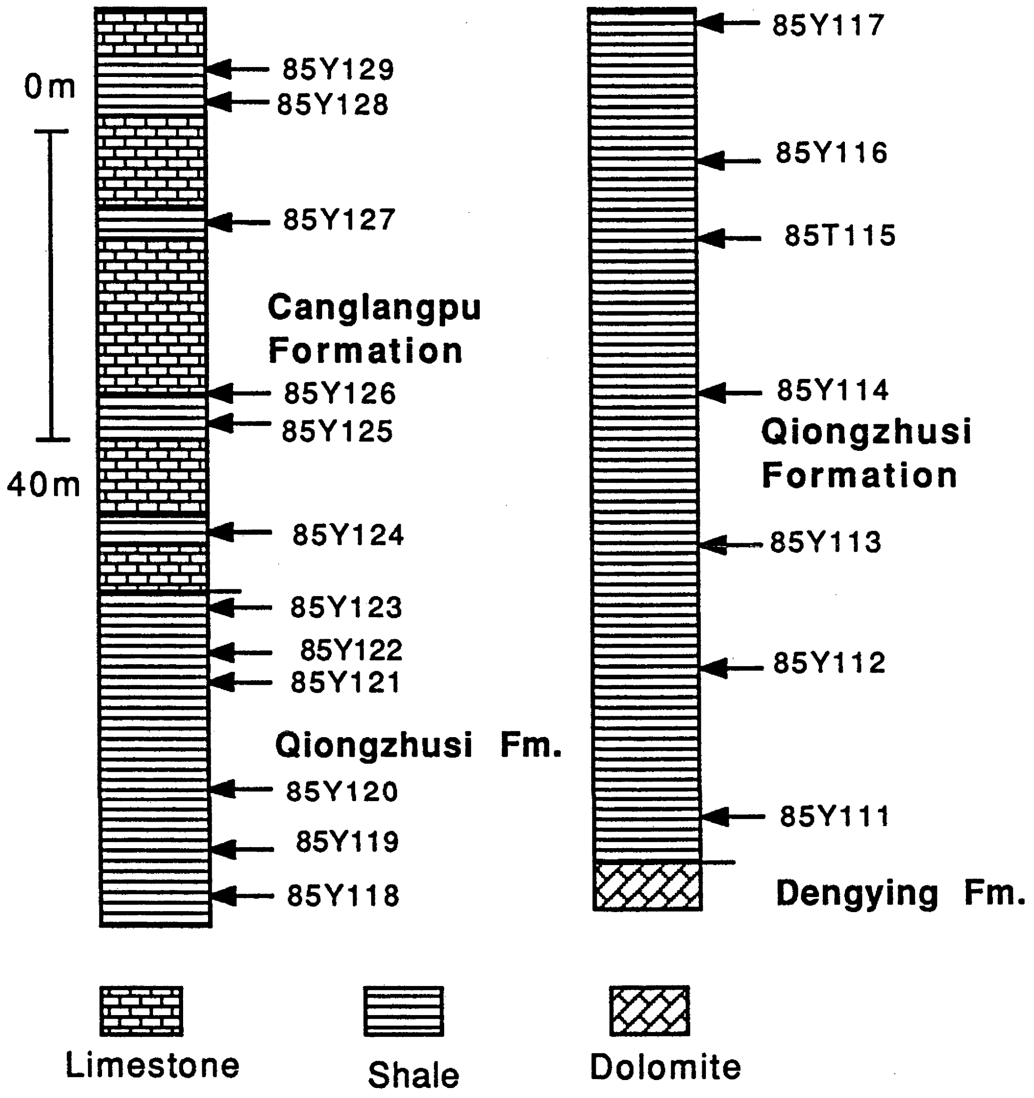
Subassemblage 1 of the Badaowan Member may be correlated with the division 2 of the Scottish assemblage at the Skiag Bridge in Scotland, where Downie recognized six divisions (Downie, 1982); the subassemblage 2 (Yu'anshan Member) with Scotland division 3 and division 4; and Chinese subassemblage 3 possibly with the division 5 and division 6 of Scotland.

The Lower Cambrian microfossils from the sequences in the Yangtze Gorges display low diversity. The Lower Cambrian Shuijingtuo Formation consists of black shales and unconformably overlies the Tianzhushan Member (the Dengying Formation) which contains the lowest two shelly fossil zones of the basal Cambrian. Trilobites *Hubediscus, Redlichia*, hyolithids, brachiopods and other fossils have been found in the Shuijingtuo Formation and the fossil assemblage may be correlated with *Eoredlichia- Wutingaspis* Zone (or *Yunnanocephalus* Zone) of the Yu'anshan Member. Few microfossils have been collected from the black shales of the Shuijingtuo Formation at the Huangshantong section; and one sample from the basal Shuijingtuo Formation at the Tianzhushan section contains *Gorgonisphaeridium?, Micrhystridium, Protoleiosphaeridium* and some vase-shaped forms. This assemblage differs from that of the Yu'anshan Member (the Qiongzhusi Formation).

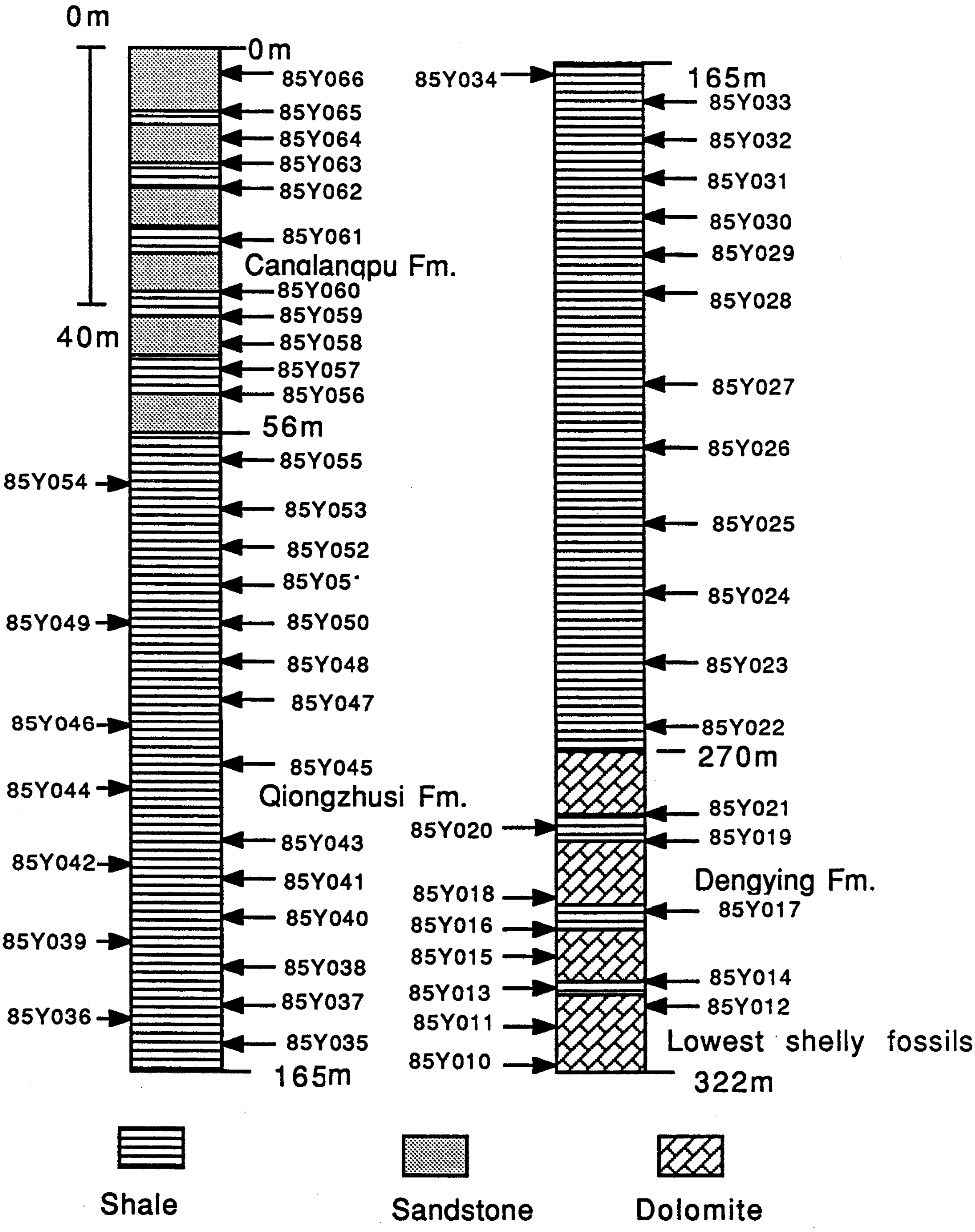
The Shipai Formation contains shales interbedded with limestones and sandy shales. Several beds of yellow - grey shales yield the microfossils *Kildinosphaera, Sinianella, Leiosphaeridia, Pyritosphaera, Synsphaeridium, Stictosphaeridium,* some fragments of spinose *Baltisphaeridium, Verysphaeridium*? and some filaments. Also in this assemblage one specimen displays double walls.

The Shipai Formation yields the trilobites *Redlichia, Ichangia,* and *Neocobboldia,* and can be correlated with the lower part of the Canglangpu Formation.

The Lower Cambrian microfossil assemblages in the Yangtze Gorges do not contain *Skiagia.*



Text-fig. III-11. Geological log of the Lower Cambrian Qiongzhusi Formation at Qiongzhusi Temple section near Kunming City, eastern Yunnan, southern China. Sample levels are indicated by arrows.



Text-fig. III-12. Geological log of the borecore at the Maotianshan, Chengjiang County, eastern Yunnan, southern China. Sample levels are indicated by arrows.

3.6. SIGNIFICANCE OF *SKIAGIA* OCCURRENCE

Recent arguments about the age of the Liulaobei Formation, Huainan Group in northern Anhui, central China commenced when Sun Weiguo et al. (1986) claimed *Sinosabellidites* was a worm-like organism of questionable metazoan origin. Cloud (1986) expressed his disagreement about the age of the Liulaobei Formation, and Vidal and Moczydlowska (1987) considered that the Liulaobei Formation is of Early Cambrian *Holmia* age because scattered specimens of *Skiagia* have been found in it.

The Liulaobei Formation probably does not belong to the Cambrian. The Huainan Group conformably underlies the Lower Cambrian Houjiashan Formation, which contains the trilobites *Megapalaeolenus fengyangensis* , *Redlichia* sp., *Hsuaspis* sp., and other shelly fossils (Zhang Wentang et al., 1979). The trilobites suggest the Houjiashan Formation may be correlated with the Canglangpu Formation in eastern Yunnan. A bed of phosphorites (0 - 25m) underlies the Houjiashan Formation and possibly belongs to the late Qiongzhusi Stage (Zhou Benhe et al., 1984). In the Qiongzhusi section, the Qiongzhusi Formation is about 200m thick, and contains trilobites and *Skiagia.* In northern Anhui, the Liulaobei Formation is below the glacial diamictite of the Fengtai Formation. The Fengtai Formation corresponds to the Luoquan Tillite and is considered to be the latest Proterozoic in age (Wang Yuelun et al., 1982; Guan Baode et al., 1985; Ren Yunshen, 1982), though other arguments have been proposed (Mu Yongji, 1981; Chumakov, 1981; Sun Weiguo et al., 1986). The investigations of stromatolites from the Sidingshan and Jiuliqiao Formation have suggested that the Huainan Group is of a late Proterozoic age (Yang Qinghe et al., 1980; Cao Ruiji et al., 1985), and previous study of microfossils suggested the Liulaobei Formation possibly belonged to the pre-Sinian Qingbeikouan System (Yan Yongkui, 1982; Yan Yongkui et al., 1984; Yin Leiming, 1983; Yin Chongyu, 1985). On the other hand, no trilobites and small shelly fossils have been found from the beds underlying the Houjiashan Formation in the Huainan region.

The Liulaobei Formation cannot be of *Holmia* age. Abundant specimens of *Skiagia* have been described from the Lower Cambrian sequences from Scotland, Norway, Greenland, the Soviet Union and other places (Downie, 1982). Microfossil investigation in eastern Yunnan suggests *Skiagia* abundantly appears from the trilobite *Eoredlichia - Wutingaspis* Zone of the Qiongzhusi Stage. The microfossil assemblage from the Qiongzhusi Formation contains *Liepaina*, *Comasphaeridium*, *Baltisphaeridium*, *Micrhystridium*, *Goniosphaeridium*, and *Ooidium*. Similar assemblages have been reported from the Lower Cambrian in the Soviet Union (Volkova et al., 1979), Scotland, Norway, Greenland and Newfoundland (Downie, 1982); but *Eoredlichia - Wutingaspis* Zone is one trilobite Zone below the *Drepanuroides* Zone which is considered to correspond to *Hsuaspis*-bearing beds in the Houjiashan Formation of northern Anhui. In northern Anhui *Skiagia*-bearing strata occur five formations below the Houjiashan Formation. It seems impossible to correlate the *Skiagia*-bearing strata in northern Anhui with other occurrences in the Early Cambrian. Thus the occurrence of *Skiagia* in the Liulaobei Formation is not good evidence of a Cambrian age.

Skiagia-bearing strata on the South China Platform contain the worm fossils *Maotianshania cylindrica* Sun and Hou (Sun Weiguo and Hou, 1987). These are well preserved. Morphologically they are similar to *Sabellidites cambrianensis*. The questionable worm-like fossils in the Liulaobei Formation are quite different in their circular terminals. On the other hand, sabelliditids are demonstrated to have a relatively long range (Tang Tianfu et al., 1978; Luo Huilin and Zhang Shishan, 1986; Chen Meng-e et al., 1982; Korkutis, 1981; Wang Guixiang, 1982). Those fossils are of doubtful value for intercontinental correlation.

In my study of microfossils from the Liulaobei Formation, more than forty form species, but no *Skiagia*, have been recorded. The assemblage consists of *Micrhystridium circulapertum*, *M. oligum*, *M.* cf. *oligum*, *M. quadratapertum*, *M. spinosum*, *Micrhystridium.* spp., *Alliumella baltica*, *Ambiguaspora* sp., *Favososphaeridium favosum*, *Kildinosphaera* spp., *Leiofusa bicornuta*, *Leiomarginata simplex*, *Leiosphaeridia asperata*, *Lophosphaeridium tuberosum*, *Sinianella* spp., and *Trachysphaeridium* spp. (this thesis, Chapter II). Mega-algal fossils include *Chuaria circularis* and *Tawuia dalensis*. The microfossils suggest the Liulaobei Formation is probably late Sinian in age.

The microfossils from the Pertatataka Formation in the Amadeus Basin, central Australia reveal a remarkably diverse assemblage in the Ediacarian. The formation overlies the glaciogenic Olympic Formation and underlies the Lower Cambrian Todd Formation and upper Arumbera Sandstone, and the Upper Proterozoic lower Arumbera Sandstone and Julie Formation (Preiss et al., 1981). The microfossil assemblage from the Pertatataka Formation contains abundant and diverse well-preserved acritarchs. Some specimens obviously have funnel-shaped processes: one form is similar to that of *S. ciliosa* (Volkova) and another to that of *S. insigne* (Fridrichsone), but the specimens differ from Cambrian species in their very large vesicles (>150*u*m) and variable funnel-shaped processes. Thus the 'scattered' specimens of *Skiagia* reported by Vidal and Moczydlowska (1987) are not good evidence of a Cambrian age (Text-figure III-13).

	Eastern Yunnan		Northern Anhui	
	Formation	Fossil Zone	Formation	Fossils
Cambrian	Canglangpu Formation 235m	*Megapalaeolenus* Zone *Palaeolenus* Zone *Yunnanaspis-Yiliangella* Zone	Houjiashan Formation Phosphorite Beds	*Megapalaeolenus fengyangensis* *Hsuaspis* sp. Small shelly fossils
	Qiongzhusi Formation 178m	*Eoredlichia-* * *Wutingaspis* Zone *Parabadiella-Mianxiandiscus* Zone small shelly fossils	Stratigraphic Hiatus?	
Sinian	Dengying Formation 600m	Ediacara fauna *Vendotaenia* *Chuaria* *Tawuia*	Fengtai Fm. 0-210m Sidingshan Fm. >290m Jiuliqiao Fm. 26-45m Shouxian Fm. 45-167m Liulaobei Fm.* 250-589m GuanjiayingFm. 105-341m Bagongshan Formation 40-86m Caodian Fm. 0-21m	*Chuaria* *Tawuia* Worm fossils *Chuaria* *Tawuia* acritarchs Worm-like fossils
	Doushantuo Formation 230m	Acritarchs		
		Disconformity		
	Nantuo Formation (Tillite)		Fengyang Group	

Text-fig. III-13. Stratigraphic correlation between the Sinian System and Upper Proterozoic and Cambrian sequence in northern Anhui, central eastern China. The symbol * indicates the occurrence of *Skiagia*.

3.7. MICROFOSSIL ASSEMBLAGES ACROSS THE PROTEROZOIC-CAMBRIAN TRANSITION ON THE SOUTH CHINA PLATFORM

The Proterozoic-Cambrian transition is one of the most significant in geological history for it marks the change in the fossil record from soft-bodied to skeletonized organisms. The Cambrian explosion is indicated by the evolution of many new life forms such as hyolithids, molluscs and archaeocyathids and a little later trilobites, bivalves, brachiopods and others. An attempt to use planktonic acritarchs to mark the Proterozoic-Cambrian transition started two decades ago (Volkova, 1969) and great achievements have been made recently (Volkova et al., 1979; Downie, 1982; Vidal and Knoll, 1983; Moczydlowska and Vidal, 1986).

Volkova (1969) proposed five microfossil assemblages for the Upper Proterozoic and Cambrian sequences: the one Proterozoic assemblage contains *Micrhystridium* cf. *tornatum* and is dominated by *Leiosphaeridia*; the assemblage of the basal Cambrian is similar to that of the Proterozoic, but contains *Granomarginata, Leiomarginata* and *Tasmanites*; the third assemblage in the Lower Cambrian consists of *Baltisphaeridium, Micrhystridium, Cymatiosphaera, Peterospermopsimorpha* and *Leiosphaeridia*; the fourth assemblage contains abundant *Skiagia, Baltisphaeridium, Micrhystridium, Estiastra, Deunffia* and other genera; and the last assemblage is from the Middle Cambrian. Volkova et al (1979) reviewed the Upper Proterozoic and Cambrian microfossils from the East-European Platform and divided the Early Cambrian into five "Horizons". *Skiagia* appears from the Talsy Horizon (Volkova, et al., 1979).

Downie (1974) recognized five acritarch zones from the Proterozoic - Cambrian transition sequences in Greenland, Scotland, Norway and the Soviet Union. The first three zones occur in the Upper Proterozoic and each contains microfossils of low diversity; Zone 4 marks the beginning of the Cambrian and is characterized by the occurrence of *Micrhystridium, Coruvasphaeridium* and *Granomarginata*; and Zone 5 contains abundant *Skiagia, Baltisphaeridium* and other species. Downie (1982) published further information on the microfossils from Scotland, Norway, Greenland, Newfoundland and Alberta, and he found that most abundant specimens of *Skiagia* occurred from the Lükati Horizon (= Talsy Horizon).

Vidal (1981) recognized three distinctive acritarch assemblages in Upper Proterozoic sequences in Scandinavia and Greenland and he considered that the assemblages could be compared with Upper Proterozoic assemblages from the Russian and Siberian Platforms, China and elsewhere. Vidal and Knoll (1982, 1983) contended that the initial observable radiation of presumed cyst-forming eucaryotic plankton occurred during the late Riphean and early Vendian; the plankton biota suffered major extinction in the middle to late Vendian; and a second radiation restored high diversity levels, but not until into the Early Cambrian. The further investigation suggests that microfossil assemblages were diverse from the *Holmia* "stage" A (=Lükati Bed) (Moczydlowska and Vidal, 1986), and a similar assemblage has been described from the Lower Cambrian Formation in Spitsbergen (Knoll and Swett, 1987).

Wang Fuxing (1985) established five microfossil assemblages based on data obtained from more than one hundred Middle and Upper Proterozoic sections in the south and west China. Assemblage V consists of acritarchs from the Doushantuo and Dengying Formations, including *Baltisphaeridium, Micrhystridium, Cymatiosphaera, Lophosphaeridium, Leiosphaeridia, Trachysphaeridium* and other spheroidal forms, and he considered this assemblage contained the first spinose microfossils in the geological record.

In this study microfossils from the Sinian and Lower Cambrian sequences on the South China Platform are divided into four assemblages (Text-figure III-14) and they are numbered from the base upwards.

Assemblage I. Including microfossils from the Nantuo Formation. More than ten forms have been recorded from sandy shales interbedded the diamictite, among them, *Vandalosphaeridium varangeri* Vidal has been inferred to be Lower Vendian (Vidal, 1981b); *Pyritosphaera barbaria* Love have been found in the Upper Tillite Formation (Finnmark), the Tillite Group in East Greenland and elsewhere widely distributed in the Proterozoic and Palaeozoic rocks; also occurring are some species common in the

Era	Formations	Ass.	References
Cambrian	Canglangpu Formation		1. Abundant *Skiagia* with moderate size. 2. Occurrence of *Baltisphaeridium, Liepania, Goniosphaeridium, Comasphaeridium, Micrhystridium, Ooidium* and other common forms. 3. Most nearshore assemblages dominated by spinose acritarchs.
	Qiongzhusi Formation (shale)	IV	
Sinian	Dengying Formation (carbonate)	III	1. Occurrence of *Baltisphaeridium, Micrhystridium* etc. 2. Abundant occurrence of *Leiosphaeridia.* 3. Nearshore assemblages with the dominance of sphaeromorph acritarchs.
	Doushantuo Formation (dolomite, shale)	II	1. Occurrence of spinose acritarchs *Baltisphaeridium, Comasphaeridium, Micrhystridium, Tianzhushania* etc. 2. Many spinose acritarchs with large size. 3. Most spinose forms collected from the chert and phosphorite thin sections.
	Nantuo Formation (tillite)	I	1. Occurrence of *Vandalosphaeridium, Pyritosphaera* etc. 2. Rare occurrence of spinose acritarchs. 3. Assemblages with a low diversity.
	Liantuo Formation (sandstone)		

Text-fig. III-14. Generalizing characters of the microfossil assemblages from the Sinian and Lower Cambrian sequences on the South China Platform. Ass.--microfossil assemblages.

Proterozoic: *Kildinosphaera, Leiosphaeridia, Stictosphaeridium, Favososphaeridium, Sinianella* and *Trachysphaeridium*; and some specimens with a vase-shaped form, ornamented with reticulate meshwork surface texture.

Microfossils from tillites may have a complex source, as some may come from re-deposited rock transported by glaciers, and others may be local microorganisms. In spite of some important forms obtained from the assemblage I, it still needs more distinctive taxa before it can be used for extensive biostratigraphic correlation.

Assemblage II. Consisting of microfossils from the Doushantuo Formation. This assemblage is characterized by the occurrence of a group of large microplankton, including *Baltisphaeridium, Comasphaeridium, Papillomembrana, Mehystrichosphaeridium, Asterocapsoides, Tianzhushania* and some specimens with multicellular tissue-like structures. The assemblage also contains abundant small size *Micrhystridium* and other species common in the Proterozoic.

Assemblage II is important for its occurrence in geological history. The Doushantuo Formation underlies the Dengying Formation which contains the Ediacara fauna. The diversity and abundance of the large microplankton before the flourishing of metazoans, may imply the presence of an advanced food supply before the appearance of the Ediacara fauna. A similar assemblage has been found in the Ediacarian Pertatataka Formation of the Amadeus Basin, central Australia, which also occurs in the beds underlying the Ediacara fauna. Some other forms such as *Papillomembrana* have been reported from the Upper Proterozoic sequence in Norway (Spjeldnaes, 1963).

Assemblage III. Including the microfossils from the Dengying Formation and the Badaowan Member of the Qiongzhusi Formation. The assemblage crosses the Proterozoic - Cambrian transition on the South China Platform, and differs from assemblage II in lacking abundant large microplankton, and from assemblage IV in the absence of abundant *Skiagia*. The Dengying Formation exposed on the South China Platform consists mainly of dolomite and few rocks are available for microfossil study; however, abundant *Micrhystridium* has been collected from chert sections and shales. Some small *Comasphaeridium* and *Goniosphaeridium* may occur. A similar group has been described from the lower part of the Maidiping Formation (=Badaowan Member), which contains at least four forms of spinose acritarchs including *Baltisphaeridium* (Wang Fuxing and Chen, 1987).

Unlike animal fossils in the Proterozoic - Cambrian transition, microfossils of the assemblage III on the South China Platform do not show a dramatic change of diversity and abundance. The beds underlying the boundary contain many species common in the Proterozoic (Wang Fuxing et al., 1983; Yin Leiming, 1986), including *Micrhystridium, Lophosphaeridium* and spheroids; and these taxa continue to occur in the Lower Cambrian Maidiping Formation (the Qiongzhusi Stage) without significant innovation.

Assemblage IV Including the microfossils from the Lower Cambrian Yu'anshan Member of the Qiongzhusi Formation. This assemblage is characterized by the abundant occurrence of *Skiagia*, some new forms such as *Liepaina, Ooidium*, and many spinose acritarchs *Goniosphaeridium, Baltisphaeridium, Comasphaeridium*, and *Micrhystridium*. On the South China Platform Assemblage IV occurs with the trilobites *Eoredlichia, Wutingaspis* and *Yunnanocephalus*, and about 30m above the first occurrences of the trilobite *Parabadiella* in eastern Yunnan.

Herein I emphasize two of the above-mentioned four assemblages from the Late Proterozoic to Early Cambrian: assemblage II indicates a diversity of microplankton before the Ediacara fauna, and is characterized by its lavishly ornamented and abundant large specimens; and the assemblage IV marks the radiation of many new spinose acritarchs in the Early Cambrian, and is characterized by the occurrence of abundant and diverse *Skiagia*. The two assemblages are probably of cosmopolitan significance for biostratigraphic correlation.

	Nantuo Fm.	Doushantuo Fm.	Dengying Fm.	Qiongzhusi Fm.	Shipai Fm.
Alliumella baltica	N	N	N	R	N
Archaeodiscina umbonulata	N	N	N	R	N
Baltisphaeridium cerinum	N	N	N	C	N
Baltisphaeridium ? dubium	N	N	N	C	N
Baltisphaeridium latviense	N	N	N	C	N
Baltisphaeridium sp.	N	N	N	C	N
Comasphaeridium strigosum	N	N	N	C	N
Dictyotidium cf. *birvetense*	N	N	N	R	N
Dictyotidium ? sp.	C	N	N	N	N
Favososphaeridium sp.	R	N	N	N	N
Goniosphaeridium sp.	C	N	N	N	N
G. cf. *implicatum*	N	N	N	C	N
Kildinosphaera chagrinata	C	R	C	A	C
Kildinosphaera granulata	R	R	C	A	C
Kildinosphaera verrucata	N	N	N	R	N
Leiomarginata ? simplex	N	N	C	R	N
Leiosphaeridia asperata	C	C	A	V	A
Liepaina chengjiangensis	N	N	N	C	N
Lophosphaeridium tuberosum	N	N	C	C	R
Micrhystridium circulapertum	N	N	N	R	N
Micrhystridium spinosum	N	N	N	C	N
Micrhystridium tornatum	N	N	N	C	N
Micrhystridium sp.	N	N	R	C	R
Navifusa elongata	N	C	A	C	R
Ooidium qiongzhusiensis	N	N	N	C	N
Protoleiosphaeridium densum	C	C	C	A	C
P. flexuosum	C	C	A	A	C
P. laccatum	N	N	R	R	N
P. papyraceum	N	N	N	R	N
Pyritosphaera barbaria	A	C	C	V	C
Sinianella scabrata	N	N	R	R	C
Sinianella sp.	R	R	N	N	N
Skiagia ciliosa	N	N	N	V	N
Skiagia compressa	N	N	N	V	N
Skiagia cf. *insigne*	N	N	N	R	N

Text-fig. III-15. page1-2. (1)

	Nantuo Fm.	Doushantuo Fm.	Dengying Fm.	Qiongzhusi Fm.	Shipai Fm.
Skiagia orbiculare	N	N	N	V	N
Skiagia ornata	N	N	N	V	N
Skiagia scottica	N	N	N	V	N
Stictosphaeridium sp.	C	C	C	A	C
Synsphaeridium sp.	C	C	C	A	C
Tasmanites ? sp.	N	N	N	C	N
Trachysphaeridium levis	C	R	C	C	R
T. laminaritum	R	N	N	N	N
T. cf. *laufeldi*	C	N	N	N	N
Tremato. holtedahlii	N	N	N	C	N
Triangumorpha sp.	N	N	R	N	N
Vandalosphaeridium varangeri	R	N	N	N	N
Eomycetopsis robusta	N	R	R	V	A
Siphonophycus sp.	C	R	R	A	A
Daltaenia cf. *mackenziensis*	N	N	C	N	N
Daltaenia sp.	N	N	N	A	N
Longfengshania ? sp.	N	N	R	N	N
Tawuia dalensis	N	N	C	N	N
Tyrasotaenia ? sp. Type-1	N	N	C	N	N
Tyrasotaenia sp. Type-2	N	N	N	A	N
Vendotaenia didymos	N	N	V	N	N
Vendotaenia sp.	N	N	N	R	N

Text-fig. III-15. Microfossils and megascopic algal-fossils from the Late Proterozoic and Early Cambrian sequences on the South China Platform. V-very abundant (more than 50 specimens), A-abundant (20-50 specimens), C-common (5-20 specimens), R-rare (1-5 specimens) and N-nil.

3.8. SYSTEMATIC PALAEONTOLOGY

3.8.1. Spheroidal Microfossils

Genus *Archaeodiscina* (Naumova, 1960) Volkova, 1968

Type species. *Archaeodiscina granulata* Naumova, 1960

Archaeodiscina umbonulata Volkova, 1968
(Pl.XXXVII, fig.L)

Remarks. Present specimen has a darker disc in the centre and the disc bears radiating stripes which have not reached the margin. The vesicle diameter is 35x45*um*, surface fine granular and wall folded. Only one specimen has been found from the Lower Cambrian Qiongzhusi Formation in eastern Yunnan.

Genus *Baltisphaeridium* Eisenack, 1958

Type species. *Baltisphaeridium longispinosum* (Eisenack, 1931) Eisenack, 1958.

Discussion. Eisenack (1958) restricted genus *Hystrichosphaeridium* to include the specimens with processes open distally and erected a new genus *Baltisphaeridium* to include the specimens with processes closed distally. He transferred the species *Ovum hispidum longispinosum* Eisenack, 1931 as the type species of the new genus, and he considered that *Micrhystridium* included the vesicles under 20 microns in diameter and *Baltisphaeridium* contained larger vesicles of similar type.

Staplin (1961) expressed his dislike of the genus *Baltisphaeridium*. He suggested the type species of *Baltisphaeridium* was morphologically similar to *Micrhystridium*. The size limit of 20 microns was removed. *Baltisphaeridium longispinosum* was considered as a species of *Micrhystridium* emend.

Downie and Sarjeant (1963) emended the genus *Baltisphaeridium* Eisenack 1958. They maintained more than 20 micron diameter of vesicles was important, and "the processes are not connected together distally" and the vesicles have no outer shell.

Staplin, Jansonius and Pocock (1965) restricted the genus *Baltisphaeridium*. Their emendation was based on examination of material presumed to be *Baltisphaeridium longispinosum*, and the emended genus is characterized by the the structural difference between spine and vesicle walls and no communication exists between the process hollow and the vesicle cavity; *Micrhystridium* lacks differentiation between the spines and the vesicle wall, and the communication exists. However, Eisenack (1969) did not accept this restriction and he considered that no differentiation existed between the process and vesicle wall in *Baltisphaeridium longispinosum*.

Currently Downie and Sarjeant's emendation (1963) has been accepted (Volkova, 1969; Lister, 1970), but in Downie's recent paper (1982), he maintained Eisenack's original description and gave no comment. In this paper I attempted to describe those specimens of relatively small size, processes with widened bases and probably open freely into the vesicle cavity as the species of *Micrhystridium*; and the vesicles are relatively large, processes have no obviously widened bases and probably are not open freely into the vesicle cavity as the species of *Baltisphaeridium*; 20 micron size limit is removed.

Baltisphaeridium cerinum Volkova, 1968
(Pl.XXXIV, figs.K-P)

Baltisphaeridium cerinum sp. nov., Volkova, 1968, p.17-18, pl.I, figs.1-7; pl.XI, fig.5.

Elektoriskos cerinus (Volkova), Vanguestaine, 1978.

Baltisphaeridium cerinum Volkova, Volkova et al., 1979, pl.I, figs.4-10.

Baltisphaeridium cerinum Volkova, Downie, 1982, p.259-260, fig.5, figs.6, e-g.

Baltisphaeridium cerinum (?) Volkova, in Sokolov and Ivanovskii, 1985, p.151-152, pl.LXV, fig.4.

Baltisphaeridium cerinum Volkova, Knoll and Swett, 1987, p.915, Fig.7.2, 7.3.

Material. More than fifteen specimens.

Description. Vesicles circular to subcircular, originally spheroidal; surface psilate to fine granular; wall folded or split; processes thin, moderate long, relatively dense, tapering to points and no obviously widened at the bases; no excystment structures observed.

Dimensions. Vesicle diameters are 23-43*u*m, process length is 2-6*u*m and number 24-40 seen at outline. Previous measurements: vesicle diameter 23-38*u*m and process length 2-5*u*m (Volkova, 1968); vesicle diameter 25-36*u*m, process length 8-17% of vesicle diameter and number 35-48 seen at outline (Downie, 1982); vesicle diameter 19-33*u*m and process length 3-5*u*m (Knoll and Swett, 1987).

Remarks. Downie (1982) suggested the processes of *B. cerinum* were closed at the tips, sealed off at the bases, and the shaft was hollow; he rejected the transfer of the species to *Elektoriskos* by Vanguestaine (1978).

Distribution. Found in the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation, eastern Yunnan. Previously recorded from Lower Cambrian, Lükati Horizon (Leningrad, Estonia, Latvia, Ukraine and Poland), Vergale Horizon (Ukraine), Hardeberga Sandstone (Sweden), Holmia Shales (Norway), Green Shales (Bornholm), Upper Devillian (Belgium), Fucoid Beds (Scotland), Bastion Formation (Greenland), and Holmia Shales (Norway) (Volkova, 1968; Volkova et al., 1979; Downie, 1982).

Stratigraphic range. Lower Cambrian.

Baltisphaeridium? *dubium* Volkova, 1968

(Pl.XXXV, fig.G,L)

Baltisphaeridium dubium sp. nov., Volkova, 1968, p.18, pl.I, figs.8-9, pl.XI, fig.6.

Baltisphaeridium dubium Volkova, Volkova et al., 1979, pl.V, figs.3-4.

Material. Three specimens.

Description. Vesicles circular, originally spheroidal; surface smooth or psilate; wall commonly folded; processes dense, short conical-like, tapering to point and widened at the base; probably open freely into the vesicle cavity; no excystment structures observed; specimens brown.

Dimensions. Vesicle diameters are 25-37*um*, process length 1-2*um* and number 25-50 visible at outline. Previous measurement: vesicle diameter 30-65*um* (Volkova, 1968).

Remarks. Dense, conical spines are probably open freely into the vesicle cavity and the feature suggests the species is questionable to be described in *Baltisphaeridium.*

Morphologically *B. acerosum* Jankauskas et Posti, 1976 is similar to *B. dubium* Volkova, and both bearing conical short spines.

Distribution. Found in the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation in eastern Yunnan. Previously recorded from Lower Cambrian Talsy Horizon (Liningrad, Estonia, Latvia, Poland), and Vergale Horizon (Latvia, Ukraine) (Volkova et al., 1979).

Stratigraphic range. Lower Cambrian.

Baltisphaeridium latviense Volkova, 1974
(Pl.XXXV, figs.A-F, K)

Baltisphaeridium latviense sp. nov. Volkova, 1974, p.196, pl.XXVII, figs. 8-9.

Baltisphaeridium latviense Volkova, Volkova et al., 1979, pl.IX, figs.26-27.

Material. More than ten specimens.

Description. Vesicles circular to subcircular, originally spheroidal; surface smooth to fine-granular; wall folded or split; no convincing opening observed; processes sparse, short, obtuse or sharp at the apices and slightly widened at the bases; specimens yellow to brown.

Dimensions. Vesicle diameters are 30-39*u*m, process length 1-2*u*m and number 14-31 seen at outline.

Remarks. Present species differs *Baltisphaeridium*? *dubium* Volkova in its sparse, relatively long processes, the processes possibly are not open into the vesicle cavity.

Distribution. Found in the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation from eastern Yunnan. Previously recorded from Middle Cambrian, Kibartu Horizon (Latvia) (Volkova et al., 1979).

Stratigraphic range. Cambrian.

Baltisphaeridium sp.
(Pl.XXXIV, figs.G-J)

Material. Seven specimens.

Description. Vesicles circular to subcircular; surface psilate to fine-granular; wall commonly folded; processes relatively dense, short, sharp or obtuse at points and widened at the bases; no excystment structures observed; specimens brown.

Dimensions. Vesicle diameters are 27-35*u*m, process length 2-3*u*m and number 32-39 seen at outline.

Remarks. Present specimens have the processes with widened bases which possibly suggest they are open freely into the vesicle cavity. The specimens are more or less intergrade with some specimens of *Micrhystridium*.

Distribution. Found in the sample 85Y119 from the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation at the Qiongzhusi section near Kunming City, Yunnan.

Genus *Comasphaeridium* Staplin, Jansonius and Pocock, 1965

Type species. *Comasphaeridium cometes* (Valensi) Staplin, Jansonius et Pocock, 1965.

Comasphaeridium strigosum (Jankauskas) Downie, 1982
(Pl.XXXVI, figs.A-E)

Baltisphaeridium sp.2, Volkova, 1969, p.226, pl.XLIX, fig.21; pl.11, fig.38.

Baltisphaeridium ? strigosum sp.nov., Jankauskas; Jankauskas and Posti, 1976, pp.146-147, pl.1:14.

Baltisphaeridium? strigosum Jankauskas, 1976; Volkova et al., 1979, pl.X, fig.16-18.

Baltisphaeridium? strigosum Jankauskas, 1976; Vidal, 1979, p.18, pl.1a.

Comasphaeridium strigosum (Jankauskas) comb. nov., Downie, 1982, fig.6, p.260.

Baltisphaeridium? strigosum Jankauskas, 1976; in Sokolov and Ivanovskii, 1985, pp.152-153, pl.LXIII, figs.7-9, pl.LXIV, figs.1-3.

Comasphaeridium strigosum Jankauskas, Knoll and Swett, 1987, p.916, Fig.7.5.

Material. More than thirty specimens.

Description. Vesicles circular to subcircular, originally spheroidal; processes densely crowed, simple, thin, solid, more or less flexible hair-like spines; wall sometimes folded; margin of vesicle commonly thickened to form a ring-like texture; occasionally a darker spot in the vesicles; no opening observed; specimens commonly brown.

Dimensions. Specimens are 20-35*um* in diameter, hair-like spines are 4-8*um* long and

100-200 seen at outline. Previous measurements: vesicle 30*um* in diameter (Jankauskas, 1976); vesicle diameter 16-32*um*, process length 14-15% of vesicle diameter, and about 100 seen at periphery (Downie, 1982).

Remarks. This species is characterized by its dense, thin, solid, hair-like spines.

Comasphaeridium cometes (Valensi) has some heteromorphic thickened processes besides the hair-like spines (cf. Staplin et al., 1965, Text-fig.5).

Distribution. Found in the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation from eastern Yunnan. Previously recorded from Lower Cambrian: Lükati Horizon (Latvia, Poland), Vergale Horizon (Latvia, Lithuania, Poland), Rausve Horizon (Estonia, Latvia, Lithuania, Poland), Ella Island Formation (Greenland), Brantevik Sandstone (Sweden), Hardeberga Sandstone (Sweden), Holmia A and B (Norway); Middle Cambrian: Kibartai Horizon (Latvia, Lithuania, Poland); Lower Cambrian Fucoid Beds (Scotland), Bastion Formation (Greenland) and Holmia Beds (Norway) (Jankauskas, 1976; Volkova et al., 1979; Downie, 1982)

Stratigraphic range. Cambrian.

Genus *Dictyotidium* Eisenack 1955

Type species. *Dictyotidium dictyotum* (Eisenack) Eisenack, 1955

Dictyotidium cf. *birvetense* Paskeviciene, 1979

(Pl.XXXVIII, fig.J)

Dictyotidium cf. *birvetense* Paskeviciene 1979, Downie, 1982, p.265, fig.10:a-b.

Description. Two badly-preserved specimens resemble *D. birvetense*. Vesicles subcircular; surface fine-granular and ornamented with polygonal reticulate, ridges low, Vesicle diameters are 34*um* and 38*um*; reticulate field 7-10*um* across.

Dictyotidium? sp.
(Pl.XXV, figs.G-J, L-N)

Material. Eight specimens.

Description. Vesicles vase-shaped; surface ornamented with irregular meshwork; ridges low; one end slightly constricted and prolonged to form a "neck" and the "neck'" truncated at the top, probably open distally; other end rounded; specimens brown in colour.

Dimensions. Vesicle length is 28-52*u*m; "neck" length 4-8*u*m, wide 8-14*u*m; meshwork field 1.5-6*u*m across.

Remarks. Present specimens are vase-shaped, resembling *Melanocyrillium*, but their surface is ornamented with meshwork. They are tentatively described in *Dictyotidium*.

Distribution. Found in the Sinian Nantuo Formation at the Wangfenggang section near Liantuo, Yichang, Hubei Province.

Genus *Favososphaeridium* Timofeev, (1956, 1959) 1966

Type species. *Favososphaeridium scandicum* Timofeev, 1966

Favososphaeridium sp.
(Pl.XXV, figs.B-F)

Material. Ten specimens.

Description. Vesicles circular or subcircular; surface ornamented with irregular honeycomb-like meshwork; meshwork irregular square to irregular circular, more or less deformed; a circular opening sometimes observed; specimens brown to dark.

Dimensions. Vesicle diameters are 32-45*u*m, and opening diameter 12-16*u*m.

Remarks. The unnamed species of *Favososphaeridium* is characterized by a large circular opening and the irregular surface meshwork. The vesicles are more or less diagenetically deformed. *F. favosum* Tim. has a relatively regular, small honeycomb-like meshwork on surface.

Distribution. Found in the Sinian Nantuo Formation at the Wangfenggang section near Liantuo, Yichang, Hubei Province.

Genus *Goniosphaeridium* (Eisenack, 1969)

Goniosphaeridium cf. *implicatum* (Fridrichsone) Downie, 1982

(Pl.XXXIV, figs.A-E)

Goniosphaeridium implicatum (Fridrichsone, 1971) comb. nov., Downie, 1982, p.278, fig.10, V-W.

Material. Ten specimens.

Description. Vesicles circular to irregular circular; surface psilate to fine-granular; processes relatively long, blade-like, tapering to points, narrow or slight widened at the bases, and open freely into the vesicle cavity; no opening observed; specimens yellow or brown.

Dimensions. Vesicle diameters are 23-31*u*m, process length 7-16*u*m and number 20-45 seen at periphery.

Remarks. Present specimens are more or less deformed, and they cannot be confidently referred to *G. implicatum* (Fridrichsone, 1971) Downie, 1982.

Distribution. Found in the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation at the Maotianshan Drill Core near Chengjiang County, eastern Yunnan.

Goniosphaeridium sp.
(Pl.XXXIII, figs.A-D, J-K)

Material. Eight specimens.

Description. Vesicles circular to subcircular; surface smooth or fine-granular; wall occasionally folded; processes relatively dense, blade-like, tapering to tips, and widened at the bases; processes open freely into the vesicle cavity; no excystment structures observed; specimens yellow in colour.

Dimensions. Vesicle diameters are 17-36*u*m, process length 7-11*u*m and number 15-29 seen at outline.

Remarks. The uncertain species differs from *G. implicatum* in its relatively short, thick processes and widened bases, and differs from *G. varium* (Volkova) Downie in its relatively dense processes.

Distribution. Found in the sample 85Y055 from the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation at the Maotianshan Drill Core near Chengjiang County, eastern Yunnan.

Genus *Leiomarginata*? Naumova, 1960

Leiomarginata? *simplex* Naumova, 1960
(Pl.XXVI, figs.O-P, T-U)

Remarks. Present specimens circular to irregular circular with thicken ring on the margin (ring width 5-8*u*m), surface shagreen and with a spongy wall. Vesicle diameters are 28-31*u*m.

Five specimens are found in the Sinian Dengying Formation at the Wangjiawan section in eastern Yunnan.

Genus *Liepaina* Jankauskas et Volkova, 1979

Type species. *Liepaina plana* Jankauskas et Volkova, 1979.

Discussion. *Liepaina* was described by its processes joined by webs with an irregularly indented edge (Volkova et al., 1979). The observation of Chinese specimens suggests that the processes are probably communicating freely with the vesicle cavity.

Liepaina chengjiangensis sp. nov.
(Pl.XXXIII, figs.F-I, L-N)

Etymology. Name is derived from the sampling locality, Chengjiang County.

Holotype. Pl.XXXIII, figs.H-I, two focus levels, 85Y055-1 (10.5 x 96), collected from the Lower Cambrian Qiongzhusi Formation at the Maotianshan Drill Core near Chengjiang County, eastern yunnan.

Material. Twenty specimens.

Diagnosis. Vesicles granular surface with dense processes and indented outline; processes having no webs.

Description. Vesicles circular, subcircular or irregular with indented outline; processes dense, blade-shaped, unbranched or with minor branches, tapering to the closed points and widened at the bases; sometimes webs surrounding vesicles, but not covering processes; surface granular; wall occasionally folded; no excystment structures observed; specimens yellow to brown.

Dimensions. Vesicle diameters are 18-31*u*m (holotype 20*u*m), process length 6-14*u*m, and number 16-22 seen at outline.

Remarks. Jankauskas and Volkova (in Volkova et al., 1979) described one species, *Liepaina plana* from the East-European Platform. The species is characterized by its central body circular in outline, flat rod-like processes surrounded by external webs and smooth surface texture. Present species has a central body with indented outline, processes have no surrounding webs and the vesicles have a granular surface texture.

Web structure on central body has been found in several specimens (holotype), but many specimens do not have such structure. No webs have been observed on processes. Using concentrate nitric acid may have destroyed the web structure.

The processes of the new species are more or less similar to *Goniosphaeridium* cf. *implicatum* (Fridrichsone) Downie, 1982; but the central body of *Goniosphaeridium* is circular in outline and obviously no web structure.

Distribution. Found in the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation from the Maotianshan Drill Core near Chengjiang County, eastern yunnan.

Stratigraphic range. Lower Cambrian.

Genus *Lophosphaeridium* (Timofeev, 1959) Downie, 1963

Type species. *Lophosphaeridium rarum* Timofeev, 1959

Lophosphaeridium tuberosum sp. nov.

(Pl.XXVII, figs.G-H; pl.XXXVIII, figs.K-M)

Remarks. Present specimens are small size (16-22*u*m) and the surface is ornamented with relatively big tubercles (1-2.5*u*m across). Wall is occasionally folded; and no opening has been observed.

The specimens are found in the Sinian Dengying Formation and the Lower Cambrian Qiongzhusi Formation in eastern Yunnan.

Genus *Navifusa* Combaz, Lange and Pansart, 1967

Type species. *Navifusa navis* (Eisenack) Combaz, Lange, and Pansart, 1967.

Navifusa crassa (Sin and Liu, 1978) comb.

(Pl.XXVI, fig.Q; pl.XXVII, figs.A-F; pl.XL, figs.H-I)

Leiofusa crassa Sin and Liu sp. nov., Sin and Liu, 1978, pl.6, figs.16, 17; p.119.

Leiofusa aff. *digitata* Sin, Sin and Liu, 1978, pl.6, figs.14, 15; p.119.

Material. More than fifty specimens.

Description. Vesicles ellipsoidal or elongate of rodlike form with rounded ends; surface smooth or psilate; wall spongy; rob straight or slight bent, and commonly wider at the centre and slightly constricted at the ends; some specimens having an opening at the apix; specimens yellow to brown.

Dimensions. Specimens are 30-61*um* long and 12-22*um* wide (holotype 52x19*um*). The ratio of length to width ranges 2.5:1 to 5.5:1. The measurements for *Leiofusa crassa*: 50-120*um* long and 15-25*um* wide; for *Leiofusa* aff. *digitata*: 50-60*um* long and 12-23*um* wide (Xing Yusheng and Liu, 1978).

Remarks. The specimens are characterized by its rounded ends, spongy wall and an opening at one end. *Navifusa bacillum* (Deunff) Playford, 1977 has a granulate or scabrate surface, and *Navifusa multistriata* (Brito) Combaz, Lange, and Pansart, 1967 has a striate surface texture. Commonly *Leiofusa* has sharp terminals or spines at the apices.

Distribution. Widely distributed on the South China Platform, including the Sinian Doushantuo Formation, and Dengying Formation, and the Lower Cambrian Qiongzhusi Formation.

Stratigraphic range. Sinian to Cambrian.

Genus *Ooidium* Timofeev, 1957

Type species. *Ooidium rossicum* Timofeev, 1957; fixed by subsequent designation by Norris and Sarjeant, 1965, p.45, (cf. Loeblich, 1969).

Ooidium Qiongzhusiense sp. nov.
(Pl.XXXVI, figs.F-M)

Etymology. Name is derived from the Lower Cambrian Qiongzhusi Formation.

Holotype. Pl.XXXVI, fig.I, 85Y043-1 (13.2 x 100.7), collected from the Lower Cambrian Qiongzhusi Formation at the Maotianshan Drill Core near Chengjiang County, eastern Yunnan. The others (figs.F-H, J-M) are paratypes.

Material. More than thirty specimens.

Description. Vesicles ovate, circular or subcircular; wall thin, commonly folded, occasionally split; surface granular; vesicle with one pole ornamented with trabeculae; trabeculae separated, obtuse at the tips and slightly widened at the bases, and circularly crowned on surface; generally vesicle constricted in crowned area to form a short "neck"; occasionally vesicle bearing a darker centre spot; colonies binary, two vesicles equivalent size or not, connecting with trabecular poles; specimens commonly yellow brown.

Dimensions. Specimens are 28-50*u*m in diameter (high:wide = 1:1 to 1.2:1); holotype: high = 44*u*m, wide = 41*u*m; crowned area is 16 - 30*u*m across; trabeculae are 3-5*u*m high and 2-4*u*m wide; binary colony is up to 80*u*m long.

Remarks. Loeblish (1969) considered *Zonooidium* was congeneric to *Ooidium* and he described *Ooidium rossicum* Timofeev and erected a new species *Ooidium timofeevii*. *Ooidium rossicum* is ornamented with "upper half of the body with elevated discontinuous ridges" and trabeculae anastomosed to form small arches. The present species has simple surface texture and its trabeculae are separated. *Ooidium timofeevii* has a slightly thicker wall and very faint striae in the upper half of the body.

Binary colonies may be one o the reproductive forms. Possibly the trabecular area functionally germinates.

Distribution. Found in the Lower Cambrian Yu'anshan Member, (Qiongzhusi Formation) from eastern Yunnan.

Stratigraphic range. Early Cambrian.

Genus *Protoleiosphaeridium* (Timofeev, 1959) Timofeev, 1960

Type species. *Protoleiosphaeridium conglutinatum* (Tim.) Timofeev, 1960

Protoleiosphaeridium papyraceum (Timofeev, 1966), comb.

(Pl.XXXVIII, figs.F-G)

Protosphaeridium papyraceum sp. nov., Timofeev, 1966, p.20, pl.IV, fig.3.

Protosphaeridium papyraceum Tim., Timofeev, 1969, p.7, pl.1, fig.2.

Protosphaeridium papyraceum Tim., Vidal, 1976, p.26-27, pl.13:D-E.

Material. Five specimens.

Description. Vesicles circular to subcircular, originally spheroidal; surface smooth to fine-granular; wall commonly folded or split; wrinkles concentric arrangement and 3-5 rings seen on the surface; occasionally an opening observed; specimens yellow to brown.

Dimensions. Vesicles are 20-31*u*m in diameter. Previous measurements: 35-60*u*m (Timofeev, 1966), 35 - 70*u*m (Timofeev, 1969), 46-68*u*m in diameter (Vidal, 1976).

Remarks. *Protoleiosphaeridium papyraceum* is characterized by its remarkably concentric wrinkles.

Distribution. Found in the sample 85Y055 from the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation at the Maotianshan Drill Core near Chengjiang County, Yunnan. Previously recorded from the Upper Proterozoic Avzyan and Katav Beds (Urals), Serebryanka Beds (Priargun), Tsipanda Beds (Yakut), Memchan Beds (River

Isakovka); Priozersk Beds (Ladoga); Middle Cambrian Oland (southwestern Sweden); a well at Adze (Latvia), Sventok Mountains (Yugoshuv), Upper Cambrian borehole at Tosterup (southern Sweden), and Visingsö Beds (Sweden) (Timofeev, 1966, 1969; Vidal, 1976). Some specimens have been observed from the Bitter Springs Formation in the Amadeus Basin, central Australia.

Stratigraphic range. Late Proterozoic to Cambrian.

Genus *Pyritosphaera* Love, 1957

Type species. *Pyritosphaera barbaria* Love, 1957

Pyritosphaera barbaria Love, 1957

(Pl.XXVI, figs.I-K, N; pl.XXXIX, figs.A-R; pl.XL, figs.A-G;
pl.XLI, fig.L)

Remarks. *Pyritosphaera barbaria* Love widely occurs in the Upper Proterozoic to Cambrian rocks on the South China Platform, particularly abundant in the Lower Cambrian Qiongzhusi Formation. Their spheroidal aggregates of numerous tightly packed cells vary in forms, cells 1-8*um* in diameter, aggregates 10-60*um* in diameter and aggregates sometimes combine to form colonies. Some spheroids obviously have an external wall.

Moorman (1974) has studied the life-cycle of *Pyritosphaera barbaria.* Many forms have been found in present material, 2, 4, 8, 16, 32 or more. It is noted that in the colonies some small spheroids have been observed (pl.XXXIX, figs.C, H, I). Few linear arrangement of colonies have been found. More than one thousand specimens have been observed, only a few have a circular opening (pl.XXXIX, fig.P) and some specimens have a deformed slit.

Genus *Sinianella* (Yin L., 1980) emend.

Type species. *Sinianella uniplicata* (Yin L., 1980) emend.

Sinianella scabrata sp. nov.
(Pl.XXXVIII, fig.O; pl.XLI, figs.B-C)

Remarks. Present specimens are subcircular to oval at outline, with a single prominent process drawn out from the vesicle. Surface texture is granular or verruculose. No colonies observed. Vesicle diameters are 35-55*u*m.

The specimens are found in the Lower Cambrian Qiongzhusi and Shipai Formations on the South China Platform.

Sinianella sp.
(Pl.XXV, figs.O-P)

Remarks. Five specimens found in the Sinian Nantuo Formation. Vesicles subcircular to elongate; surface spongy and porous; one end with a truncated process and the other end rounded; no colonies observed. Specimens are 75-85*u*m in diameter.

Present specimens differ from *S. uniplicata* (Yin L.) and *S. scabrata* in their spongy surface texture.

Genus *Skiagia* Downie, 1982

Type species. *Skiagia scottica* Downie, 1982

Discussion. Genus *Skiagia* was erected by Downie (1982) for its processes which are hollow and widened distal to form essentially funnel-shaped terminations. The genus included several species transferred from *Baltisphaeridium* and *Hystrichosphaeridium*? (Volkova, 1968; Fridrichsone, 1971).

Downie differed the species by plug structure and process forms, but he did not described clearly. For instance he considered *Skiagia compressa* (Volkova) having a plug at the base of the cone and presented four photographs in the paper (Downie, 1982, Fig.7: r, s, t, u), but he also named Fig.7:s as *Skiagia ornata* (Volkova) (Fig.8:h), and Fig.7:u as *Skiagia orbiculare* (Volkova) (Fig.8:d). For the later two species he considered to have questionable plug structures (Fig.5). In Volkova's holotype (Volkova, 1968) it is also difficult to find a plug structure. Therefore plug structures may have its theoretical significance in identification, but not in observation. In my observation some specimens display part of the processes possibly having a plug structure and others probably communicating with the vesicle cavity. On the other hand, without thin section through the processes it is very hard to observed the structure confidently.

Process forms may vary in life cycle of *Skiagia*. In the Qiongzhusi Formation many colonies and small specimens have been observed. The cells in groups are tightly packed and the groups are enclosed by an external wall. The individuals with small size generally have thin, short processes with a slightly thickened tips; with increasing vesicle size, the processes become longer, stronger and are shaped in form of funnel terminations. The number of processes and the process length percent of the vesicle diameter may vary in the cycle.

Skiagia brevispinosa is characterized by its short slender processes that flare only slightly at the tips and its diagnosis seems to be in the range of *S. ciliosa* (Volkova). The differences among *Skiagia* are summarized as follows (Text-figure III-16).

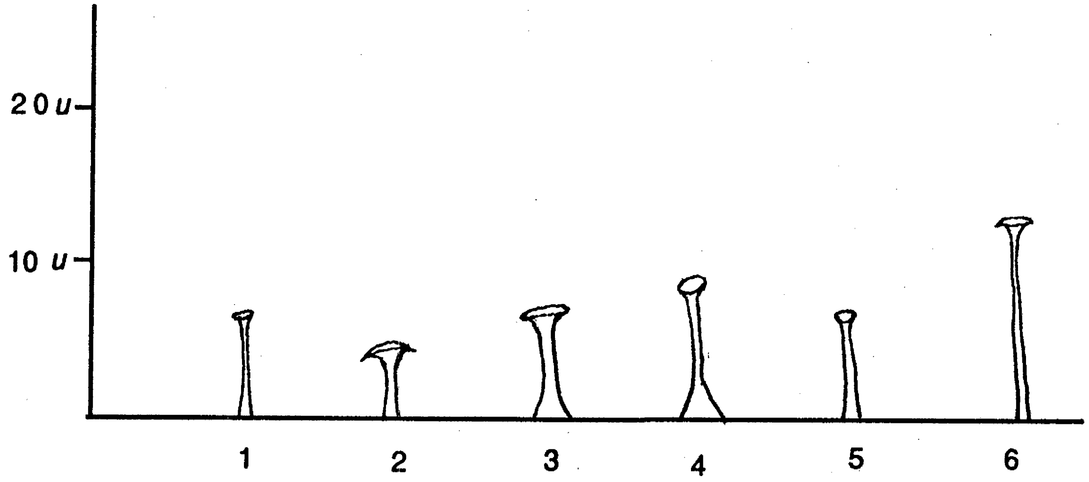
S. ciliosa: slender or thin processes, thickened or slightly funnel-shaped tips. (including *S brevispinosa* Downie , 1982).

S. compressa: obviously widened bases.

S. cf. *insigne*: wide distal funnel, relatively widened bases, and more processes at outline (compared to *S. insigne*).

S. orbiculare: relatively short, thickened processes (1/4 to 1/3 of of vesicle diameter).

S. ornata: very long, sinuous processes (process length 1/3 - 2/3 of vesicle diameter).



1. *Skiagia ciliosa.*
2. *Skiagia scottica.*
3. *Skiagia* cf.*insigne*
4. *Skiagia compressa*
5. *Skiagia orbiculare*
6. *Skiagia ornata*

Text-fig. III-16. Processes of *Skiagia,* lateral view.

S. scottica: processes dense, occasional distal branching and linkages.

The identification mentioned above is empirical. Observation suggests many specimens are transitional.

Skiagia ciliosa (Volkova, 1969) Downie, 1982
(pl.XXVIII, figs.C-H)

Baltisphaeridium ciliosum Volkova sp. nov., Volkova, 1969 pl.L, figs. 1-3; pl.LI, figs.11-12.

Baltisphaeridium ciliosum Volkova, Fridrichsone, 1971, pl.I, figs.9-10.

Baltisphaeridium ciliosum Volkova, Volkova et al., 1979, pl.II, figs.1-5.

Skiagia ciliosa (Volkova, 1969) comb. nov., Downie, 1982, fig.5, 7. p-q. p.263.

Skiagia brevispinosa sp. nov., Downie, 1982, fig.7, m-o. p.263.

Skiagia ornata (Volkova, 1968) comb. nov., Downie, 1982, fig.8, j.

Baltisphaeridium ciliosum Volkova, in Sokolov and Ivanovskii, 1985, p.152, pl.LXV, figs.2,3.

Skiagia ciliosa (Volkova) Downie, 1982, Moczydlowska et Vidal, 1986, type A: fig.13, A-B; type B: fig.13, C-F.

Skiagia ciliosa (Volkova), Knoll and Swett, 1987, p.921, Fig.9.3, 9.6-9.8, 9.11, 9.14, 9.15, 10.2, 10.4, 10.7.

Material. More than fifty specimens.

Description. Circular or sub-circular vesicles with processes slightly funnel-shaped at the tips; surface smooth or fine granular; wall usually folded or split; processes slender or thin, length generally less than 1/2 of vesicle diameter, and base slightly widened; specimens yellow or brown in colour.

Dimension. Vesicles are 25-45*um* in diameter, the processes 4-8*um* long and 20-80 observed at outline. Previous dimensions: vesicle diameter 30-49*um* for *B. ciliosum* (Volkova, 1969); vesicle diameter 24-50*um*, processes length 2-8*um* for *B. ciliosum* (Fridrichsone, 1971); vesicle diameter 38-41, process length 15-18% of diameter; number seen at outline about 40 for *S. ciliosa* (Volkova) and vesicle diameter 24-33*u*, process length 9-14% of diameter, number seen at outline 45-85 for *S. brevispinosa* (Downie, 1982); vesicle diameter 20-43*um*, process length 3-9*um* and number visible around vesicle 30-50 (Knoll and Swett, 1987).

Remarks. *S. ciliosa* (Volkova) differs from other species of *Skiagia* by its slender processes with slightly thickened funnel-shaped tips.

Downie (1982) erected new species *S. brevispinosa* with diagnosis of short, slender processes that flare only slightly at the tips. The features have no significant difference from *S. ciliosa* (Volkova).

Volkova (1969) considered that the wall of vesicles was differentiated with the processes because vesicles were darker and the processes were lighter and translucent. She suggested a translucent cover surrounded the darker inner body. In my observation no such surrounding cover has been found and different colours between vesicles and processes, most likely, are diagenetical.

Distribution. Found from the lower Cambrian Qiongzhusi Formation at the Maotianshan Drill Core and Qiongzhusi section in eastern Yunnan; Previously recorded from Lower Cambrian: Vergale Horizon (Latvia, Lithuania, Ukraine), Rausve Horizon (Estonia, Latvia, Lithuania, Ukraine, Poland), Hells Mouth Grit (Wales), Purley Shales (England), Rispebjerg Sandstone, (Sweden), Mickwitzia Sandstone (Sweden), Lingulid Sandstone (Sweden), *Holmia* B (Norway); Middle Cambrian: Kibartai Horizon (Latvia, Lithuania, Poland), Lower Cared Mudstones (Wales) (Volkova, 1969, Volkova et al., 1979); Bastion Formation (Greenland), Fucoid Beds (Scotland), Gog Formation (Alberta), Holmia shales (Norway) (Downie, 1982); *Holmia* Zone at Tomten (southern Norway), and Lingulid Sandstone (Vastergotland) (Moczydlowska and Vidal, 1986); and Tokammane Formation (Spitsbergen) (Knoll and Swett, 1987).

Stratigraphic range. Cambrian.

Skiagia compressa (Volkova, 1968) Downie, 1982
(Plate XXIX, figs.A-L)

Baltisphaeridium compressum Volkova, sp. nov., Volkova, 1968, pl.II, fig.6?, 7-9; pl.XI, fig.2?.

Baltisphaeridium compressum Volkova, Volkova, 1969, pl.XLIX, fig.17-19.

Baltisphaeridium compressum Volkova, Fridrichsone, 1971, pl.I, fig.8, p.9.

Baltisphaeridium compressum Volkova, Volkova et al., 1979, pl.II, figs.7-10, 6?.

Baltisphaeridium compressum Volkova, Vidal, 1979, p.17, pl.1b,d,f.

Skiagia compressa (Volkova, 1968) comb. nov., Downie, 1982, fig.7, r-t. p.263.

Skiagia orbiculare (Volkova, 1968) comb. nov., Downie, 1982, fig.8, d.

Skiagia ornata (Volkova, 1968) comb. nov., Downie, 1982, fig.8 h-i.

Skiagia compressa (Volkova) Downie, Moczydlowska et Vidal, 1986, fig.9, c-F.

Skiagia compressa (Volkova) Downie, Knoll and Swett, 1987, p.921, Fig. 9.4, 9.5, 9.10.

Material: more than one hundred specimens.

Description. Circular to sub-circular vesicles with funnel-shaped processes obviously widened at the base; surface smooth or fine granular; wall sometimes folded; processes slender, occasionally branched, and length 1/4 to 1/2 of vesicle diameter; some processes with a constriction at the widened base; specimens yellow or brown in colour.

Dimension. Vesicles are 25-40*u*m in diameter, process length 5-13*u*m and number 21-55 observed at outline. Previously dimensions: vesicle diameter 23-36*u*m and process length 9-18*u*m (Volkova, 1968); vesicle diameter 23-40*u*m (Volkova, 1969); vesicle diameter 20-39*u*m and process length 8-14*u*m (Fridrichsone, 1971); vesicle diameter 24-38*u*m, process length 29-32% of diameter and number observed 30-60 at outline (Downie, 1982); vesicle diameter 25-42*u*m, process length 5-13*u*m and number seen at outline about 40 (Knoll and Swett, 1987).

Remarks. *S. compressa* (Volkova) differs from other species with similar morphology in its obviously widened process bases. Volkova (1969) emphasized a constriction at the point of transition of widened base and Downie (1982) illustrated a plug for the joint. In my observation, some processes have a constriction at the base, but others do not have, even two forms can be observed on one vesicle. The constriction of the processes perhaps is not a characteristic feature for this species.

Distribution. Recorded from the Lower Cambrian Qiongzhusi Formation, eastern Yunnan; Previously recorded from Lower Cambrian: Lükati Horizon (Leningrad, Estonia, Latvia, Ukraine, Poland), Vergale Horizon (Latvia, Ukraine, Poland), Rausve Horizon (Latvia, Lithuania, Ukraine, Poland), Ella Island Formation, Lower Limestones (Greenland), Mickwitzia Sandstone (Sweden), Lingulid Sandstone (Sweden), *Holmia* A and B (Norway), Upper Devillian (Belgium) (Volkova, 1968, 1969, 1979; Fridrichsone, 1971), Fucoid Beds (Scotland), Bastion Formation (Greenland), and Holmia Shale (Norway), Tokammane Formation (Spitsbergen) (Downie, 1982; Moczydlowska & Vidal, 1986; Knoll and Swett, 1987).

Stratigraphic range. Lower Cambrian.

Skiagia cf. *insigne* (Fridrichsone, 1971) Downie, 1982

(Plate XXIX, figs.A-B)

Skiagia cf. *insigne* (Fridrichsone, 1971) comb. nov., Downie, 1982, fig.5, fig.8, a-c, p.264.

Material. Two specimens.

Description. Vesicle circular to subcircular; processes with wide distal funnels; surface smooth to fine granular; wall commonly folded or split; processes relatively thick, with an approximately equivalent length, and base slightly widened; no confident plug structures observed; specimens yellow to brown in colour.

Dimensions. Vesicle diameters are 26-28*u*m, process length 6-7*u*m and 27-30 processes observed at outline. Previous specimens had 15-25 processes at outline (Downie, 1982).

Remarks. The confer species is characterized by its broad shafts with wide distal funnels and relatively equivalent length of processes. The Processes are slightly widened at the bases, some display a constriction but no confidence to suggest a plug structure. *S. insigne* (Fridrichsone) bears very broad, short and sparse processes (process number less than 10).

Distribution. Recorded from the Qiongzhusi Formation, eastern Yunnan. Previously recorded from the Fucoid Beds, Scotland (Downie, 1982).

Stratigraphic range. Cambrian.

Skiagia orbiculare (Volkova, 1968) Downie, 1982

(Plate XXX, figs.A-G)

Baltisphaeridium orbiculare Volkova, sp. nov., Volkova, 1969, pl.II, figs.1-5; pl.XI, fig.3; p.19.

Baltisphaeridium orbiculare Volkova, Fridrichsone, 1971, pl.I, figs.1-2?, p.7-8.

Baltisphaeridium orbiculare Volkova, Volkova et al., 1979, pl.I, figs.1-2, 3?.

Baltisphaeridium aff. ***ornatum*** Volkova, Volkova et al., 1979, pl.IV, fig.8.

Baltisphaeridium orbiculare Volkova, Vidal, 1979, pp.17-18, pl.1c,e.

Skiagia orbiculare (Volkova, 1968) comb. nov., Downie, 1982, fig.8, e-f. p.264.

Skiagia orbiculare (Volkova, 1968) Downie, Knoll and Swett, 1987, p.921, Fig.10.6, 10.8.

Material. More than sixty specimens.

Description. Vesicles circular to irregularly circular with relatively short and thickened processes; surface smooth to fine granular; wall usually folded or split; process length 1/4 to 1/3 of vesicle diameter, slightly widened at the bases and moderately funnel-shaped at the tips; specimens yellow to brown in colour.

Dimensions. Vesicle diameters are 22-35*u*m, process length 2-9*u*m and number seen at outline 32-60. Previous dimensions: vesicle diameter 22-34*u*m, and process length 6-11*u*m (Volkova, 1968); vesicle diameter 22-37*u*m and process length 5-13*u*m (Fridrichsone, 1971); vesicle diameter 25-40*u*m, process length 25-38% of diameter and number seen at outline 30-48 (Downie, 1982); vesicle diameter 25-35*u*m, process length 4-8*u*m and number seen at outline about 25 (Knoll and Swett, 1987).

Remarks. Volkova (1968) described *Baltisphaeridium orbiculare* and *B. ornatum* from the Russian specimens, but photographs display few differences except the length of the processes. Downie (1982) suggested the two species possibly communicate with the vesicle cavity, and the vesicles with long slender processes referring to *S. ornata* and relatively short, thickened processes to *S. orbiculare*; *S. compressa* (Volkova) differs from the two species in its widened process bases.

In this identification *S. orbiculare* (Volkova) bears the processes with length of 1/4 to 1/3 of the vesicle diameter, relatively short and not bent; *S. ornata* Volkova) with process length of 1/3-2/3 of the vesicle diameter, relatively long and commonly bent. The transitional specimens exist.

Some specimens reported from the Meishucun section in Jinning, Yunnan were named to *Baltisphaeridium* (Xing Yusheng, in Luo Huilin et al.,1984) and possibly referred to this species.

Distribution. Found in the Lower Cambrian Qiongzhusi Formation, eastern Yunnan; previously recorded from Lower Cambrian: Lükati Horizon (Estonia, Latvia, Ukraine), Vergale Horizon (Ukraine), Rausve Horizon (UKraine), Ella Island Formation

(Greenland), Norretorp Sandstone (Sweden), Mickwitzia Sandstone (Sweden), Lingulid Sandstone (Sweden), Holmia Norway), ?Bray Group (Eire), Lower Cambrian (Northern Siberia) (Volkova, 1968; Fridrichsone, 1971; Volkova et al. 1979); Fucoid Beds (Scotland), Bastion Formation (Greenland), and Holmia shales (Norway) (Downie, 1982); Tokammane Formation (Spitsbergen) (Knoll and Swett, 1987).

Stratigraphic range. Lower Cambrian.

Skiagia ornata (Volkova, 1968) Downie, 1982
(Plate XXX, figs.H-O; plate XXI, figs.A-L)

Baltisphaeridium ornatum Volkova, sp. nov., Volkova, 1968, pl.I, figs.10-14; pl.XI, fig.1.

Baltisphaeridium cf. *ornatum* Volkova, Fridrichsone, 1971, pl.I, fig.7?.

Baltisphaeridium ornatum Volkova, 1968, Volkova et al., 1979, pl.IV; figs.9-11.

Skiagia ornata (Volkova, 1968) comb. nov., Downie, 1982, fig.5, p.264.

Skiagia orbiculare (Volkova, 1968) comb. nov., Downie, 1982, fig.8, g.

Skiagia ornata (Volkova, 1968) Downie, 1982, Moczydlowska et Vidal, 1982, fig.11, C-D.

Skiagia ornata (Volkova, 1968) Downie, Knoll and Swett, 1987, p.922, Fig.10.1, 10.3, 10.5.

Material. More than four hundred specimens.

Description. Vesicles circular to subcircular with very long funnel-shaped processes; surface smooth to granular; wall folded or split; processes very long, 1/3 to 2/3 of vesicle diameter, slender, straight, bent or sinuous, slightly widened at the bases and with a moderately funnel-shaped at the tips; no process linkages observed distally; specimens yellow to brown in colour.

Dimensions. Vesicle diameters are 21-45*u*m, process length 8-18*u*m, processes seen at outline 32-85. Previous dimensions: vesicle diameter 27-40*u*m and process length 16-22*u*m (Volkova, 1968); vesicle diameter 28-29*u*m, process length 32-43% of diameter, number seen at outline 32-54 (Downie, 1982); vesicle diameter 20-40*u*m, process length 7-19*u*m and number seen at outline 45-65 (Knoll and Swett, 1987).

Remarks. This species is abundant in the Qiongzhusi Formation, and characterized by very long processes. Some specimens are dense arrangement of processes, but no distal linkages have been observed, which differs it from *S. scottica.*

Distribution. Recorded from the Lower Cambrian Qiongzhusi Formation, eastern Yunnan. Previously recorded from Lower Cambrian: Lükati Horizon (Estonia, Latvia, Ukraine), Vergale Horizon (Ukraine), Rausve Horizon (Ukraine), Norretorp Sandstone (Sweden), Mickwitzia Sandstone (Sweden) (Volkova, 1968; Volkova et al., 1979); Fucoid Beds (Scotland), Gog Formation (Greenland), and Holmia Shales (Norway) (Downie, 1982); Tokammane Formation (Spitsbergen) (Knoll and Swett, 1987).

Stratigraphic range. Cambrian.

Skiagia scottica Downie, 1982
(Plate XXXII, figs.C-J)

Skiagia scottica sp. nov., Downie, 1982, fig.5, fig.8, k-l, fig.9, a-f, p.264.

Skiagia scottica Downie, Knoll and Swett, 1987, p.922, Fig.9.9, 9.12.

Material. More than twenty specimens.

Description. Vesicles circular to subcircular with dense, relatively short processes; surface smooth to granular; wall folded, split or broken; process length 1/6 to 1/4 of vesicle diameter; processes slightly widened at the bases, moderate to wide funnel at the tips, occasionally branching and linkage distally; specimens yellow to brown in colour.

Dimensions. Vesicle diameters are 20-33*u*m, process length 3-7*u*m and number at outline 65-100. Previous dimensions: vesicle diameter 20-35*u*m, process length 13-26% of diameter and number at outline 60-80 (Downie, 1982); vesicle diameter 22-33*u*m, process length 4-7*u*m and number seen at outline 74-90 (Knoll and Swett, 1987).

Remarks. *S. scottica* differs from *S. orbiculare* (Volkova) in its dense processes and the tendency to link up with neighboring processes distally; differs from *S. ornata* (Volkova) in its short, approximately equivalent length of the processes; and differs from *S. ciliosa* (Volkova) in its relatively thick processes and widely distal funnels. *S.* cf. *insigne* has sparse processes.

Distribution. Recorded from the Qiongzhusi Formation in eastern Yunnan. Previously recorded from Fucoid Beds, Scotland; Bastion Formation, Greenland and Holmia Shales, Norway (Downie, 1982); Tokammane Formation (Spitsbergen) (Knoll and Swett, 1987).

Stratigraphic range. Lower Cambrian.

Genus *Trachysphaeridium* Timofeev (1956) 1959

Type species - *Trachysphaeridium attenutum* Timofeev, 1959

Trachysphaeridium laminaritum (Timofeev) Vidal, 1976

(pl. XXVI, fig. H)

Remarks. Vidal (1976) described *Trachysphaeridium laminaritum* (Tim.) as a vesicle with alveolar surface and the alveoli are very shallow, giving a pseudo-reticular appearance. Two specimens from the Nantuo Formation fit this description. Also dozens of specimens with alveoli-like structures (pl.XXXVIII, figs.B-C) are named as a confer species.

Trachysphaeridium levis (Lopukhia, 1971) Vidal, 1974

(pl.XXXVIII, fig.A)

Menneria levis Lopukhin sp. nov. - Lopukhin, 1971a, p.157, figs.1, 2.

Menneria levis - Lopukhin, 1971b, p.85, pl.III, figs.1-3, Pl.IV, figs.1-3.

Trachysphaeridium levis (Lopukhin, 1971) comb. nov., Vidal, 1974, p.8, pl.1, figs.13-14.

Trachysphaeridium levis (Lopukhin) Vidal, 1974, Vidal, 1976, p.3b, fig.20:c.

Pseudozonosphaeridium verrucosa Sin and Liu gen. et sp. nov., Sin Yusheng and Liu, 1973, p.56, pl.2:1, 6, 7.

Trachysphaeridium levis (Lopukhin) Vidal, 1974, Knoll et Calder, 1983, p.494, pl.60, fig.3.

Material. Six specimens.

Description. Vesicles circular to subcircular; surface texture granulate; wall spongy, commonly folded, displaying narrow wrinkles in the margin; specimens yellow to brown.

Dimensions. Vesicle diameters are 30-40*u*m. Previous measurements: vesicle diameters 10-100*u*m for *Menneriz levis* (Lopukhin, 1971, cf. Vidal, 1974), 30-120*u*m (Vidal, 1974), 30-100*u*m (Vidal, 1976) and 56-92*u*m (Knoll et Calder, 1983).

Remarks. *Trachysphaeridium levis* (Lopukhin) is characterized by its densely granulate surface texture and spongy wall.

Distribution. Found in the Lower Cambrian Yu'anshan Member, Qiongzhusi Formation, eastern Yunnan. Previously recorded from the Middle Riphean Kokdzhot Beds (Karatau Mountains), Bakairskaya beds (Talas Mountains), Ashuturukskaya Beds (Terskey Alatau Mountains), Upper Riphean (early Late Proterozoic) Chatkaragayskaya Beds (Talas Mountains), Mureskaya Beds (Mongolia), the Pachelma Beds (Russian Platform), Visingsö Beds (Sweden), Stappogiedde Formation (Norway), Lower Cambrian Ella O Formation (Greenland), and Rysso Formation (Svalbard) (Vidal, 1974, 1976).

Stratigraphic range. Middle Proterozoic to Cambrian.

Trachysphaeridium cf. *laufeldi* Vidal, 1976
(Pl.XXVI, figs.A-E)

Remarks. Vidal (1976) described *Trachysphaeridium laufeldii* as that vesicle surface was tightly covered by very short, conical spines. Present specimens are 30-37*um* in diameter and covered with dense conical short spines, but the spines are relatively larger, sharp at the point and widen at the base. Eleven specimens are found from the Sinian Nantuo Formation at the Wangjiawan section, eastern Yunnan.

Genus *Trematosphaeridium* Timofeev (1956, 1959) 1966

Type species - *Trematosphaeridium holtedahlii* Timofeev, 1966

Trematosphaeridium holtedahlii Timofeev, 1966
(pl.XXVII, fig.K)

Trematosphaeridium holtedahlii sp. nov., Timofeev, 1966, p.28, pl.V, fig.1.

Trematosphaeridium holtedahlii Timofeev, Timofeev, 1969, p.22-23, pl.5, fig.1; pl.9, fig.10.

Trematosphaeridium sp., Timofeev, 1969, pl.21, fig.5.

Trematosphaeridium holtedahlii Timofeev, Timofeev, 1973: p.11, pl21, fig.2.

Costatosphaerina septata sp.nov., Lopukhin, 1966, p.38, pl.1, fig.6.

Trematosphaeridium holtedahlii Timofeev, Vidal, 1976, p.38-40, fig.18:C-E.

Material. Four specimens.

Description. Vesicles circular or subcircular; surface smooth or psilate; wall occasionally folded; vesicle having many large, circular, oval or irregularly shaped openings with random distribution; specimens brown to dark.

Dimensions. Vesicle diameters are 25-30*u*m and opening diameters are 2-5*u*m. Previous measurements: vesicle diameters 25-60*u*m (Timofeev, 1966), 10-70*u*m (Timofeev, 1969), 28-64*u*m and opening diameters 2-10*u*m (Vidal, 1976).

Remarks. The genus was erected by Timofeev (1956) and re-described in 1959, but until 1966 a new species *Trematosphaeridium holtedahlii* was not described as the type species.

The species is characterized by many large openings with random distribution and care is called for some openings are diagenetic.

Distribution and stratigraphic range. Found in the upper Sinian Dengying Formation at the Wangjiawan section, Jinning, Yunnan. The species was widely recorded from the Upper Riphean, Vendian and Lower Cambrian (?) rocks in the Soviet Union and Europe (cf. Vidal, 1976).

Genus *Triangumorpha* Sin et Liu, 1973

Type species. *Triangumorpha striata* Sin et Liu, 1973

Triangumorpha sp.

(pl.XXVI, figs.L-M)

Material. Two specimens.

Description. Vesicles triangular (quadrilateral); angles rounded; surface smooth; wall spongy; no opening observed; specimens yellow-brown in colour.

Dimensions. Side length is 20-23*u*m.

Remarks. Sin (Xing) et Liu (1973) erected the genus and described the new species

Triangumorpha striata, which is triangular or rounded triangular with "ribs" (tunnel) radiating from the centre to margin. Present specimens have no radiating "ribs", but with a spongy wall.

Distribution. Found in the Sinian Doushantuo Formation at the Wangfenggang section near Liantuo, Yichang, Hubei Province.

Genus *Vandalosphaeridium* Vidal, 1981

Type species - *Vandalosphaeridium reticulatum* (Vidal, 1976) Vidal, 1981 (=*Peteinosphaeridium reticulatum* Vidal, 1976)

Vandalosphaeridium varangeri Vidal, 1981

(Pl.XXV, fig.A)

Vandalosphaeridium varangeri sp. nov., Vidal, 1981b, p.38-39, fig.18:A-I.

Material. Three specimens.

Description. Vesicles circular or subcircular; surface smooth or psilate; processes short, not branched, slightly tapering and rounded at the top and widen at the bases; a thin, external lighter transparent membrane enclosing the vesicles; specimens yellow-brown.

Dimensions. Vesicle diameters are 35-40um (including outer membrane), process length 3-5um and number 13-15 seen at outline. Previous measurements: Vesicle diameters are 25-50um (including outer membrane) (Vidal, 1981b).

Remarks. Present specimens are collected from the tillite and more or less damaged; non-branching processes indicate that they differ from *Vandalosphaeridium reticulatum* (Vidal), which bears furcated processes.

Distribution. Found in the Nantuo Formation at the Wangfenggang section near Liantuo, Yichang, Hubei. Previously recorded from the Ekkeroy, Dakkovarre and

Grasdal Formations in East Finnmark, northern Norway, Dundas and Nassarssuk Formations, Thule Group in northwestern Greenland (Vidal, 1981b).

Stratigraphic range. Lower Vendian (lower Sinian).

Note

The species without description in this paper:

Alliumella baltica Vanderflit, 1971 (pl.XXXVII, fig.1; pl.XXXVII, fig. I).

Kildinosphaera chagrinata Vidal, 1983 (pl.XXVII, fig.1; pl.XXXVII, figs.D, J).

Kildinosphaera granulata Vidal, 1983 (Pl.XVI, figs.F-G, R; pl.XXVII, fig.Q; pl.XXXVII, figs.F-I; pl.XXXVIII, fig.P; pl.XLI, figs.N-P)

Kildinosphaera verrucata Vidal, 1983 (pl.XXXVII, fig.K)

Kildinosphaera sp. (pl.XLI, figs.D-F)

Leiosphaeridia asperata (Naumova) Lindgren, 1982 (pl.XXVII, fig.Q; pl.XXXVII, figs.A-C)

Micrhystridium circulapertum sp. nov. (pl.XXXV, figs.J, N-O).

Micrhystridium spinosum Volkova, 1969 (pl.XXXV, fig.M)

Micrhystridium tornatum Volkova, 1968 (pl.XXXV, figs.H-I)

Micrhystridium sp. (pl.XXVII, fig.P)

Protoleiosphaeridium densum (Timofeev) comb. nov., (Pl.XXXVIII, fig.E)

Protoleiosphaeridium flexuosum (Timofeev, 1966) (pl.XXVI, fig.S; pl.XXVII, figs.M-N; pl.XXXVIII, fig.H)

Protoleiosphaeridium laccatum (Timofeev, 1966) (pl.XLI, fig.H)

Stictosphaeridium sp. (pl.XXV, fig.K; pl.XXXVII, fig.E; pl.XXXVIII, fig.N)

Synsphaeridium sp.(pl.XLI, fig.J)

Tasmanites? sp. (pl.XXXV, fig.R)

Filaments:

Eomycetopsis robusta (Schopf) Knoll et Golubic, 1979 (pl.XL, figs. J-N; pl.XLI, fig.Q)

Siphonophycus sp. (pl.XL, figs.O-P; pl.XLI, fig.K)

Vase-shaped specimens (pl.XLi, figs.G, I)

3.8.2. Mega-algal Fossils

Genus *Daltaenia* Hofmann, 1985

Type species. *Daltaenia mackenziensis* Hofmann, 1985

Daltaenia cf. *mackenziensis* Hofmann, 1985

(Plate XXIII, figs.H-K)

Daltaenia mackenziensis sp. nov., Hofmann, 1985, p.346-347, pl.39, figs.1-3; text fig.6.

Description. Slender, carbonaceous ribbon-like structure; commonly black; ribbons untwisted and not tightly bend; lateral branches observed; edge of the ribbon usually diagenetic damaged; no surface texture observed.

Dimensions. Ribbons are 0.8 mm to 1.4 mm wide and up to several centimeters long.

Remarks. Hofmann (1985) erected the genus *Daltaenia* by its ribbons lateral branching. The present specimens are carbonized, some damaged, but apparently display lateral branching.

Distribution. Upper Sinian Baiyunshao Member, Yuhucun Formation from the Baimashan section near Chengjiang County, eastern Yunnan.

Daltaenia sp.

(Pl.XXIV, figs.A-B)

Description. Slender, carbonaceous ribbon-like thallus with lateral branching; equivalent width within one thallus and the thallus not twisted; branching commonly acute angle, to second or third order; no surface texture observed.

Dimensions. Ribbons are 0.6 - 1.0 mm wide and up to several centimeters long.

Distribution. Lower Cambrian Yu'anshan Member, Qiongzhusi Formation from the Maotianshan section near Chengjiang County, eastern Yunnan.

Genus *Longfengshania* Du, 1982

Type species. *Longfengshania stipitata* Du, 1982

Longfengshania? sp.

(Pl.XXIII, fig.G)

Description. Elongate oval carbonaceous vesicle with a stalk-like appendage drawn out from the vesicle; no terminal structure of the appendage observed; specimens black and damaged; no surface texture observed.

Dimensions. Vesicle is 1.4mm wide and 2.5mm long; appendage 2mm long and 0.1 - 0.2mm wide.

Remarks. Present specimens are small and fragmented, but a stalk-like appendage can be observed. The specimens are badly preserved.

Distribution. Upper Sinian Jiucheng Member, Yuhucun Formation from the Baimashan section near Chengjiang County, eastern Yunnan.

Genus *Tawuia* Hofmann, 1979

Type species. (*Tawuia dalensis* Hofmann, 1979)

Tawuia dalensis Hofmann, 1979

(pl.XXIII, figs.C-D)

Remarks. The two specimens are from the upper Sinian Jiucheng Member, Yuhucun Formation at the Baimashan section near Chengjiang County, eastern Yunnan. The specimen are carbonized and damaged, but rounded terminals convince their taxonomic position.

Genus *Tyrasotaenia* Gnilovskaya, 1971

Type species. *Tyrasotaenia podolica* Gnilovskaya, 1971

Tyrasotaenia? sp. (Type-1)

(Pl.XXII, figs.G-H, pl.XXIII, figs.E-F)

Description. Slender ribbons with tapering terminals; ribbons untwisted, commonly bent, wide at the middle part and tapering to obtuse terminals; specimens generally carbonized, occasionally some folds observed; ribbons commonly solitarily preserved.

Dimensions. Ribbons vary in width, 0.4-1mm at the middle part and 0.2-0.3mm at the terminals and the length up to 2cm.

Remarks. *Tyrasotaenia* differs from *Vendotaenia* in its ribbons relatively narrower (0.3-0.5) and shorter, uniform surface and no longitudinal series of cell structures (Gnilovskaya, 1979). The present ribbons are relatively larger, wider, with a distinctive tapering terminals, and the surface more or less damaged.

Distribution. upper Sinian Jiucheng Member, Yuhucun Formation from the Baimashan section near Chengjiang County, eastern Yunnan.

Tyrasotaenia sp. (Type-2)

(Pl.XXIV, figs.D-F)

Description. Fairly narrow ribbons without convincing lateral branching; width stable within one specimen and various in different specimens; ribbons straight or bent, not twisted; no surface texture observed; ribbons solitary or massive occurrence.

Dimensions. Ribbons are 0.2 - 0.6mm wide (commonly 0.2-0.4mm) and length is up to several centimeters.

Remarks. Present specimens are carbonised and no surface texture is observed. The thalli are uncertainly named.

Distribution. Lower Cambrian Yu'anshan Member, Qiongzhusi Formation from the Maotianshan section near Chengjiang County, eastern Yunnan.

Genus *Vendotaenia* Gnilovskaya, 1971

Type species. *Vendotaenia antiqua* Gnilovskaya, 1971

Vendotaenia didymos (Cao et Zhao, 1978) comb. nov.

Vendotaenia didymos Cao et Zhao (sp. nov.) Cao and Zhao, 1978, p.18, pl.2, figs.5-6.

Vendotaenia antiqua Gnilovskaya, Cao et Zhao, 1978, p.17, pl.2, figs.1-4.

Tyrasotaenia cf. *podolica* Gnilovskaya, Sin Yusheng and Liu, 1978, pl.9, figs.9-10; pl.10, figs.1-2.

? *Tyrasotaenia* sp., Sin Yusheng and Liu, 1978, pl.10, fig.3.

Vendotaenia sp., Sin Yusheng and Liu, 1978, pl.10, fig.4.

Description. Specimens mass occurrence, various in forms; thin string-like, lanceolate, straight, bent or twisted ribbons; ribbons 'C', 'S', 'U' or 'V'- shaped; commonly varying width within a specimen, wider at the middle part and slightly tapering to terminals; no convincing branching; occasionally longitudinal stripes seen on the ribbon surface; no reproductive organs observed; specimens brown to dark in colour.

Dimensions. Ribbons are 0.15 to 1.5mm wide and length up to 25mm. Previous measurements: 0.3 - 2.0mm wide, length reach 25-30mm (Cao et Zhao, 1978).

Remarks. Gnilovskaya (1971) described *Vendotaenia antiqua* from the East-European Platform. The ribbon width of *V. antiqua* is stable within a specimen and varies in different specimens (0.25-3.0). The new taxon differs in its various width within a single thallus.

Vendotaenia may be a heterogenetic taxon. Gnilovskaya (1979) described four morphological varieties by the width of ribbons in *V. antiqua* and she suggested no difference in thallus structures of the four forms. Cao Ruiji and Zhao (1978) found very difficult to identify *Vendotaenia* from *Tyrasotaenia* and they doubted two form taxa might contain similar thalli with different sizes or represent different reproductive stages. *Tyrasotaenia*, according to Gnilovskaya (1979), lacks of longitudinal series of cells and with a relatively narrow width (0.3 to 0.5mm).

Cao and Zhao (1978) erected *Vendotaenia didymos* based on two 'U'-shaped ribbons with parallel arrangement. The ribbons could be one growth or preservation form.

Distribution. Upper Sinian Shipantan Member, Dengying Formation in the Yangtze Gorges, Hubei; upper Sinian Jiucheng Member, Yuhucun Formation at the Baimashan section near Chengjiang County, eastern Yunnan.

Stratigraphic range. Upper Sinian.

Vendotaenia sp.

(Pl.XXIII, figs.A-B; pl.XXIV, fig.C)

Description. Ribbon mats displaying spiral structure; thalli straight to tightly bent, untwisted; width stable within one specimen; no surface texture observed; specimens yellow to brown in colour.

Dimensions. Ribbons are 0.4-0.6mm width and up to several centimeters long.

Remarks. Present specimens are similar to *V. antiqua* Gnilovskaya, but no surface textures and cell structures observed.

Distribution. Lower Cambrian Yu'anshan Member, Qiongzhusi Formation from the Maotianshan section near Chengjiang County, eastern Yunnan.

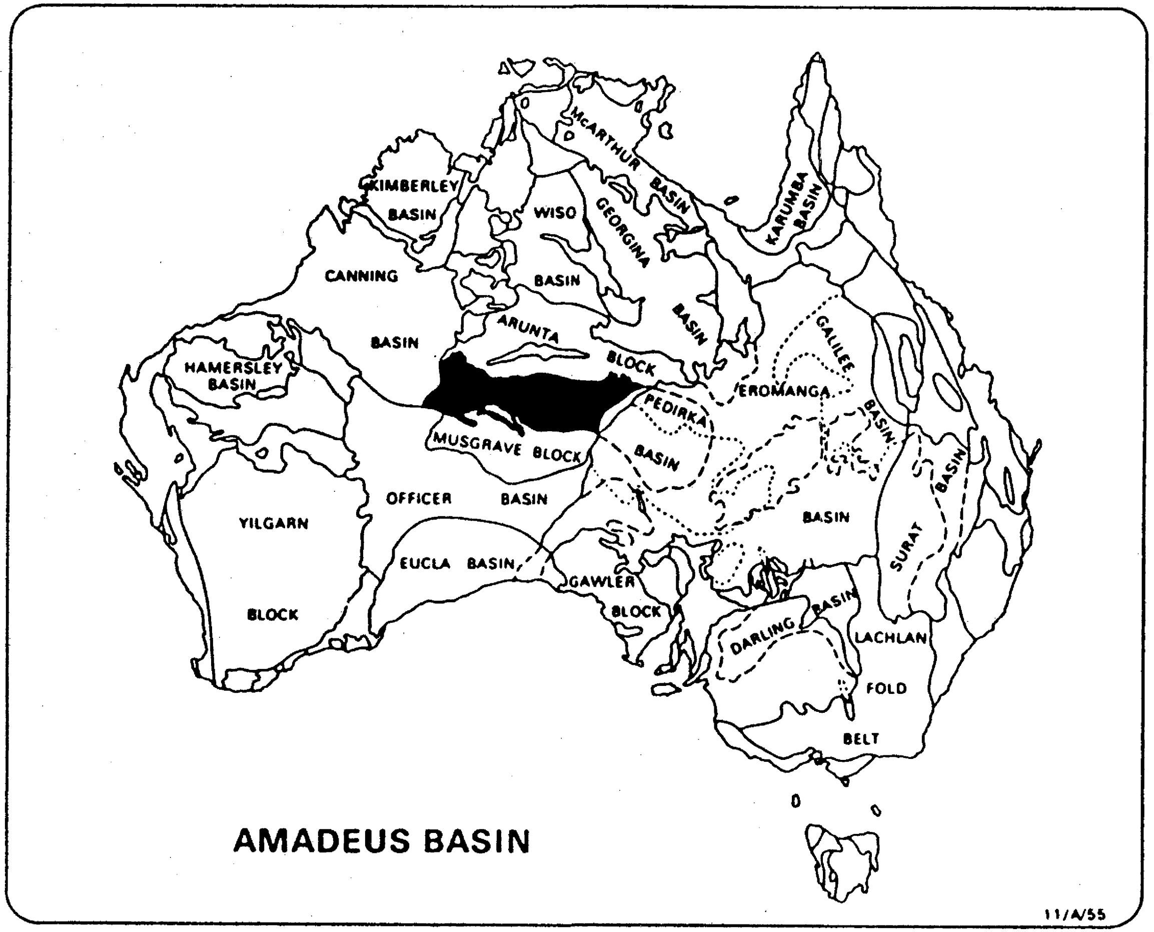
Chapter 4

LATE PROTEROZOIC AND CAMBRIAN MICROFOSSILS FROM THE AMADEUS BASIN, CENTRAL AUSTRALIA

4.1. INTRODUCTION

The Amadeus Basin is an intracratonic trough in central Australia. It unconformably contacts with the metamorphosed rocks of the Musgrave Block to the south and the Arunta Block to the north. The Pedirka Basin is located to the east and Canning Basin to the west (Palfreyman, 1984) (Text-figure IV-1). The basin has an east-west length of about 800km and an area of about 170000 square kilometers. Upper Proterozoic to Carboniferous sequences are exposed in the basin (Text-figure IV-2), and they are marine and continental deposits with a maximum preserved thickness of about 10000 - 14000m; volcanic rocks are rare.

The Upper Proterozoic to Lower Cambrian sequence in the Amadeus Basin is shown in Text-figure IV-3. The lowest sandstone of the Heavitree Quartzite (=Dean Quartzite) unconformably overlies the metamorphosed basement of the Arunta Block in the north of the basin. These sands were accumulated on a stable, shallow epicontinental shelf no more than 900 Ma ago, and are approximately 600m thick. After mild epirogenic movements, up to 1300m of evaporites (sulphate and halite), shallow marine stromatolitic carbonates, lacustrine carbonates, terrestrial red beds and locally basalts of the Bitter Springs Formation (=Pinyinna Beds) were deposited (Kennard and Nicoll, eds., 1986; Southgate, 1986). The Bitter Springs Formation has been subdivided into the lower Gillen and upper Loves Creek Members, and it mainly outcrops in the northern part of the basin.



Text-figure. IV-1. Index map of study area, showing tectonic location of the Amadeus Basin(after Palfreyman, 1984).

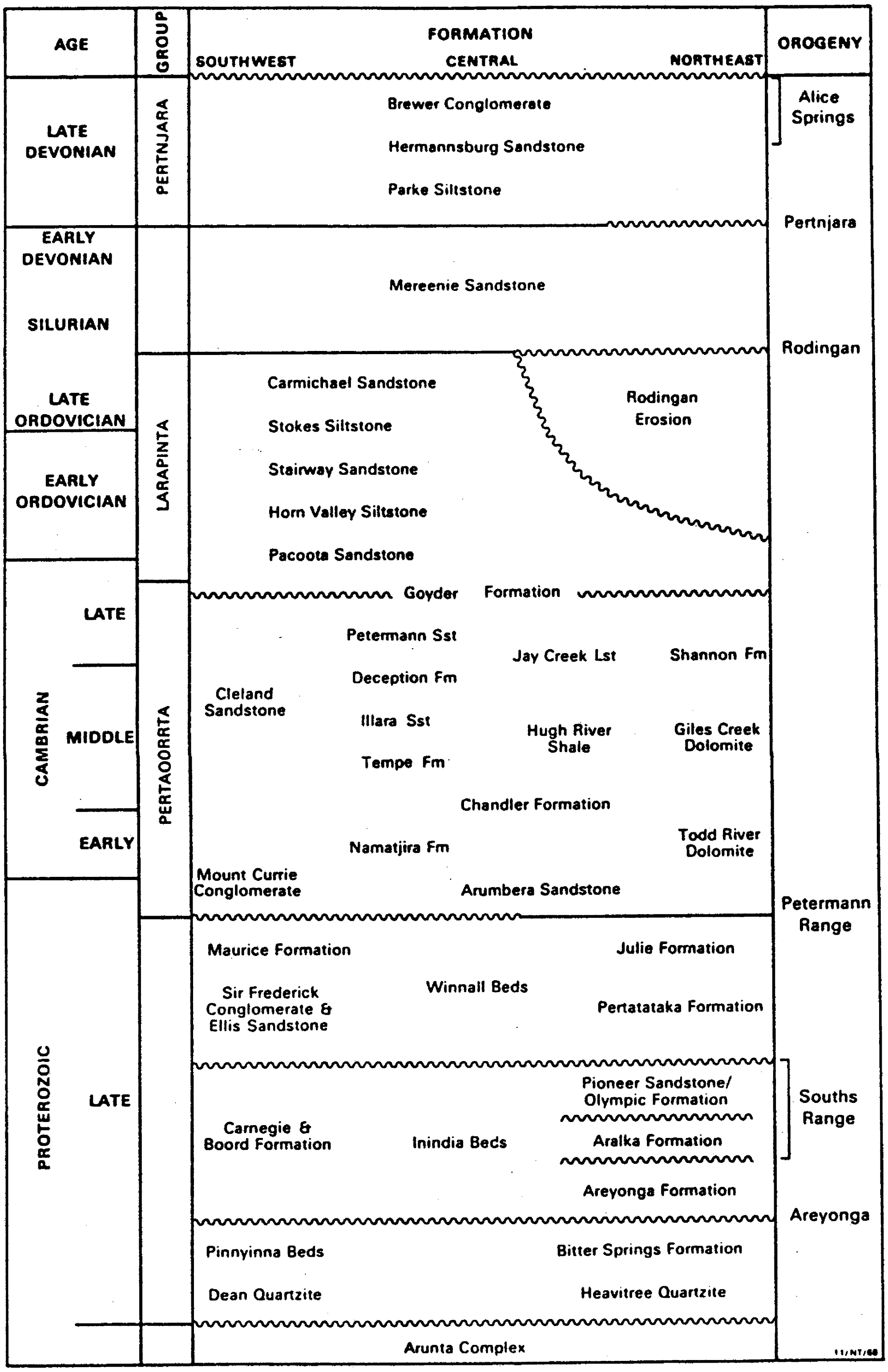
Two Upper Proterozoic glacial diamictites have been recorded in the basin. The older one is the Areyonga Formation and the younger is the Olympic Formation (=Pioneer Sandstone). The diamictites are separated by interglacial shale and siltstone of the Aralka Formation, which is up to 1000m thick and conformably overlies the Areyonga Formation and disconformably underlies the Olympic Formation. Generally tillites are considered as important marker units for stratigraphic correlation in the Late Proterozoic (Preiss et al., 1978).

The Pertatataka Formation was deposited conformably above the Olympic Formation and consists mainly of brown, grey and green shales and siltstones, with minor thin sandstone beds. The formation is considered to be turbidites which were deposited in an outer submarine fan to basin plain environment (Korsch, 1986). The turbidites shallow up into the dolomite and limestone of the Julie Formation.

The Cambrian sequence in the Amadeus Basin is named the Pertaoorrta Group. The lowest formation is the Arumbera Sandstone which is divided into four units; the lower two units contain traces of the Ediacara fauna and have been considered as latest Proterozoic (Daily, 1972). The upper two units contain abundant horizontal and vertical burrows and the ichnofaunas can be biostratigraphically correlated worldwide (Glaessner, 1969; Walter et al., in press). The sandstone passes upward into the Atdabanian (early Early Cambrian) Todd River Dolomite which yields an archaeocyathan fauna and phosphatic fossils (Kruse and West, 1980; Laurie and Shergold, 1985). This is then succeeded by the Chandler and Tempe Formations, and other Cambrian units. The Pertaoorrta Group consists of more than ten rock units, and their stratigraphic relationships are shown in Text-figure IV-4.

Radiomatric chronology of the Amadeus Basin has not provided clear shown isotopic data for basal the sediments. The data on the dykes in the basement underlying the Heavitree Quartzite are 897±9 Ma (Rb/Sr on separated minerals) (Black et al., 1980). An estimated maximum age of 900 Ma is suggested for the Basin.

Fossils of the Ediacara fauna are not widely reported in the Amadeus Basin (Wade, 1969). Daily (1972) reported an element of the Ediacara metazoan assemblage, *Rangea*



Text-figure. IV-2. Stratigraphy of the Amadeus Basin (after Kennard et al., 1986).

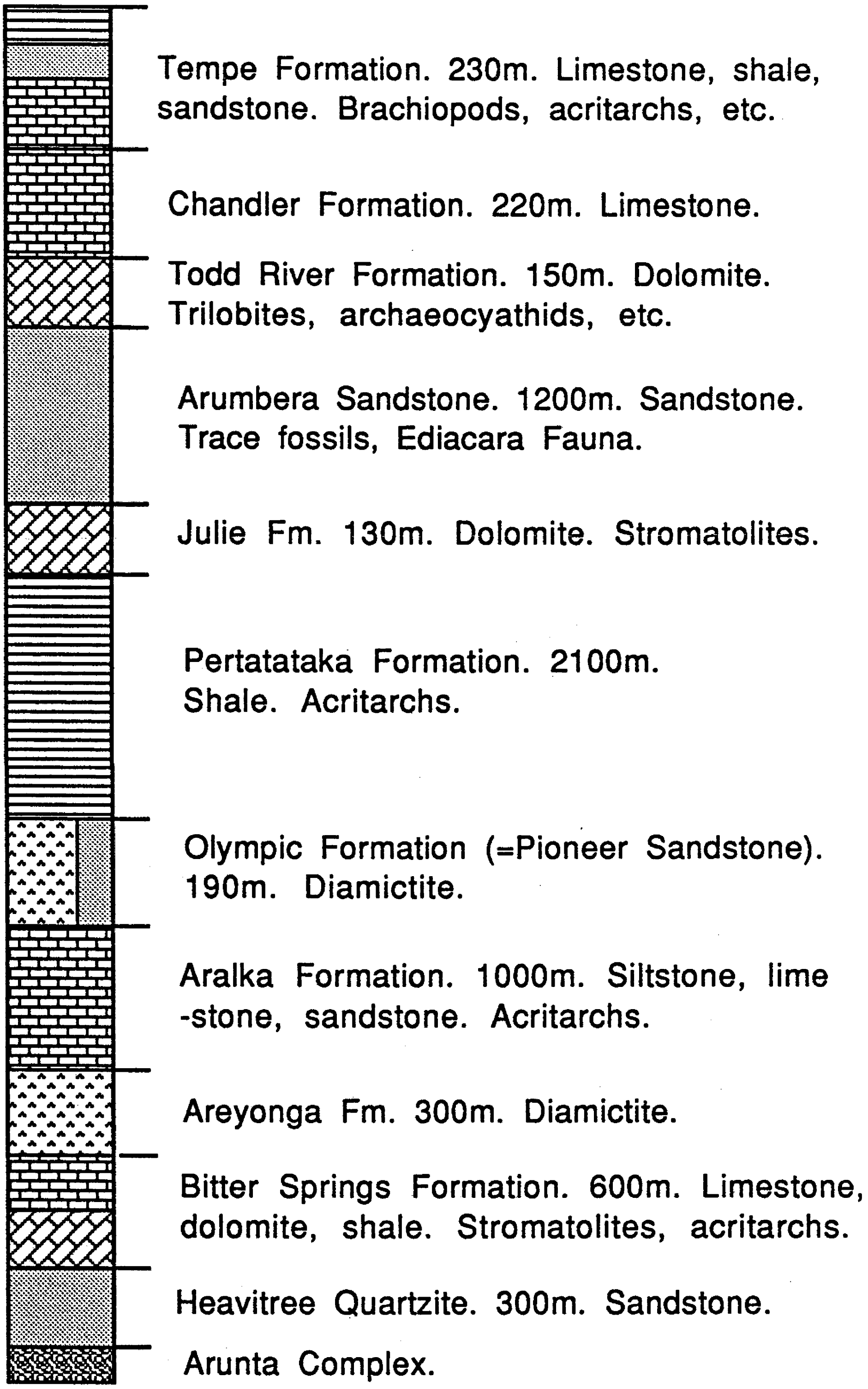
sp., from the Arumbera Sandstone, and another fossil, *Arumberia banksi*, provisionally regarded as a coelenterate (note: recently Walter considered it as a pseudofossil, pers. comm.) has been described from the same unit by Glaessner and Walter (1975). The fossils may support the correlation between the lower Arumbera Sandstone and the Pound Subgroup in the Adelaidean Geosyncline in the South Australia.

Stromatolites are extensively exposed in the Amadeus Basin. Walter (1972) comprehensively studied stromatolites and their stratigraphic significance in the Precambrian and Cambrian sequences in central Australia, and using these biosedimentary structures and the Upper Proterozoic tillites for correlation, he suggested a Late Riphean age for the Bitter Springs Formation.

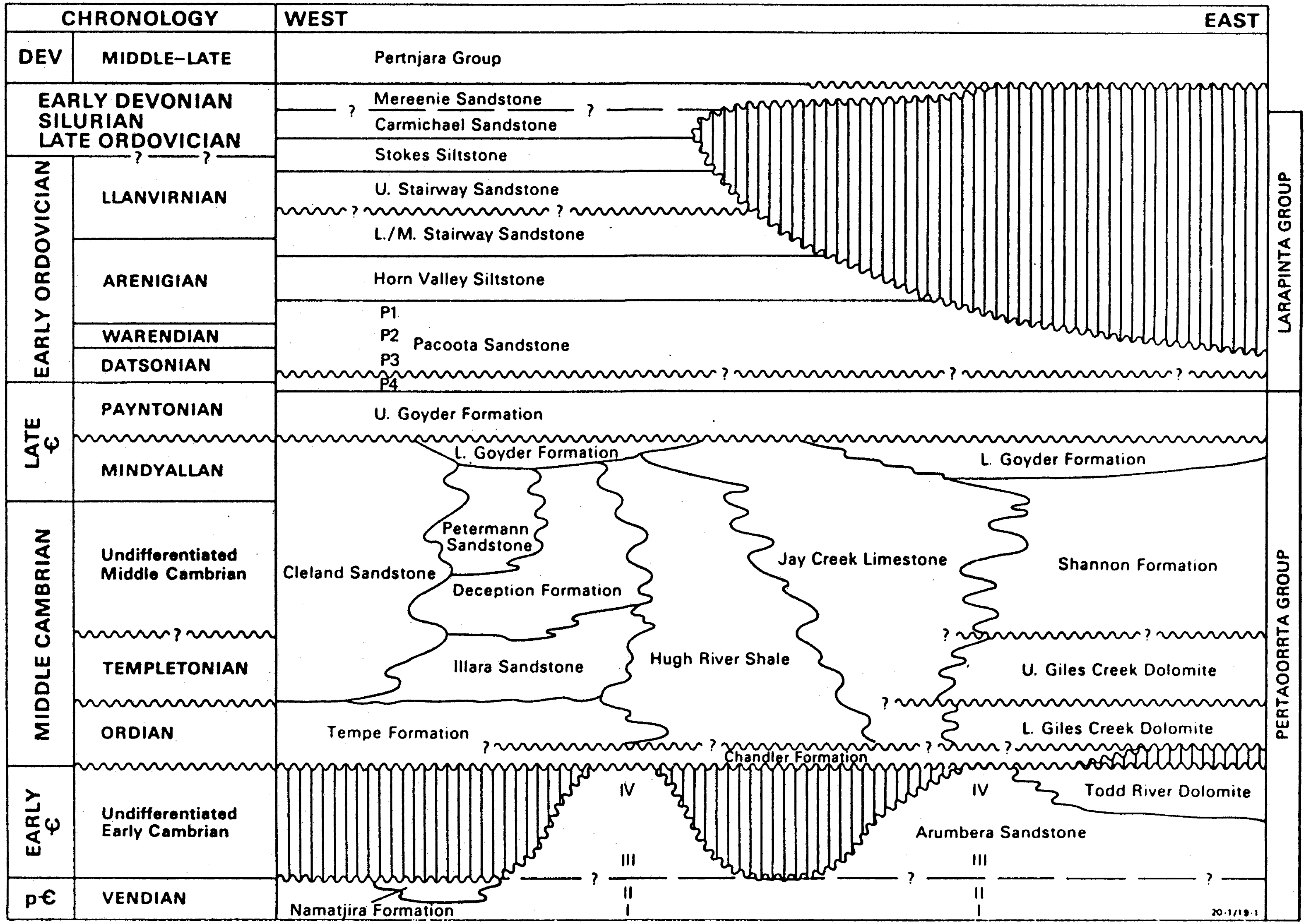
Microfossils from black cherts in the Loves Creek Member of the Bitter Springs Formation show surperb preservation and diversity (Barghoorn and Schopf, 1965; Schopf, 1968; Schopf and Blacic, 1971; Knoll and Golubic, 1979). Cherts are the favoured facies of microbiologists for their excellent preservation, but they have not made a major contribution to biostratigraphic correlation (Plumb, 1985). Acid-resistant microfossils have not been systematically studied in the basin before now.

Systematic investigation of the Amadeus Basin started in the 1960's with geological mapping and oil and mineral exploration. The Upper Proterozoic and Cambrian succession has long been recognized (Wells et al., 1967; Wells et al., 1970; Walter, 1972; Preiss et al., 1978; Preiss and Forbes, 1981; Shergold, 1986). The Amadeus Basin has become a clasical area in the study of the Late Proterozoic.

This study is mainly concentrated on microfossils gained by maceration. The samples were collected from two surface sections and nine boreholes. The cores were sampled from the BMR Core Laboratory at Fyshwick, Canberra ACT, the core store of the Geological Survey of the Northern Territory at Power St., Alice Springs and the core store of Pancontinental Oil Company in Alice Springs. All slides in this paper will be stored in the BMR Commonwealth Palaeontological Collection at Fyshwick, Canberra ACT, Australia.



Text-fig. IV-3. Generalized stratigraphic column of Upper Proterozoic and Lower Cambrian sequence in the Amadeus Basin, central Australia. Thicknesses give an indication of approximate maxima only.



Text-figure. IV-4. Cambro-Ordovician stratigraphic relationships in the Amadeus Basin (after Kennard et al., 1986).

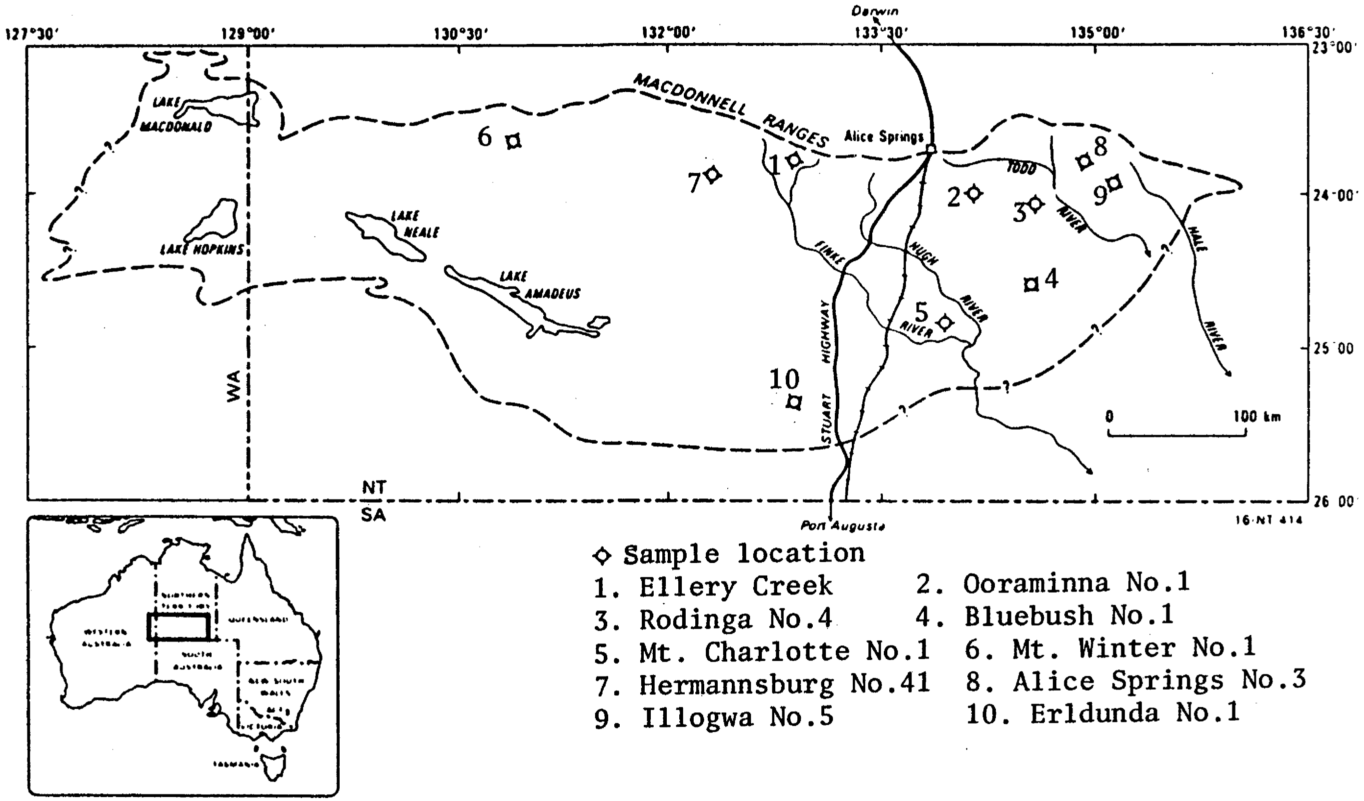
4.2. LOCALITIES AND SAMPLING

Sedimentation in the Amadeus Basin was modified by tectonic movements which occurred intermittently from Late Proterozoic to Late Devonian (Wells et al., 1967; Wells et al., 1970). The Basin commenced with Late Proterozoic clastics which rest on an older Precambrian basement of metamorphic and igneous rocks, followed by Palaeozoic sequence of Cambrian, Ordovician, possibly Silurian, Devonian and minor Carboniferrous or younger age. Silurian? - Devonian sandstones have been deposited in arid environments, partly fluviatile and aeolian. Minor lacustrine deposits in the Permian and in the Tertiary concluded the sedimentary history of the Basin (Wells et al., 1970).

Most area of the Amadeus Basin is covered by Recent and sub-Recent aeolian sands, and the Upper Proterozoic to Ordovician sequences are mainly exposed in the northern or northeastern margin of the Basin. Few surface samples are suitable for collection and most analysed samples were collected from the drill cores. This study includes more than one hundred and fifty samples from the two sections and nine boreholes. They are: Ellery Creek section, Ross River section, boreholes Rodinga No.4, Ooraminna No.1, Hermannsburg No.41, Mt. Charlotte No.1, Mt. Winter No.1, Bluebush No.1, Alice Springs No.3, Erldunda No.1 and Illogwa No.5 (Text-figure IV-5).

4.2.1. Ellery Creek and Ross River sections

Ellery Creek is located in the northern margin at the Amadeus Basin and provides one of the most complete upper Proterozoic and Palaeozoic sections in the eastern central portion of the basin. The ridge on the north side of Ellery Creek Big Hole occurs in the Heavitree Quartzite which is the basal formation of the Amadeus Basin. The Quartzite is overlain by the dolomites, limestones and siltstones of the Gillen Member of the Bitter Springs Formation and then the 200m thick stromatolitic upper Loves Creek Member of the Formation. In the Ellery Creek area, stromatolites, desiccated mudstones, chert nodules and concretions, halite pseudomorphs and bipyramidal quartz crystals are common in the Loves Creek Member (Southgate, 1986).



◇ Sample location
1. Ellery Creek
2. Ooraminna No.1
3. Rodinga No.4
4. Bluebush No.1
5. Mt. Charlotte No.1
6. Mt. Winter No.1
7. Hermannsburg No.41
8. Alice Springs No.3
9. Illogwa No.5
10. Erldunda No.1

Text-figure. IV-5. Index map of the Amadeus Basin, showing sample localities.

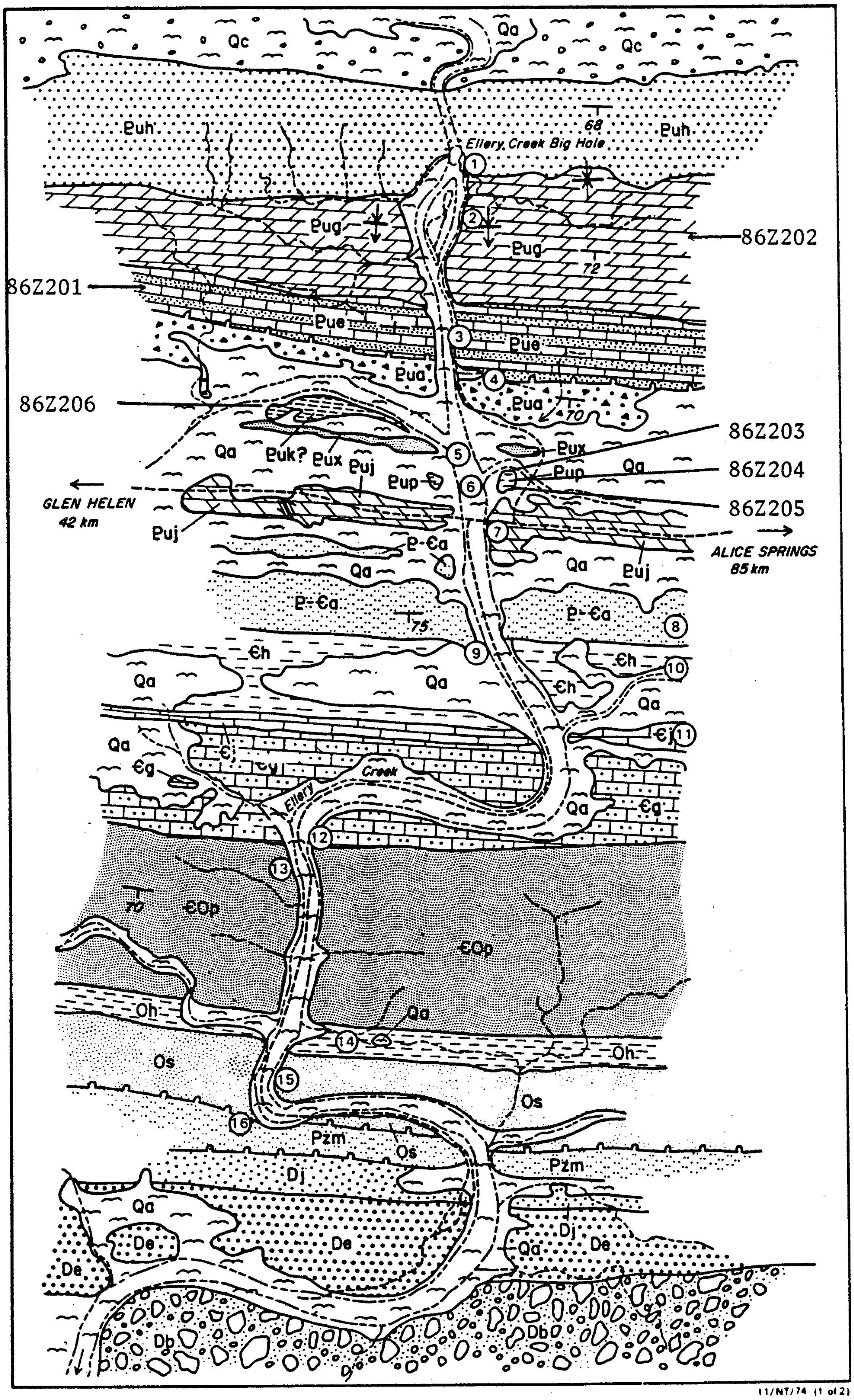
The Areyonga Formation unconformably overlies the Bitter Springs Formation and consists of conglomerate and sandstone. Dispersed pebbles and boulders (up to 1.5m in diameter) in a pale grey muddy matrix are exposed near the base of the Formation, and faceted and striated boulders and other indications of a glacial origin have been observed. Several beds of the calcareous shales and siltstones of the Aralka Formation are found overlying the conglomerate.

In the Ellery Creek section only the Pioneer Sandstone is exposed, which has been considered transitionally equivalent to the Olympic Formation. Planar, trough and herringbone cross-beddings are present in the sandstone and probably indicate an intertidal depositional environment. The sandstone is overlain by the poor exposures of the Pertatataka Formation which consists of red to grey-green shale or mudstone and minor very thin beds of siltstone to very fine grained sandstone, and the Pertatataka Formation has been considered to be distal turbidites of marine origin (Korsch, 1986).

The Julie Formation conformably overlies the Pertatataka Formation and consists of dolomites and limestones with features indicating a shallow marine environment. The carbonate beds shallow up to the mainly Cambrian Pertaoorrta Group. The basal Arumbera Sandstone of the group is considered to have been deposited as two major depositional sequences in a shallow marine and deltaic or coastal-plain setting (Lindsay, 1987).

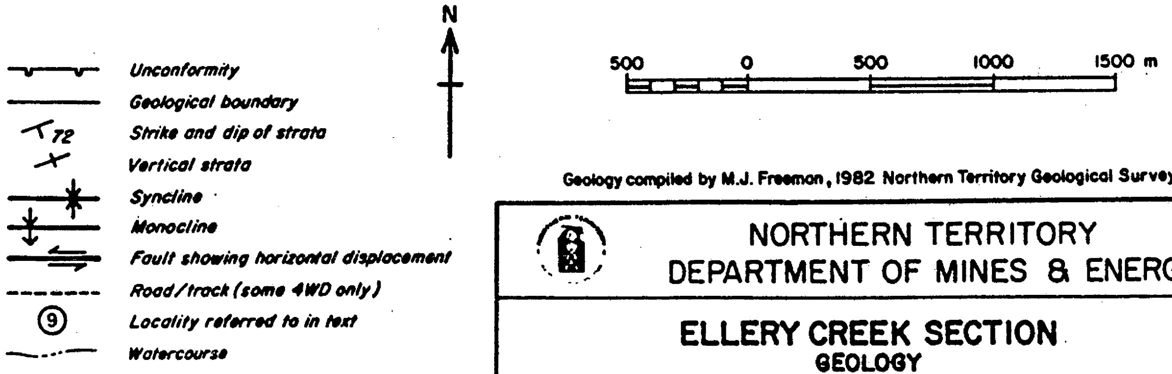
The sequence exposed in the Ross River section can be correlated with that of the Ellery Creek section. It is noted that a thin-bedded, stromatolitic cherty dolomite up to 7m thick forms the uppermost part of the Bitter Springs Formation at the both localities and the black cherts from which Barghoorn and Schopf (1965), Schopf (1968), Schopf and Blacic (1971), Knoll and Golubic (1979) and Knoll (1981) described the well known Bitter Springs microfossils are from this stratigraphic interval. These Bitter Springs microfossils have been considered to have thrived in a series of nonmarine shallow metahaline to hypersaline lakes and ponds (Southgate, 1986).

A total of seven samples have been collected from the two sections; two chert samples collected from the Ross River section (86Z200) and Ellery Creek section (86Z201); and



Text-figure. IV-6. Geological map of the Ellery Creek section, showing sample localities (after Nicoll, 1986).

Era/Period	Group	Unit	Symbol	Description
CAINOZOIC			Qa	*Alluvium, scree deposits*
			Qc	*Colluvium*
DEVONIAN	Pertnjara Group	BREWER CONGLOMERATE	Db	*Boulder conglomerate, sandstone lenses*
		HERMANNSBURG SANDSTONE Ljiltera Member	De	*Pebbly sandstone, siltstone, conglomerate lenses*
		PARKE SILTSTONE Harajica Sandstone Member	Dj	*Sandstone, locally pebbly*
SILURO? DEVONIAN		MEREENIE SANDSTONE	Pzm	*Sandstone; boldly cross-bedded*
ORDOVICIAN	Larapinta Group	STAIRWAY SANDSTONE	Os	*Sandstone, siltstone; fossiliferous, phosphatic*
		HORN VALLEY SILTSTONE	Oh	*Siltstone, limestone; prolific fauna, trilobites, brachiopods, pelecypods, nautiloids, gastropods etc*
		PACOOTA SANDSTONE	€Op	*Sandstone, siltstone, fossiliferous with* Scolithus, Cruziana, *cross-bedded*
CAMBRIAN	Pertaoorta Group	GOYDER FORMATION	€g	*Sandstone, limestone*
		JAY CREEK LIMESTONE	€j	*Fossiliferous dolomitic limestone*
		HUGH RIVER SHALE	€h	*Shale, siltstone (Chandler limestone at base)*
		ARUMBERA SANDSTONE	P-€a	*Fine sandstone, siltstone; weakly cupriferous in upper part, prominent red unit*
ADELAIDEAN		JULIE FORMATION	Puj	*Dolostone, limestone, sandstone; oolitic and stromatolitic*
		PERTATATAKA FORMATION	Pup	*Shale, siltstone*
		PIONEER SANDSTONE	[illegible]	*Sandstone, dolostone, "Upper Cap Marker Dolostone"*
		ARALKA FORMATION	Puk	*Shale, limestone*
		AREYONGA FORMATION	Pua	*Diamictite, conglomerate, calcareous sandstone, tillitic siltstone*
		BITTER SPRINGS FORMATION Loves Creek Member	Pue	*Dolostone (stromatolitic), limestone, pink siltstone*
		BITTER SPRINGS FORMATION Gillen Member	Pug	*Dolostone, limestone, shale, siltstone*
		HEAVITREE QUARTZITE	Puh	*Quartzite, sandstone*



Geology compiled by M.J. Freeman, 1982 Northern Territory Geological Survey

NORTHERN TERRITORY
DEPARTMENT OF MINES & ENERGY

ELLERY CREEK SECTION
GEOLOGY

Division: N.T.G.S.	*Geologist:* M.J. Freeman		*Drawing No.*
Drawn: A.B.Brook	*Date:* 13·3·84	*Checked:* MJF	AS 137/001

11/NT/74 (2 of 2)

Text-figure. IV-6. continued.

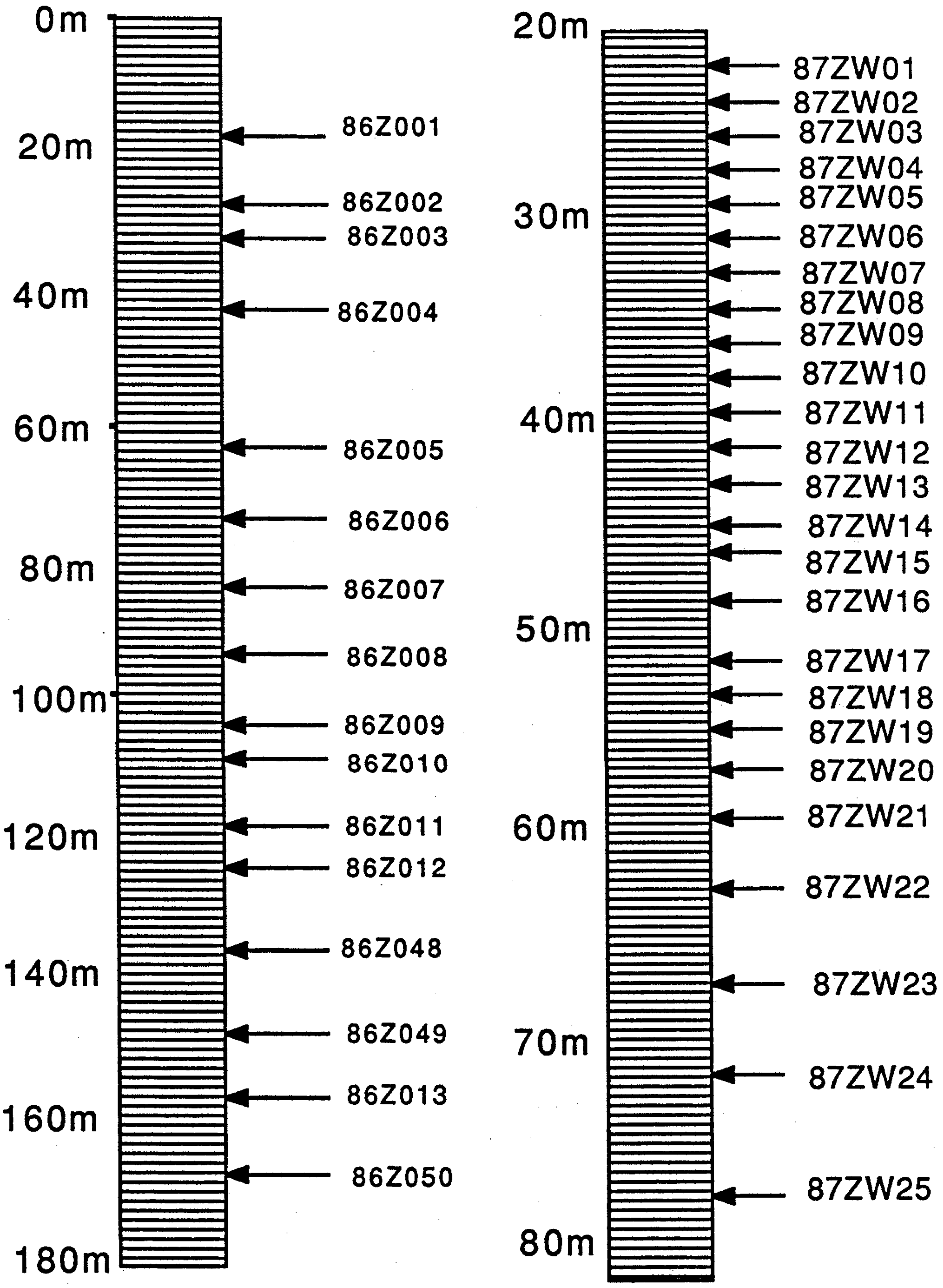
five other samples from shales or siltstone, one from the Gillen Member, one from the Aralka Formation and other three from the Pertatataka Formation (Text-figure IV-6). All samples have been cut or processed for microfossil investigation.

4.2.2. Rodinga No.4.*1

BMR Rodinga No.4 is one of the fully-cored holes drilled in 1981 to test the petroleum source rock potential of the Proterozoic Pertatataka Formation in the eastern Amadeus Basin. The borehole was located on the gently dipping (12° - 15°) southern limb of a syncline in the southeastern part of Phillipson Pound (134°36'E and 24°11'S), and spudded in about 30m from the base of a hill formed by the dolomite of Julie Formation, close to the base of formation. The weathered grey green siltstones and shales of the Pertatataka Formation are overlain by scree and Quaternary aeolian sand, and the weathered level in the borehole is at 23m deep.

From 23m to the total depth of 170m the core consists of a monotonous sequence of dark greenish grey to greenish black shales (or silty mudstone) with interlaminated, partly dolomitic siltstone, much of which was contorted and disrupted. Pyrite is finely disseminated throughout the sequence and also occurred both as laminae up to 5mm thick as irregular blebs up to 10mm across. Calcite occurred as veinlets filling fractures, particularly in the intervals 15-42m and 141-170m. Some pyritic black shale fragments were present at 96m and between 110 and 120m. At the total depth the hole was still in the shales of the Pertatataka Formation.

Low values of total organic carbon were obtained from the samples of the Pertatataka Formation. The formation averaged 133mg per gram of organic carbon of extract with 13% hydrocarbons. Petrophysical tests of the formation showed a lack of porosity and permeability, indicating poor reservoir potential and poor prospects for migration of any hydrocarbons generated. One reflectance determination of 0.9% on a vitrinite-like maceral from the rock at the depth 119.71-119.77m indicated that the sample is mature i.e. in the oil-generating zone (Felton and West, 1982). The observation of the borecore



Text-fig. IV-7. Lithological log of the Pertatataka Formation from the borehole Rodinga No.4 in the Amadeus Basin. Sample levels are indicated by arrows. Right hand side is enlargement of the borehole from 20-80m, with second set sample numbers.

indicates the upper part of the core is grey or yellow-grey and the lower part dark or dark-grey. The microfossils are commonly well-preserved at the upper part and most organic matters are fragmented at the lower part. The rocks in the lower part of the borehole have suffered relatively higher temperature in diagenesis or post-diagenesis.

The borehole Rodinga No.4 was first sampled in 1986, at a ten meter interval. Early in 1987 the borehole was re-sampled, specially at the upper part (total fifty samples collected, see Text-figure IV-7).

***1** General information on the borehole BMR Rodinga No.4 is from unpublished record (Felton, E. A. and West B.G., 1982), stored in BMR Library, Canberra ACT. File No. 1982/37.

4.2.3. Ooraminna No.1. *2

The borehole Ooraminna No.1 is located about 80km south-east of Alice Springs on the Ooraminna Anticline (24°00'06"S and 134°09'50"E), and was the first oil exploratory test drilled in the Basin. The borehole commenced in February, 1963 and was completed in June, with a total depth of 6107 feet (1861.4m).

The borehole spudded from the Lower Cambrian Arumbera Sandstone which is characterized by the presence of poorly consolidated sandstone with siltstone interbeds. The Julie Formation ranges from 1530 feet (466.3m) to 1950 feet (594.4m). The rocks between 1720 feet (524.3m) to 1530 feet (466.3m) consist of dolomitic limestone and 1950 feet (594.4m) to 1720 feet (524.3m) of interbedded dolomitic limestone, shale, siltstone and sandstone. The Pertatataka Formation in the borehole contains monotonous shale and siltstone from 3730 feet (1136.9m) to 1950 feet (594.4m). The lithological succession demonstrates that the Pertatataka Formation conformably underlies the Julie Formation.

The Areyonga Formation may start from 3730 feet (1136.9m) in depth. The sediments can be divided into two intervals: sandstone and siltstone with interbedded dolomitic limestone between 4265 (1300m) and 3785 feet (1153.7m), and dolomitic limestone between 3785 feet (1153.7m) and 3730 feet (1136.9m). The Areyonga Formation is currently considered to be of glacial origin (Preiss et al., 1978). The identification of the Areyonga Formation in the borecore has been doubted by Schmerber (1966, unpublished).

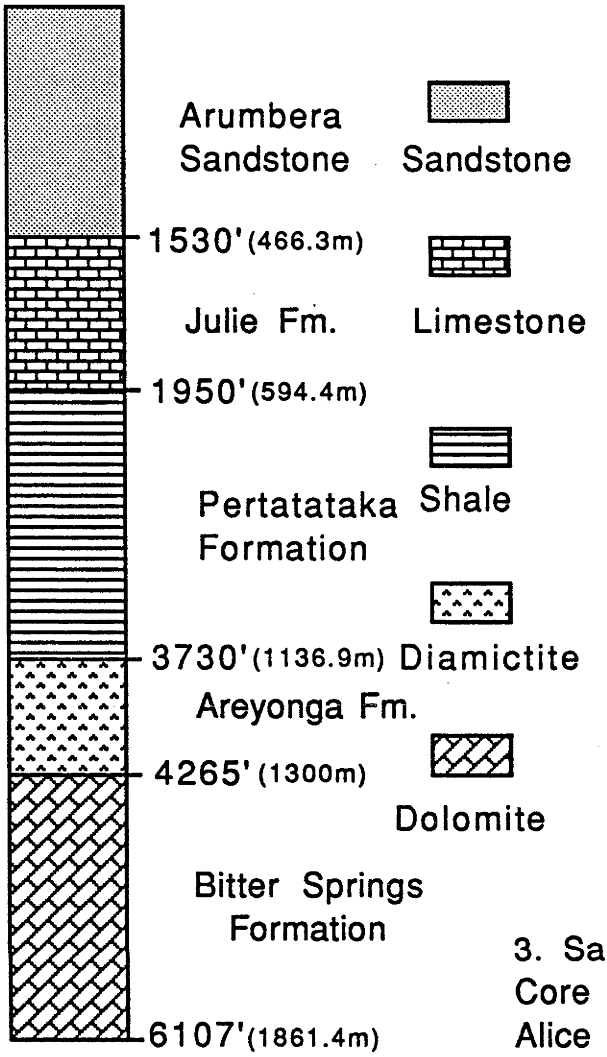
The Bitter Springs Formation in the borehole is differentiated from the overlying unit by a marked change in lithology with a bed of sandstone or siltstone of the Areyonga Formation. Two members have been recognized in the Bitter Springs Formation: the Gillen Member (6107 feet or 1861.4m to 5920 feet or 1804.4m), and the Loves Creek Member (5920 feet to 4265 feet or 1300m). The Gillen Member is represented by soft, rusty red, ferruginous, calcitic shales with very coarse anhydrite crystals, mixed with transparent halite. The Loves Creek Member consists mainly of dolomite.

Twenty-one cores were collected from the borehole and they are stored in the BMR Core Library at Fyshwick, Canberra ACT; the core store of Magellan Petroleum Pty Ltd, in Alice Springs; and the core store of the Geological Survey of NT. at Power Street, Alice Springs. All cores have been sampled and most of them have been processed (Text-figure IV-8).

***2** Data about the borehole Ooraminna No.1 mainly from unpublished well completion report:

Planalp, R.N. and Pemberton, R.L., 1963. Well completion report Exoil (N.T.) Ooraminna No.1.

Schmerber, G., 1966. A Petrological Study of the Sediments from Ooraminna No.1 Well, Amadeus Basin, Northern Territory.



1. Samples collected from BMR Fyshwick Core Library, Canberra ACT.

Sample No.	Depth
86Z016	2054'
86Z017	2058'
86Z018	2357'
86Z019	2700'
86Z020	3027-3029'
86Z021	3439'
86Z022	3441-3445'
86Z023	4166-4168'

2. Samples collected from Magellan Core Library, Alice Springs, NT.

Sample No.	Depth
86Z222	2055'
86Z223	2060'
86Z224	2355'
86Z225	2361'
86Z226	2700-2706'
86Z227	3027-3032'
86Z228	3437-3447'
86Z229	3921-3928'
86Z230	4166-4170'

3. Samples collected from the Core Library at Power Street, Alice Springs, NT.

Sample No.	Depth	Sample No.	Depth
86Z382	2050-51'	86Z383	2051-53'
86Z384	2053-55'	86Z385	2056-58'
86Z386	2058-60'	86Z387	2355-56'
86Z388	2356-58'	86Z389	2358-60'
86Z390	2360-61'	86Z391	2700-02'
86Z392	2702-04'	86Z393	2704-06'
86Z395	3030-32'	86Z396	3437-41'
86Z397	3441-44'	86Z398	3444-47'
86Z399	3921-28'	86Z400	4166-68'
86Z401	4168-70'	86Z402	4649-54'
86Z403	5546-47'		

Text-fig. IV-8. Geological log of the borehole Ooraminna No.1. and sample levels.

4.2.4. Hermannsburg No.41*3

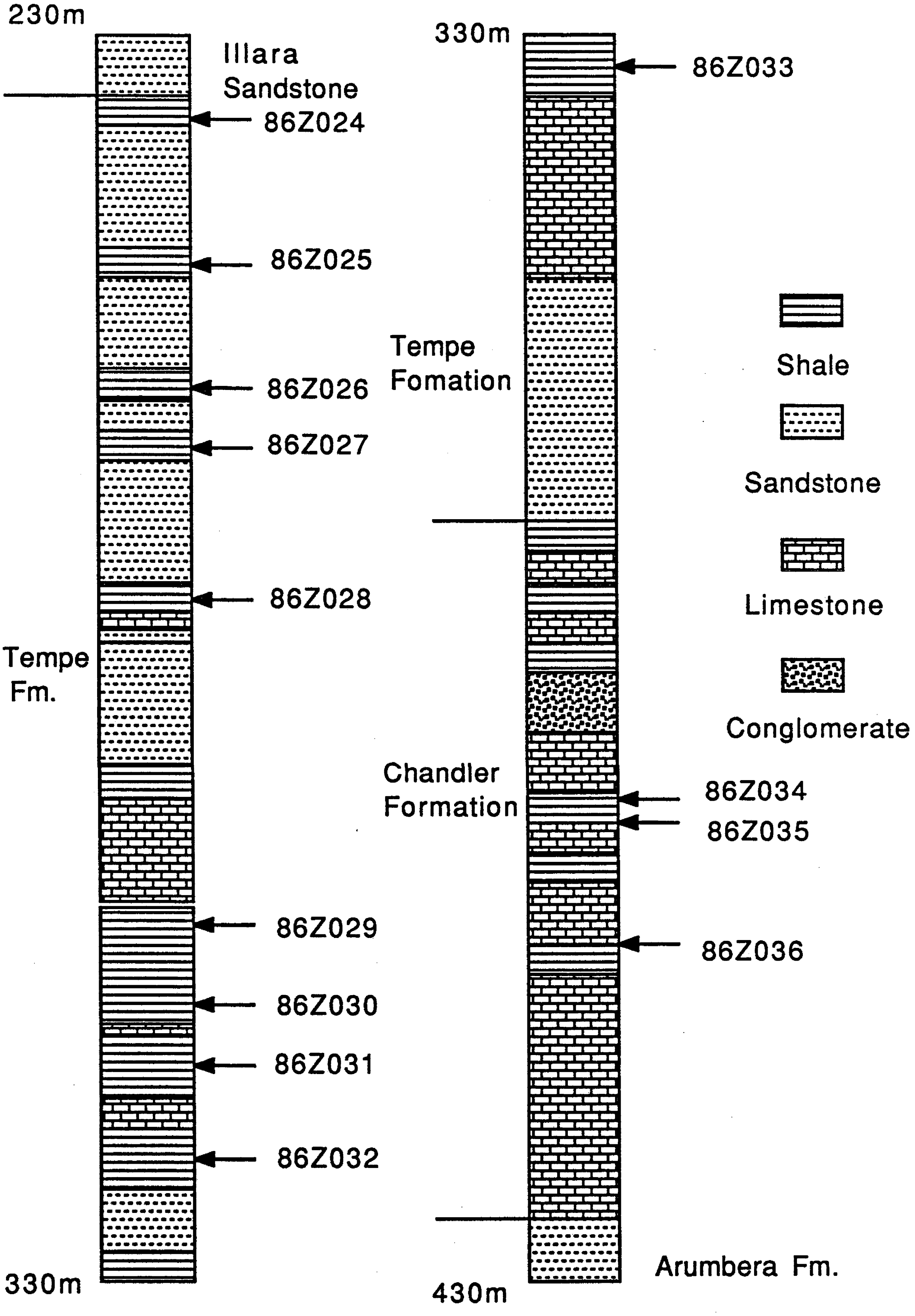
The borehole Hermannsburg No.41 was drilled by the Bureau of the Mineral Resources in the Amadeus Basin in 1985 to investigate the Cambrian sequence in the Gardiner Range, about 200km west of Alice Springs (23°56'03"S and 132°05'36"E). The borehole was spudded from the upper Deception Siltstone and penetrated a complete section of the Illara Sandstone, Tempe Formation, and Chandler Limestone before being completed in the uppermost Arumbera Sandstone. The total depth is 444.5m. A disconformity between the Tempe Formation and Chandler Formation has been detected.

The borehole was spudded about 65m below the contact of the Deception Siltstone and the overlying Petermann Sandstone. The Deception Siltstone consists mainly of thinly interbedded brown micaceous siltstone and sandstone with occasional thicker beds of fine to medium grained sandstone, and the cores of the Sandstone are unfossiliferous.

The Illara Sandstone starts at 112.68m with a thick quartz sandstone. Thin mudstone laminae are quite common, and several thicker mudstone beds, up to 5m thick are also present. The contact of the Illara Sandstone with the underlying Tempe Formation is gradational, the boundary being placed at 241.04m, which is marked by sharp contact of re-worked glauconitic calcareous sandstone (personal communication with J. Bradshaw in BMR). Owen (1986) considered the boundary was at the depth 256.81m. In this study I tentatively accepted the former boundary based on the microfossil distribution.

The Tempe Formation consists of dark grey mudstone with interbedded limestone, dolomite and cross-bedded sandstone. Limestone is commonly dolomitic and some beds are glauconitic. Stylolites are present in the thicker beds, and comminuted fossil debris occurs at several levels. Siltstone and fine sandstone are common as thin laminae in mudstone. In the Tempe Formation two beds of intraclast breccia have been found at 272.8m and 278.9m.

The Chandler Formation starts from the depth 372.97m (384.64m by Bradshaw) and the boundary with overlying Tempe Formation is considered as a disconformity, with cross-bedded fine sandstone of the Tempe Formation resting on dark reddish-brown siltstone of



Text-fig. IV-9. Geological log of the borehole Hermannsburg No.41 in the Amadeus Basin. Sample levels are indicated by arrows.

the upper Chandler Limestone. The silty limestone contains small-scale intraclasts and some thin, vertical, infilled fissures. This passes down at 384.60m into a breccia of dolomite or limestone. The Chandler Limestone probably unconformably overlies the Arumbera Sandstone at 426.9m.

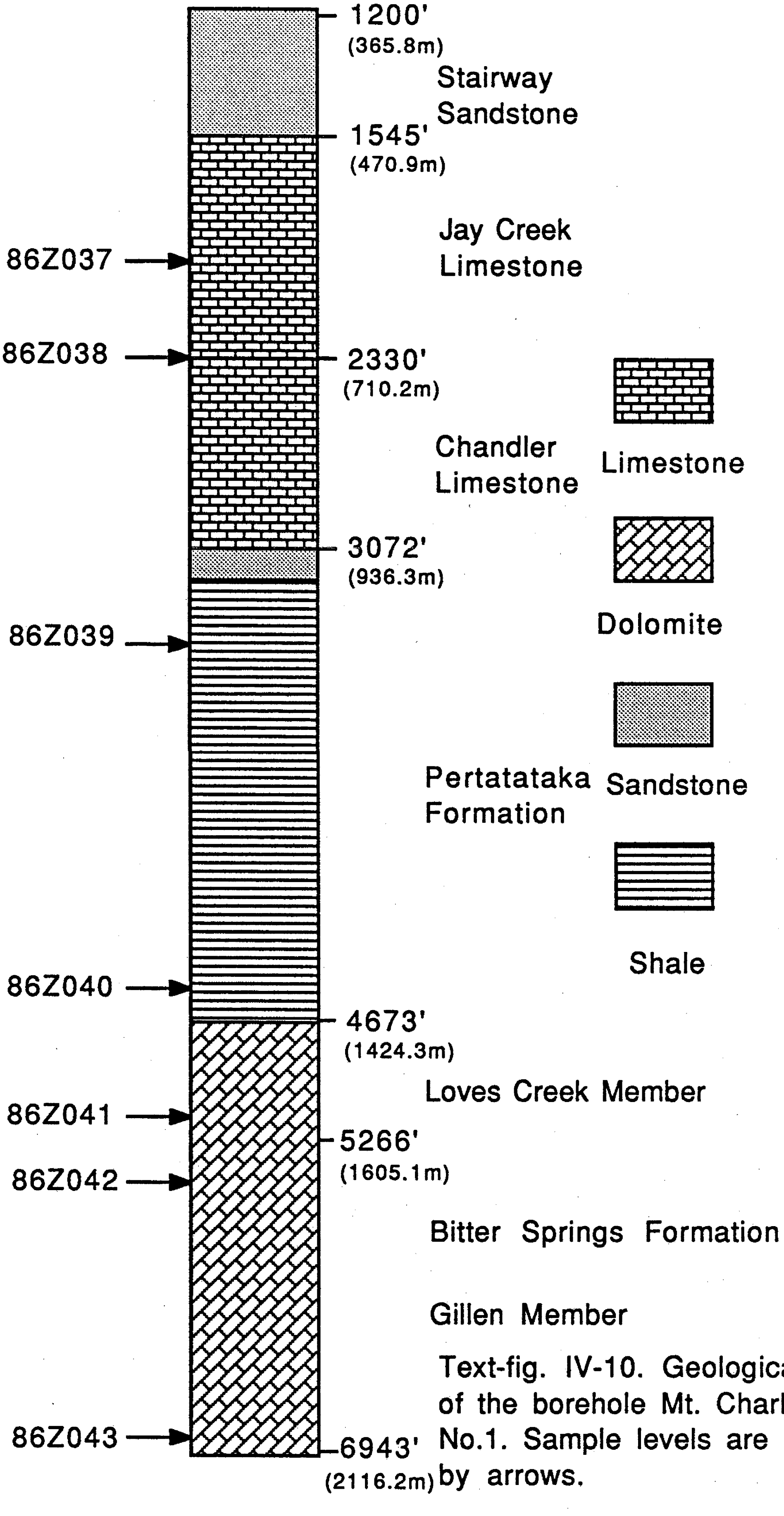
The samples for maceration are collected from the siltstone of the Chandler Formation and the mudstone of the Tempe Formation. Abundant and well-preserved microfossils have been obtained from the Tempe Formation. The microfossils in the Chandler Formation include a few filaments and most organic matter is fragmented (Text-figure IV-9).

*3 The data for the borehole Hermannsburg No.41 are based on well completion report: Owen, M., 1986. BMR Stratigraphic drilling in the Amadeus Basin, Northern Territory, 1985. BMR Record 1986/8.

4.2.5. Mt. Charlotte No.1 *4

The borehole Mt. Charlotte No.1 was drilled by TRANSOIL (N.T.) PTY. LTD. to final depth of 6943 feet (2116.2m) as a stratigraphic and structure test of the Mount Charlotte Anticline (24°52'41"S and 133°59' 11" E). It was spudded in December of 1964 and plugged in February of 1965 in the dolomite and shale of the Upper Proterozoic Bitter Springs Formation (Gillen Member).

The Bitter Springs Formation is detected from 4673' (1424.3m) to 6943' (2116.2m) (TD), including the Loves Creek Member (4673' - 5266' or 1605.1m) and the Gillen Member (5266' - 6943' or 2116.2m). The Loves Creek Member consists predominantly of dolomite interbedded with minor thin grey or brown silty micaceous shale. Some stromatolites and anhydrite layers have been observed. The Gillen Member contains mainly dolomite. Dark grey and grey green and purple silty shales are finely interbedded with dolomite through the sequence. Some siltstones and sandstones locally occur in the



Text-fig. IV-10. Geological log of the borehole Mt. Charlotte No.1. Sample levels are indicated by arrows.

interval of 5600' (1706.9m) - 6040' (1841m). Wells (1980) considered the two members in the Bitter Springs Formation were divided at the depth of 1554.4m.

The Pertatataka Formation (3072' or 936.3m - 4673' or 1424.3m) consists mainly of grey, brownish-grey, brown, silty shales. Thin interbeds of siltstones, dolomites and sandstones have been found. The contact between the Pertatataka Formation and the underlying Bitter Springs Formation is not clearly defined.

Cambrian Chandler Limestone disconformably overlies the Pertatataka Formation. One thin bed of fine sandstone underlying the limestone may be the Arumbera Sandstone. The Chandler Formation conformably underlies the Jay Creek Limestone.

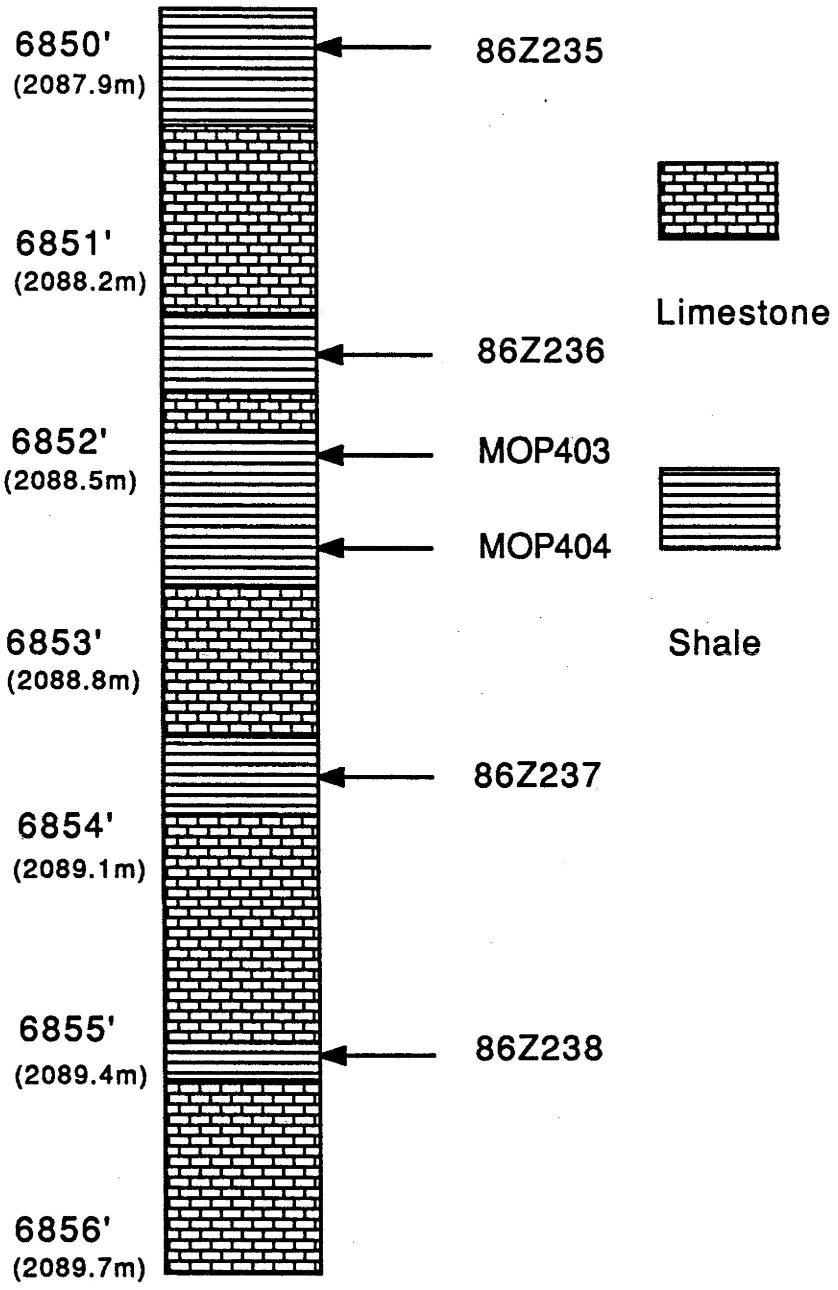
Seven levels of the borehole have been sampled (Text-figure IV-10). The two Cambrian samples yield poorly preserved organic matter and the other Upper Proterozoic sample, specially 86Z043, have been found to contain abundant microfossils.

*4 Data about the borehole Mt Charlotte No.1 are based on the unpublished well completion report (McTaggart, Pemberton and Planalp 1965).

4.2.6. Bluebush No.1*5

The borehole Bluebush No.1 was located at 24°35'15"S and 134°39'00"E and spudded in 1983 by Magellan Petroleum Australia Limited. The borehole started from Silurian? - Ordovician? Mereenie Sandstone to the Upper Proterozoic Gillen Member of the Bitter Springs Formation, with a total depth of 6857 feet (2090m).

The Upper Proterozoic sequence in Bluebush No.1 correlates with that of the Mt. Charlotte No.1. The evaporites of the Todd River Dolomite? (? Chandler Formation) overlie what is probably the Julie Formation. The evaporites consist of red brown to brown siltstones with rare limestone or dolomite streaks. The siltstones are dolomitic and grade in part to a very fine grained grey silty sandstone.



Text-fig. IV-11. Geological log of the Core No. 2 from the borehole Bluebush No.1. Sample levels are indicated by arrows. (Samples MOP403 and MOP404 were collected by Dr. Owen)

A well defined zone of limestone and dolomites of the probable Julie Formation underlies glauconitic sandstone (the Arumbera Sandstone?), and from 5110' (1557.5m) to 5358' (1633.1m) the core consists of predominantly chocolate brown and red brown shale with minor interbeds and stringers of green and orange brown shale of the Pertatataka Formation. The Pertatataka Formation contains shale, siltstone, sandstone and minor dolomite and conformably overlies the Bitter Springs Formation (6312 feet or 1923.9m).

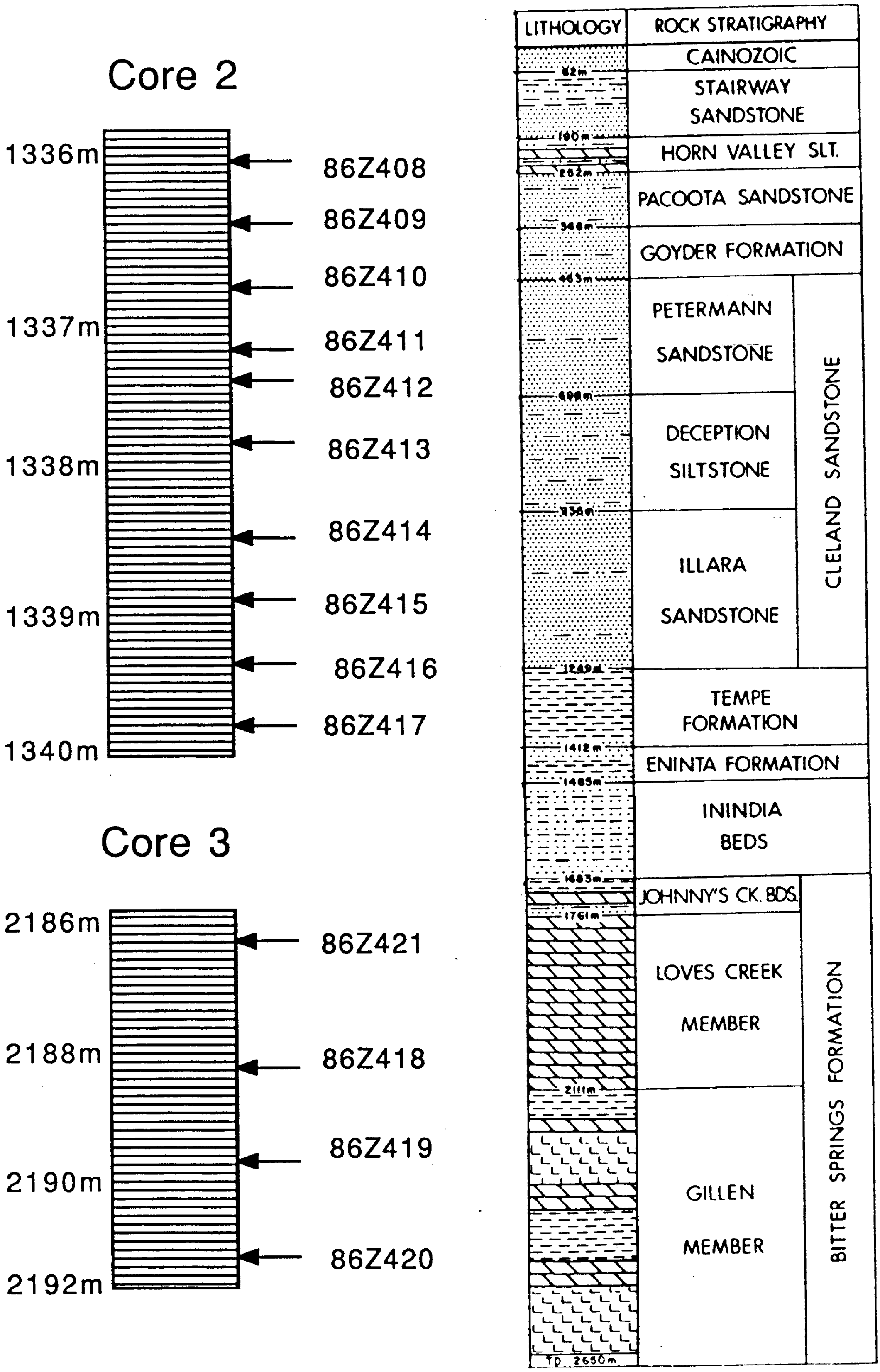
The Bitter Springs Formation consists of the upper Loves Creek Member (6312' - 6578' or 2005m) and the lower Gillen Member (6578' - 6857' or 2090m TD). The upper Member contains mainly dolomite, and lower dolomitic limestone, dolomite with interbedded shales, and the interbeds of carbonates and shales become more prevalent towards the base of the borehole. The Gillen Member consists of anhydrite layers.

Two cores were collected from the borehole Bluebush No.1. Core No.2 is dark grey shale interbedded with dolomitic limestone from the Gillen Member of the Bitter Springs Formation and abundant microfossils have been collected by maceration (Text-figure IV-11).

*5 Data about the borehole Bluebush No.1 are mainly from the unpublished final well report (Bell, R.M., 1983; Magellan Petroleum Australia Limited).

4.2.7. Mt. Winter No.1 *6

The borehole Mt. Winter No.1 is located 65km west of the Mereenie Oil and Gas Field in the Amadeus Basin, Northern Territory (23° 51' 57.3" and 130° 47'40.6") and the borehole was drilled to assess the hydrocarbon potential of the Cambrian sequence, and to investigate the stratigraphic succession below the basal Cambrian unconformity, particularly emphasizing the stratigraphy, reservoir and source rock potential, and maturation history of the Upper Proterozoic sediments.



Text-fig. IV-12. Geological log of the Core 2 and Core 3 of the borehole Mt. Winter No.1. Sample levels are indicated by arrows. The right hand side is the generalized stratigraphic column in the Mt. Winter region of the Amadeus Basin.

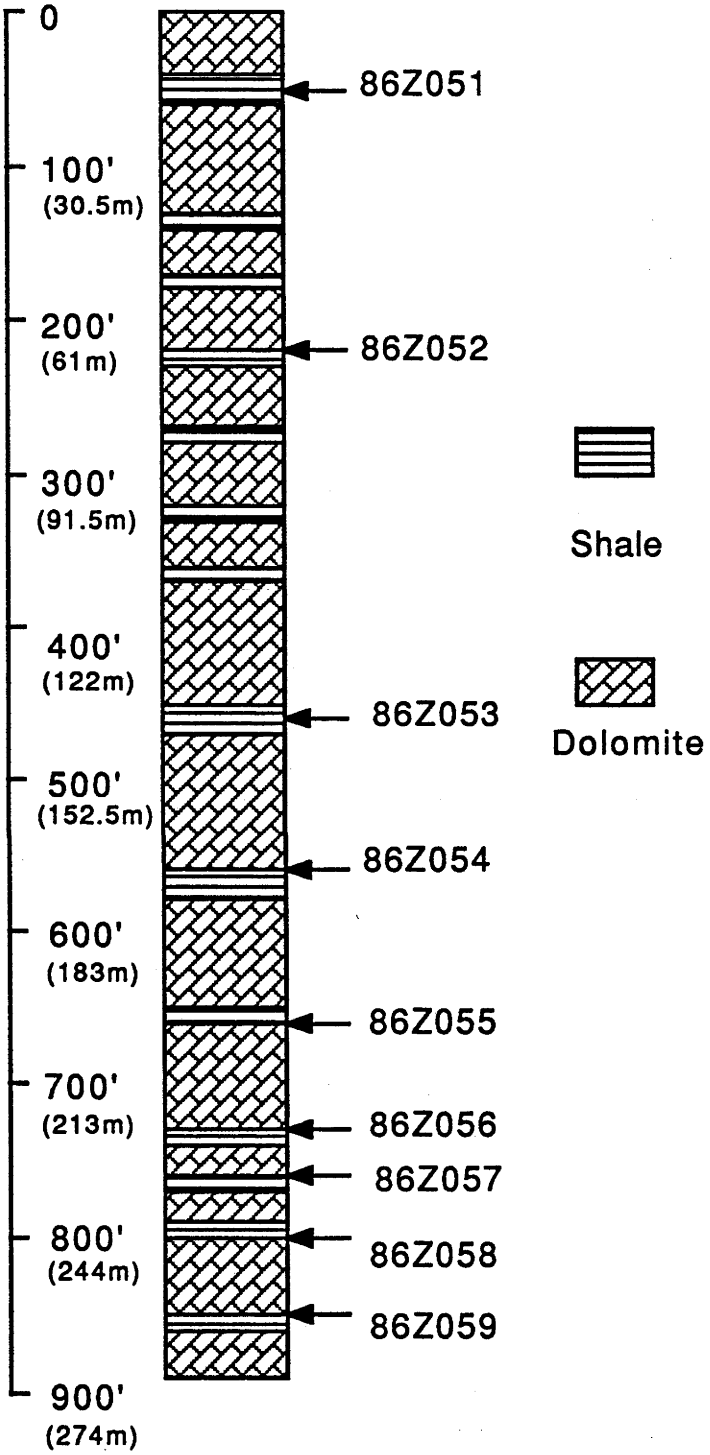
The borehole was completed by the Pancontinental Petroleum Limited. The borehole was spudded from the Middle Ordovician Stairway Sandstone to the basal Gillen Member of the Bitter Springs Formation, with a total depth of 2650m.

Two cores have been collected from the borehole Mt. Winter No.1, one from the Middle Cambrian Tempe Formation and the other from the Gillen Member of the Bitter Springs Formation. Fourteen samples have been cut from the cores and processed to obtain microfossils (Text-figure IV-12).

***6** The data about the borehole Mt. Winter No.1 came from the well report of Pancontinental Petroleum Limited.

4.2.8. Other boreholes

The boreholes Alice Springs No.3, Erldunda No.1 and Illogwa No.5 have been sampled in the levels of the Bitter Springs Formation (ten samples for Alice Springs No.3, see Text-figure IV-13, one each for Erldunda No.1 and Illogwa No.5 respectively), and the microfossils in the boreholes are commonly ill-preserved.



Text-fig. IV-13. Geological log of the Gillen Member at the borehole Alice Springs No.3. Sample levels are indicated by arrrows.

4.3. MICROFOSSIL ASSEMBLAGES FROM THE BITTER SPRINGS FORMATION

4.3.1. Age

No satisfactory isotopic data have been reported from the Bitter Springs Formation. The dykes in the basement of the Amadeus Basin are unconformably overlain by the basal sandstone of the Heavitree Formation and are dated (Rb/Sr on separated minerals) at 897±9 Ma, providing a maximum age for the sedimentary sequence (Black et al., 1980). The Areyonga Formation, the lower tillite in the basin, disconformably overlies the Bitter Springs Formation and currently is correlated with the Sturtian glacials in the Adelaide Geosyncline. The Late Sturtian transgression has an estimated maximum age of 750 Ma (Preiss, 1987). The age of the Bitter Springs Formation, most likely, lies between 900-750 Ma. Based on stromatolite and tillite correlations, Walter (1972) suggested a 950±50 Ma to 740±30 Ma age range for the Bitter Springs Formation, that is a early Late Proterozoic age.

4.3.2. Sedimentary Environments of Microfossil Assemblages.

The microfossil assemblage from the black cherts of the Bitter Springs Formation is well-known for its good preservation and diversity (Schopf, 1968; Schopf and Blacic, 1971). About 50 species of microfossils have been described from the upper Loves Creek Member. Schopf (1972) considered most species were benthic organisms that inhabited a warm, shallow-marine shelf environment. Knoll (1981), using material from the Ross River sections, recognized five microbial communities, four of them for the accretion of mats in shallow subtidal and intertidal environments and the other one in the shallow water column above the benthic mats. These interpretations were consistent with the earlier work of Knoll and Golubic (1979) who suggested the microfossils in the black cherts of the Bitter Springs Formation had been deposited in a shallow subtidal and intertidal setting with associated small, possibly saline ponds.

A most significant study of the depositional environments of microbial communities in the Bitter Springs Formation was recently undertaken by Southgate (1986). The beds of black chert nodules in the Loves Creeks Member contain bipyramidal quartz, halite pseudomorphs, but no gypsum. He interpreted the environment as a series of shallow metahaline to hypersaline nonmarine lakes and ponds. "Groundwaters of halite salinity inhibited the bacterial degradation of the organic matter produced by the cyanobacterial communities. These same ground and lake waters contained large quantities of (spilite - derived) dissolved silica. During the final stages of lake-water evaporation, the solubility product of the dissolved silica was exceeded, which resulted in the early precipitation of diagenetic chert, thus facilitating the preservation of some cells and sheaths" (Southgate, 1986).

The microfossils in this study were collected from the shales of the lower Gillen Member in the Bitter Springs Formation. The Gillen Member consists of interbedded sequences of carbonates and clastics with thick evaporite deposits. The lower part of the Member is dominated by shale, siltstone and sandstone with subordinate granule conglomerate. The sandstones are commonly cross-bedded and some beds of carbonates are oolitic. The upper part of the Member has increasing dolomite and limestone. Some columnar and domal stromatolites have been found in the middle of the Member (Walter, 1972), and gypsum or anhydrite and halite pseudomorphs are observed in many sections and boreholes. Stewart (1979) interpreted the evaporite deposits at Ringwood Dome as having formed in a lagoon or barred basin. Arid environments resulted in gypsum and anhydrite deposits.

Wells et al. (1967) considered the Gillen Member was deposited in a shallow sea. This interpretation was succeeded by that of Wells et al. (1970) " the Heavitree Quartzite was deposited as a blanket sand on the irregular basement floor of a shallow sea"; as sedimentation proceeded parts of the sea became partly or totally landlocked, and in the barred basins and lagoons so formed, lutites and carbonate rocks, interspersed with evaporites, were laid down; and the evaporites accumulated in local barred basins during the period of deposition of the Gillen Member (Wells et al., 1970). Thus depositional environments in the Gillen Member probably contain open coastal or shallow marine, barred basins or lagoons, and other local variations.

Microfossils from the Gillen Member may support the interpretations of the depositional environments. In Bluebush No.1, Core No.2 was collected from the Gillen Member near the base of the borehole. The core is about 183cm long (from 6850 feet 0r 2087.9m to 6856 feet or 2089.7m) and interbedded with limestones and shales. Six layers of shales are present and each layer has been sampled within 3-20cm interval. All samples have been processed and observed for microfossils.

All six microfossil associations observed have abundant, similar filamentous cyanobacteria; four of them are dominated by the filamentous mats of *Eomycetopsis robusta* (Schopf) Knoll and Golubic, 1979 and the associations from the samples 86Z236 and MOP403 contain mainly spheroidal acritarchs. *Eomycetopsis robusta* is a cyanobacterium of benthic filaments which are commonly interwoven to form mats, possibly in coastal, shallow water environments. In his interpretation of the relationship between the microbial communities and depositional environments, Knoll (1981) considered that the mat communities were deposited in different sublittoral and interlittoral environments. This interpretation could be applied for the mat-dominated associations from the Gillen Member.

Eomycetopsis robusta (Schopf) in the Gillen Member commonly occurs with other filamentous taxa *Archaeotrichion contortum, Siphonophycus kestron, Siphonophycus* sp., *Oscillatoriopsis* sp., *Obruchevella* sp., *Heliconema fidicularis* sp. nov., *Quaestiosignum filum* gen. et sp. nov. and others. Sometimes different filaments interwove to form mats. In mat-dominant assemblages many spheroidal microfossils, such as *Protoleiosphaeridium, Pyritosphaera, Leiosphaeridia, Kildinosphaera, Myxococcoides, Palaeoanacystis, Sphaerophycus* and other leiospherids also occur. In Hamelin Pool, Shark Bay of Western Australia, abundant mat-forming microorganism communities are commonly distributed in the upper part of subtidal and intertidal. However, we should keep in mind that the stromatolites in the Late Proterozoic were widespread and the filamentous cyanobacterial mats consisted of different microorganisms.

It is interesting that the sample 86Z236 is dominated by a group of acritarchs with numerous solid, thin, spongy processes radiating from a centre and processes occasionally supporting a thin outer membrane. The acritarchs have been named as *Dasysphaeridium* gen. nov., which includes two species: *D. trichotum* and *D. walterii*. *Dasysphaeridium* consists of more than 80% of specimens in sample 86Z236, and it is associated with a new filamentous genus *Quaestiosignum* and other spheroidal microfossils such as *Protoleiosphaeridium, Alliumella* etc.; some filaments of *Eomycetopsis, Siphonophycus* and *Archaeotrichion* have been found; no spinose acritarchs have been observed.

The shales of sample 86Z236 are dark, and consists of quartz, muscovite, some chlorite and pyrite grains, which were possibly deposited in a reducing environment. *Dasysphaeridium* is a distinctive acritarch; no modern bacteria or algae have been found with a similar morphology. Its dominance in the assemblage and the limited number of associated planktonic microfossils suggests the depositional environment was particularly favourable for these microorganisms and possibly harmful to other plankters. A low diversity assemblage has been observed from the Ringwood evaporite deposit in the Gillen Member (sample collected from the borehole Alice Springs No.3) and the characteristics reflect stressful conditions in a periodically stagnant, hypersaline lagoon (Oehler et al., 1979). Assemblages of low diversity dominated by one or a few taxa have been considered as characteristic of lagoonal environments (Vidal and Knoll, 1983; Knoll, 1984).

Sample MOP403 also contains abundant filamentous microfossils, but it is dominated by planktonic acritarchs. Spinose taxa *Skiagia, Trachyhystrichosphaera, Comasphaeridium* and *Micrhystridium* occur abundantly in the assemblage, and the assemblage is dominated by spheroidal microfossils such as *Leiosphaeridia, Kildinosphaera, Protoleiosphaeridium, Pyritosphaera, Pterospermopsimorpha* and others, some of which are very large (more than 300*um* in diameter). Some mat-builder spheroids such as *Myxococcoides* and *Sphaerophycus* have been observed. The plankton - dominant assemblage probably indicates an coastal environment.

Microfossil assemblages in the borehole Bluebush No.1 generally show stable microbial associations, with all samples containing filaments and some mat-builder spheroids, which probably represent benthic communities in a stable shallow water environment. Occasionally currents would bring other microorganisms to this environment, therefore leiospheroidal and spinose acritarchs have been found to dominate some samples. In the upper part of the Gillen Member in the borehole, the deposits contain light grey massive anhydrite which indicate an arid environment.

Microfossils from the Gillen Member at the borehole Mt. Charlotte No.1 display a different assemblage. Sample 86Z043 consists of almost completely spheroidal plankton, and few filaments were observed. The assemblage contains abundant specimens of *Leiomarginata*? *twamaceria, Protoleiosphaeridium* sp., *Pterospermopsimorpha spongia, Octoedryxium atroquadrum* and others, and scattered spinose specimens of *Trachyhystrichosphaera* have been found. Plankton-dominant assemblage probably indicates an nearshore open marine environment. The another sample (86Z042) from the Gillen Member contains many specimens of *Trachysphaeridium, Kildinosphaera, Stictosphaeridium* and *Protoleiosphaeridium*, but few filamentous cyanobacteria, possibly have been deposited in the similar coastal environment.

The borehole Alice Springs No.3 was drilled in the gypsum beds in the Gillen Member of the Bitter Springs Formation. Oehler et al. (1979) sampled some cherty areas of the silicified dolomite from the 170.7m level and the microfossils found are of small size, low diversity, and probably procaryotic affinities; the enclosing sediments suggested that these microfossils had been deposited in a hypersaline lagoon (Oehler et al., 1979). Ten shaly samples were collected in this study from gypsum-rich shaly layers. The uppermost two samples (86Z051 and 86Z052) yield some ill-preserved specimens. Microfossils observed display low diversity and consist of many filaments of *Eomycetopsis robusta*, and common Proterozoic spheroids such as *Protoleiosphaeridium, Trachysphaeridium, Kildinosphaera, Stictosphaeridium* and some colonies without clear structures possibly assigned to *Synsphaeridium* or *Myxococcoides*. No spinose acritarchs have been found. The low diversity of the assemblage is an important characteristic of lagoonal microfossils.

Knoll (1984) recognized two microfossil assemblages from the Upper Riphean Hunnberg Formation in Svalbard, one lagoonal and the other in open coastal facies. The lagoonal assemblage found in cherts includes a low diversity of plankton and two species are dominant; in strong contrast, the plankton assemblage in open coastal cherts contains more than two dozen taxa. The two assemblages are comparable with those of the Gillen Member.

4.3.3. Significance of Microfossil Assemblages from the Gillen Member

The microfossil assemblage from the Gillen Member consists of about 35 spheroidal form species and about 10 filamentous cyanobacteria. Compared to the microfossils from the upper Loves Creek Member, the assemblage from the Gillen Member contains more planktonic species, especially spinose acritarchs which are probably important in biostratigraphic correlation. The Bitter Springs Formation is early Late Proterozoic in age. Its assemblage is probably the most abundant and diverse one so far found in the rocks of this age.

The genus *Skiagia* was described by Downie (1982) to include a group of Cambrian spinose acritarchs with funnel-shaped processes, and some species have been reported from the Lower Cambrian Holmia Shale level (=?*Eoredlichia* Zone in China) worldwide (Downie, 1982; Knoll and Swett, 1987). One species, *Skiagia pusilla* sp. nov., observed from the Gillen Member is characterized by its tiny size, short processes with broad funnels linking up with neighbouring processes distally, and it differs from *Skiagia scottica* in having no "plug" structure at the bases of processes. Since there are no other specimens reported below the Ediacarian sequences the occurrence of *Skiagia* in the Bitter Springs Formation is probably the lowest level so far known in the geological record.

Another important species assigned to *Comasphaeridium pollostum* sp. nov. differs from other species in same genus in its small size and villus-like processes. Other species such as *C. strigosum* (Jankauskas) Downie have been reported worldwide in the Cambrian sequence (Downie, 1982; Moczydlowska and Vidal, 1986; Knoll and Swett, 1987; Zang, in Chapter III), some large specimens of *C. magnum* Zhang, 1986 are observed in the Sinian Doushantuo Formation (Zhang, 1984), and another two forms from the Ediacarian Pertatataka Formation. The occurrence of the *C. pollostum* in the Gillen Member suggests that the genus *Comasphaeridium* at least ranged back into the early Late Proterozoic.

Three large vesicles of *Trachyhystrichosphaera* have been found in the samples MOP403 and 86Z043. In this genus, *Trachyhystrichosphaera aimika* Hermann has been reported from the early Late Proterozoic of the Soviet Union (in Timofeev et al., 1976) and *T. vidalii* Knoll from the latest Riphean Hunnberg Formation in Svalbard (Knoll, 1984). Abundant specimens of *Trachyhystrichosphaera* have been observed from the Ediacarian Pertatataka Formation.

Four forms of micrhystrids have been observed in the Gillen Member, including one long ranging taxon, two new species and an uncertain taxon. *M. circulapertum* has been recorded from the Sinian Liulaobei Formation and Lower Cambrian Qiongzhusi and Gouhou Formations, but the other three taxa have not been found elsewhere. Abundant occurrence of micrhystrids is another important feature of the microfossil assemblage in the Gillen Member.

The microfossil assemblage of the Gillen Member contains many new taxa. One new genus *Dasysphaeridium* consists of two species; *D. trichotum* and *D. walterii*. The former species has been found ranging into the Ediacarian Pertatataka Formation and the latter is only recorded from the Gillen Member. Their unique structures of numerous solid spongy processes occasionally supporting an outer membrane, are different from any other fossil acritarchs and modern analogues, and their affinities are enigmatic. Also another species *Octoedryxium atroquadrum* sp. nov. is restricted in the sample 86Z043 of the borehole Mt. Charlotte No.1. It differs from *O. truncatum* (Rudavskaja) Vidal, 1976 in the presence of a darker square in the centre. *O. truncatum* is commonly considered as an Ediacarian (or Late Vendian) species and widely distributed in the Europe, the Soviet Union, China and Australia (Vidal, 1976), but some of them may range back into the early Late Proterozoic (Sin and Liu, 1973). In the Amadeus Basin, *O. truncatum* has been found in the Pertatataka Formation and but not from the Bitter Springs Formation. The occurrence of *O. atroquadrum*, *Dasysphaeridium trichotum*, *D. walterii* and other species in the Gillen Member may suggest that the early Late Proterozoic is an important period for the appearance of many new taxa before the Late Proterozoic glaciations.

Many taxa in the Gillen Member have been recorded through the Upper Proterozoic and Cambrian or younger ages. *Leiomarginata*? *simplex* Naumova is characterized by its thickened ring with stable width around margin and has been described from upper Sinian Liulaobei Formation and many localities of lower Cambrian sequences in China, the Soviet Union, Poland and elsewhere. Its occurrence in the Gillen Member is associated with another new species *Leiomarginata*? *twamaceria* which is abundant in the boreholes Mt. Charlotte No.1 and Bluebush No.1, and particularly the Mt. Charlotte No.1, in which the species almost dominates the assemblage. Also the occurrence of other species previously reported from the Ediacarian (or upper Sinian or Upper Vendian) includes *Tasmanites* sp., *Alliumella baltica, Alliumella* sp., *Pterospermopsimorpha binata, P. spongia, Sinianella uniplicata, S. scabrata, Lophosphaeridium tuberosum* and *Teophipolia* sp., and the presence of these species in the Bitter Springs Formation may suggest they are long ranging taxa in the Upper Proterozoic.

Leiospheroidal microfossils have been considered as common species in the Proterozoic and younger rocks, though Volkova (1969) suggested that *Leiosphaeridia*-dominant assemblages were a characteristic feature of the Vendian. Leiosphaerids occur abundantly in almost every sample in the Gillen Member, and even dominate some assemblages. The species include *Leiosphaeridia asperata, Kildinosphaera chagrinata, K. granulata, Protoleiosphaeridium densum, P. flexuosum, P. papyraceum, Stictosphaeridium* sp.,and *Synsphaeridium* sp.. The specimens of the genus *Trachysphaeridium* and *Pyritosphaera barbaria* commonly occur with leiospherids.

A single specimen of a vase-shaped microfossil has been observed in sample 86Z043 of the Mt. Charlotte No.1. The vesicle is spongy, but no oral structures have been observed. It is named *Melanocyrillium* sp. B. Vase-shaped microfossils have been considered as heterotrophic protists which functioned as predators in the nearshore planktonic ecosystem, feeding upon bacteria, algae and other protists (Knoll and Vidal, 1980). Bloeser (1985) described the new genus *Melanocyrillium* from the shales of the Kwagnut Formation of the Chuar Group in Arizona and the genus includes three species. Many vase-shaped microfossils have been reported in the Upper Proterozoic.

Many specimens previously described from the cherts are superbly preserved in the Gillen Member. Some of them, such as *Myxococcoides minor* Schopf, *Gloeodiniopsis lamellosa* (Schopf) Knoll and Golubic and others have been recorded from the upper Loves Creek Member of the Bitter Springs Formation; some are described as new, and most of them form colonies, like the mat builders, some even associated with filamentous mats. Their occurrence may not be important in stratigraphic correlation for mat-builder species have commonly been considered to be environmentally controlled.

Filamentous cyanobacteria are abundant and beautifully preserved in the Gillen Member. Many forms have been described from the upper Loves Creek Member (Schopf, 1968; Schopf and Blacic, 1971). *Eomycetopsis robusta* (Schopf) dominates some assemblages and occurs in almost every sample. *Siphonophycus* sp. and *Archaeotrichion contortum* are abundant in most samples. As an exception, two specimens of the spring-like *Obruchevella* have been found; this genus has not been recorded from the cherts of the Loves Creek Member. In addition, two new species have been described - one is the twisted form *Heliconema fidicularis* sp. nov., and the other is "question-mark"-like form *Quaestiosignum filum* gen. et sp. nov.

The borehole BMR Alice Springs No.3 was drilled in the gypsum-rich beds of the Gillen Member and interbedded shales are black or carbonized. Microfossils are observed from the upper two samples (86Z051 and 86Z052) and they are commonly ill-preserved. The assemblage consists of the spheroids *Protoleiosphaeridium flexuosum, Trachysphaeridium levis, Trachysphaeridium* sp., *Sinianella* sp., *Kildinosphaera* sp.,

	Bluebush1.	Mt. Charlotte1.	Alice Springs 3.
Alliumella baltica	C	N	N
Comasphaeridium pollostum	C	N	N
Dasysphaeridium trichotum	V	C	N
Dasysphaeridium walterii	V	R	N
Glenobotrydion sp.	V	N	N
Gloeodiniopsis lamellosa	V	N	N
Kildinosphaera chagrinata	V	A	C
Kildinosphaera granulata	A	C	R
Kildinosphaera verrucata	R	N	N
Leiomarginata ? simplex	R	V	N
Leiomarginata ? twamaceria	R	V	N
Leiosphaeridia asperata	V	A	R
Lophosphaeridium tuberosum	R	N	N
Melanocyrillium sp. A	N	R	N
Micrhystridium circulapertum	R	N	N
Micrhystridium geminatum	V	N	N
Micrhystridium pisinnum	V	N	N
Myxococcoides minor	C	N	N
Myxococcoides multiplicis	V	N	N
Myxococcoides sp.	V	R	R
Octoedryxium atroquadrum	N	C	N
Palaeoanacystis compacta	C	N	N
Protoleiosphaeridium densum	V	A	R
P. flexuosum	V	V	V
P. papyraceum	R	N	N
Protoleiosphaeridium sp.	R	N	N
Pterospermopsimorpha binata	R	N	N
P. spongia	V	A	C
Pterospermopsimorpha sp.	R	N	N
Pyritosphaera barbaria	V	C	R
Sinianella scabrata	C	N	N
Sinianella uniplicata	C	N	N
Sinianella sp.	R	R	N
Skiagia pusilla	C	N	N
Sphaerophycus sphairum	V	N	N
Stictosphaeridium sp.	V	C	C
Synsphaeridium sp.	V	C	C

Text-fig. IV-14. page1-2. (1)

	Bluebush1	Mt. Charlotte1	Alice Springs 3
Tasmanites sp.	R	N	N
Teophipolia sp.	R	N	N
Trachyhystrichosphaera sp.	R	R	N
Trachysphaeridium levis	C	C	R
Trachysphaeridium sp.	A	C	C
Unnamed specimen A	R	N	N
Archaeotrichion contortum	V	N	N
Eomycetopsis robusta	V	N	V
Eomycetopsis spiralata	R	N	N
Heliconema fidicularis	A	N	N
Obruchevella sp. A	R	N	N
Oscillatoriopsis spp.	V	N	N
Quaestiosignum filum	V	N	N
Siphonophycus kestron	V	N	N
Siphonophycus sp. A	V	N	N

Text-fig. IV-14. Microfossils from the Gillen Member of the Bitter Springs Formation at the boreholes Bluebush No.1, Mt. Charlotte No.1 and Alice Springs No.3 in the Amadeus Basin. V-very abundant (more than 50 specimens), A-abundant (20-50 specimens), C-common (5-20 specimens), R-rare (1-5 specimens) and N-nil.

Pyritosphaera barbaria, and filaments *Eomycetopsis robusta*, and *Siphonophycus* sp. Most of these species have been considered as common taxa in the Upper Proterozoic. A similar assemblage has been recorded from the borehole BMR Illogwa No.5, which was drilled on the southwestern limb of a major asymmetrical northwest-trending anticline, about 30km southeast of the BMR Alice Springs No.3. McKirdy (1977, Ph.D. Thesis, unpublished) concluded from geochemical data that the Bitter Springs Formation is overmature in this area.

Core No.3 of the borehole Mt. Winter No.1 was collected from the Gillen Member and consists of interbedded black shales and dolomites. Microfossils from the black shale are badly preserved and fragmented, and have no value for identification, and like the black shales in BMR Alice Springs No.3 are probably overmature. Also two samples were collected from Ooraminna No.1, and one sample from the Gillen Member at the Ellery Creek section and all of them contain scattered organic fragments which provide no information for microfossil study.

The microfossils in the Gillen Member, as mentioned above, contain many common species ranging throughout the Proterozoic or younger rocks, as well as many unique forms or many new species. The specially abundant occurrence of the spinose acritarchs is a characteristic feature in this assemblage of early Late Proterozoic age. The appearance of the spinose forms *Skiagia*, *Comasphaeridium*, *Trachyhystrichosphaera*, and *Micrhystridium* is important in evolutionary successions of microorganism history and it will be discussed later in this study.

4.3.4. Microfossils from the Shale of the Loves Creek Member

Abundant microfossils have been described from the cherts of the Loves Creek Member of the Bitter Springs Formation (Schopf, 1968; Schopf and Blacic, 1971), but have not been reported from the shales so far. In this study only one sample from the Loves Creek Member is available for maceration. The sample (86Z041) consists of grey siltstone and collected from the depth of 5137 feet (1565.8m) - 5147 feet (1568.8m) at the borehole

Mt. Charlotte No.1. According to Wells (1980), this depth is within the Loves Creek Member.

The microfossils from the siltstone are different from those from the cherts, being dominated by spheroids, and having few filaments of *Eomycetopsis robusta* (Schopf). Spheroidal acritarchs include *Kildinosphaera chagrinata, K. granulata, Leiosphaeridia asperata, Protoleiosphaeridium densum, P. flexuosum, P. papyraceum, Pterospermopsimorpha spongia, Trachysphaeridium levis, Trachysphaeridium* sp. and *Stictosphaeridium* sp. All of them are common species in the Upper Proterozoic. No spinose acritarchs have been found in the Loves Creek Member.

4.4. TILLITES AND INTERGLACIAL MICROFOSSILS

4.4.1. Tillites as Important Beds for Correlation in the Upper Proterozoic

Two sets of tillites have been recorded from the Upper Proterozoic sequence in the Amadeus Basin, with the Areyonga Formation below and the Olympic Formation above. The two tillites are separated by the interglacial siltstone and calcareous shale of the Aralka Formation which has a maximum thickness of about 1000m.

In the Amadeus Basin, the tillites are exposed in a restricted region, and are mainly distributed in the north-east of the basin. The Areyonga Formation, Inindia Beds, the Carnegie and Boord Formations are considered to have a similar stratigraphical position and to be for the most part contemporaneous (Wells et al., 1970); the upper diamictite of the Olympic Formation is transitionally equivalent to the Pioneer Sandstone in the Alice Springs area and the sandstone has been deposited in an intertidal environment.

Upper Proterozoic glaciogenic sediments are well correlated in the Adelaide Geosyncline, the Amadeus, Ngalia, and Georgina Basins (Preiss et al., 1978). In South Australia, the Adelaide Geosyncline contains two glacial sequences, the lower Sturtian and upper Marinoan; the lower tillite especially has been considered as one of the most complete, best preserved and best documented late Proterozoic glacial sequences in the world (Coats and Preiss, 1987). Dunn et al. (1971) suggested these tillites are world-wide chronostratigraphic units, and proposed the name "Sturt marker" in the stratigraphical correlation in the Late Proterozoic.

There are no convincing isotopic data for the tillites in the Amadeus Basin. Compston and Arriens (1968) undertook a isotopic dating (Rb-Sr whole rock) for glacial sediments correlated with those of the Amadeus Basin; isochron patterns are complex, some indicating a 790 Ma age but others being younger at approximately 600 Ma. Compston and Arriens (1968) considered the Upper Proterozoic sediments adjacent to the glacial beds in the Amadeus Basin were not much older than 800 Ma. Some results from the Kimberley region of north - western Australia may be relevant: the older tillite was dated 740±30 Ma, interglacial shales were dated 685±70 Ma, and shales from above the younger tillite were dated 665±45 Ma (Compston and Arriens, 1968).

Preiss (1987) considered the best estimates of ages for the Adelaidean tillites to be as follows: a probable maximum age of about 750 Ma for Late Sturtian transgression (post-glaciation) and a probable maximum age of 670 Ma for mid-Marinoan transgression (post-glaciation). The two widespread tillites were considered to have been deposited in the time interval 700-800 Ma (cf. Black et al., 1980). Other data from China (Wang et al., 1980) indicate that the time interval for two Upper Proterozoic glaciations ranges 680±20 - 780±20 Ma.

Upper Proterozoic tillites are widely distributed in China. Two tillites have been found on the South China Platform - the lower Chang'an Tillite and upper Nantuo Tillite. They probably have a similar stratigraphical position to that of the Amadeus Basin. In the Xingjiang area of northwestern China, three sets of the tillites are separated by marine sediments exposed in Kuruktag region. The lower two tillites are considered to be correlated with the tillites on the South China Platform, and the uppermost tillite has been suggested to equal to the latest Proterozoic Luoquan tillite in the central China (Guan et al., 1986).

Microfossils from the tillites are poorly preserved. Four samples are collected from the borehole Ooraminna No.1 and the level (4166-4170 feet or 1269.8-1271m) has been suggested as the Areyonga Formation. Most organic matter is dark and fragmented, of no value for microfossil study.

4.4.2. Microfossils from the Aralka Formation

The interglacial Aralka Formation conformably overlies the Areyonga Formation and disconformably underlies the Olympic Formation. The unit consists of predominantly grey calcareous shale, siltstone and dolomite, and is mainly distributed in the north-east of the basin. Two members, the Ringwood (lower) and Limba (upper), have been recognized in the formation.

Several samples collected from the borehole BMR Illogwa Creek No.6 produced poorly preserved organic matter. The rock is thick calcareous siltstone and has been tested to contain low values of total organic carbon (Felton and West, 1982, unpublished data). The organic matter is commonly fragmented.

The sample (86Z206) was collected from the lowest part of the Aralka Formation in the Ellery Creek section. The calcareous shale has been weathered, and there are only scattered exposures along Ellery Creek. About 100g of shaly rocks have been processed by the normal palynological method and organic matter dealt with concentrated nitric acid (70%) for about five minutes, then sieved and floated by heavy liquid (specific gravity=2.0). Abundant organic fragments have been observed in the slides and only part of them can be identified.

The microfossil assemblage contains abundant *Pyritosphaera barbaria* Love and many spheroidal acritarchs: *Protoleiosphaeridium flexuosum* (Tim), *Protoleiosphaeridium* sp., *Kildinosphaera* sp., *Trachysphaeridium* sp., and *Favososphaeridium* sp. Some unidentified forms also occur. *Pyritosphaera barbaria* (=*Bavlinella faveolata*) has been found widespread in the Proterozoic and Palaeozoic and the forms were considered to be important species in the Tillite Group in East Greenland (Vidal, 1981).

It is interesting that only one spinose fragment observed may be assigned to *Comasphaeridium*. The specimen is about 40*u*m in diameter and bears relatively long (about 8*u*m), slender, flexible spines. Occurrence of spinose acritarchs in the interglacial assemblage is, needless to say, important, but in this study more information is needed for useful stratigraphic information to be deduced.

Several fragmented filaments may be attributed to *Eomycetopsis robusta* (Schopf), which possibly adds some useful data for a environmental analysis.

The microfossil assemblage in the Aralka Formation consists mainly of common Proterozoic and Cambrian acritarchs, without significant taxa to characterize the assemblage. Most likely, most useful microorganisms have been damaged, but also depositional environments, such as frigid weather, may limit their distribution.

In summary, the microfossils from the tillites and interglacial rocks of the Amadeus Basin have not provided valuable information for biostratigraphic correlation. The isotopic data from this time interval are questioned.