ACRITARCH BIOSTRATIGRAPHY OF THE ORDOVICIAN-SILURIAN SEQUENCE ALONG SUMNA-RIMKHIM SECTION, TETHYAN GARHWAL HIMALAYA, CHAMOLI DISTRICT, UTTAR PRADESH

A THESIS

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By

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Gratis

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **ACRITARCH BIOSTRATIGRAPHY OF THE ORDOVICIAN-SILURIAN SEQUENCE ALONG SUMNA-RIMKHIM SECTION, TETHYAN GARHWAL HIMALAYA, CHAMOLI DISTRICT, UTTAR PRADESH** in fulfilment of the requirement for the award of the Degree of **Doctor of Philosophy** and submitted in the Department of **EARTH SCIENCES** of the University is an authentic record of my own work carried out during a period from **July, 1991** to **July, 1995** under the supervision of **PROFESSOR S.S. SRIVASTAVA.**

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other University.

H. N. Sinha

HARESHWAR NARAIN SINHA

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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The Ph.D. Viva-Voce examination of **Mr. HARESHWAR NARAIN SINHA** Research Scholar, has been held on ...29-2-1996...

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Signature of Supervisor	Signature of H.O.D.	Signature of External Examiner

ABSTRACT

Rocks of the Lower Paleozoic marine sequence occur in the Tethyan Zone of the Himalaya with exposures in Kashmir, Spiti, (Himachal Pradesh) and Kumaon-Garhwal (Uttar Pradesh) regions of India.

Although, these sediments have received attention of geologists since long, very little studies have been carried on the palynological aspects so far. Published literature reveals the occurrence of brachiopods, trace-fossils, conodonts and certain other fossil microbiota in the Lower Paleozoic marine sequence. No published record is available on acritarch biostratigraphy of this sequence in the Garhwal region.

The present study, therefore, is aimed at investigating these rocks on this aspect, especially in view of well known occurrences of acritarchs in the Ordovician-Silurian rocks from many parts of the world like, United Kingdom, Belgium, Spain, Norway, Arabian Sahara, Africa, United States of America and Canada etc.

The study area lies in the Tethyan Zone of the Garhwal Himalaya in and around the village, Sumna, Chamoli district, Uttar Pradesh, India. The geographic coordinates of the region are 30°40' latitude and 80°50' longitude. The area, in general, is poorly accessible due to physiography, hostile climate, and also from the point of view of its proximity to the international border area with China. The study, therefore, was taken up along the mule track between Sumna and Rimkhim covering Ordovician-Silurian sequence outcropping in a stretch of about five kilometers.

Two geological field investigations were undertaken during the months of August and September in 1992 and in 1993. The Sumna-Rimkhim section, in the study area, was found to be an ideal section exposing a large part (Ordovician to Silurian) of the Lower Paleozoic marine sequence after a thorough reconnaissance survey. The lithostratigraphic Units

(Ordovician to Silurian) namely Garbyang (upper part), Shiala, Yong Limestone and Variegated formations in stratigraphic order were examined along this section of about 680 meters thickness. Seventyone samples of these sediments were collected at measured intervals for the present investigation. Litho-petro-stratigraphic column was prepared after necessary correction through careful computation of the field data. The broad lithology of the section examined constitutes litho-units like siltstone, shale, siltyshale, sandstone and limestone.

However, only the sediments of Shiala and Yong Limestone formations (Caradocian to Ludlovian) yielded acritarchs. Samples of Garbyang and Variegated formations (of Llandelian and uppermost Ludlovian ages respectively) were found barren of acritarchs but were found containing other macro-and microfossils.

Treatment of samples using the conventional palynological techniques yielded abundant and varied forms of acritarchs with infrequent to rare to common occurrence of chitinozoans, melanosclerites, conodonts, scolecodonts, algae and bryozoa etc. Hence, acritarchs form the principal target for age determination, palynozonation, intercontinental correlation and paleoenvironmental deductions due to the their yield in abundance.

Samples were also treated for sedimentological and chemical-sedimentological investigations by adopting conventional laboratory techniques to obtain additional supporting evidences with regard to paleoenvironmental deductions.

These detailed studies carried out, under the present investigation, bring out the following significant findings:

(1) For the first time, 20 genera and 67 speices of acritarchs have been identified and recorded from the Ordovician-Silurian (Caradocian to Ludlovian) sediments of the Tethyan Garhwal Himalaya, India.

Taxonomic descriptions of all the acritarch forms have been given. On the basis of first occurrence and last occurrence levels of selected acritarch species, four distinct acritarch assemblage zones namely *Baltisphaeridium longispinosum Var. longispinosum-Multiplicisphaeridium ornatum; Domasia trispinosa-Deunffia monospinosa; Domasia limaciforme-Dactylofusa oblancae;* and *Leiofusa algerensis-Multiplicisphaeridium osgoodense* were erected precisely in stratigraphic order with description of reference section, definition, base and top, significant accessory forms, overseas correlation and age assignment of each zone.

Top and base of each zone has been delineated in the following manner:

Zone I : Base of zone I could not be marked because of acritarch barren litho-unit.

Top : Last occurrence of *Baltisphaeridium longispinosum Var. lonispinosum* and first occurrence of *Geron* sp. cf. *G. amabilis*.

Zone II: Base: The first occurrence of Geron sp. cf. *G. amabilis* and last occurrence of *Baltisphaeridium longispinosum Var. longispinsoum*.

Top : The last occurrence of *Deunffia brevispinosa*.

Zone III: Base : The last occurrence of *Deunffia brevispinosa*.

Top : The last occurrence of *Leiofusa algerensis* and *Stellichinatum celestum*.

Zone IV : Base : Last occurrence of *Leiofusa algerensis*.

Top : Top of zone IV could not be marked because of acritarch barren litho-unit.

The acritarch biostratigraphic zonation reveals that the Ordovician-Silurian boundary lies within the Shiala Formation which was marked within the lower part of Yong Limestone Formation by earlier workers (Shah and Sinha, 1974 and Khanna et al., 1985).

(2) Paleoenvironmental deductions have been attempted mainly on the basis of acritarchs and other associated fossil microbiotic elements. Other environmental indicators such as limestone/ shale/siltstone/sandstone petrography, clay mineral assemblage, major & trace element and silt contents have also been considered in this study.

Occurrence of acritarchs and other associated fossil microbiotic elements in sediments indicates site of deposition extending mainly from inner to middle to outer Neritic Zone (transitional to marine). Results of overall study reveals that warm water conditions with normal salinity prevailed throughout in the basin of sedimentation. These inferences are supported further by the results obtained after the investigations carried on the sedimentary aspects/parameters.

In summary, the record of prolific acritarchs for the first time from the sediments of Caradocian to Ludlovian sequence of the Tethyan Garhwal Himalaya offers excellent opportunity for further detailed study, not only in this region, but also, in Kashmir and Spiti regions of India, which ultimately, would provide the scope of regional correlation within the Indian subcontinent as well.

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H. N. Sinha
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(HARESHWAR NARAIN SINHA)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

General

Combination of toughness and fascinating beauty with capitivating surroundings, full of peace and tranquility allover, the mighty and gorgeous mountain chains of the "Himalaya" attains a unique and significant status amongst other mountain chains in the world. Besides enjoying the rare privilege of being the abode of the highest peak, "Mount Everest", located in Nepal Himalaya, these mountains are quite well known for exotic beauty, enormous and varied wealth of natural resources (mineral, water, forest and wild life).

The Himalaya, so unique and exclusive in many ways, thus, has been drawing the attention of saints, devotees, religious people, astrologers, astronomers, pilgrims, philosophers, poets, mountaineers, adventurists, lovers of nature, photographers, sportsmen and women, tourists, archeologists, anthropologists, personnel of forests and wild life agencies, zoologists, botanists, geographers, horticulturists, agriculturists, sericulturists, experts of medicine, engineers, technologists, environmentalists, defence and security personnel.

Quite naturally, the vast treasure of varied rocks and minerals occurring in the Himalaya, had been attracting the attention of geologists too since over a century. Geologists of almost all the fields of specialisations from India and abroad have contributed enormously on a large variety of themes in different parts of the Himalaya.

In India, the Himalaya extends from the Indus river in the West to the Brahmaputra river in the East. Its extent from South to North is about 280 kilometers and from West to East is about 2400 kilometers. In India, it limits within 72°E to 96°E longitudes and 26°N to 36°N latitudes (Fig. 1). The general strike of the Himalaya is NW-SE.

From South to North, the Himalayan chain constitutes the following zones (Gansser, 1964 & 1974) :

Sub-Himalayan Zone (SHZ), Lesser Himalayan Zone (LHZ), High Himalayan Crystalline Zone (HHCZ), High Himalayan Sedimentary Zone (HHSZ) or Tethys Himalayan Zone and Trans Himalayan Zone (Fig. 1).

Concept of Tethys

The present study area is a part of the Higher Tethyan Garhwal Himalaya. The term "Tethys" was conceived by the celebrated Austrian geologist Edward Suess (1885), as a long expanse of Mesozoic seaway separating the old continental masses of the Gondwanaland and the Angaraland. The history of the Tethys dates back to the Paleozoic marine sediments occurring in the Himalayan region.

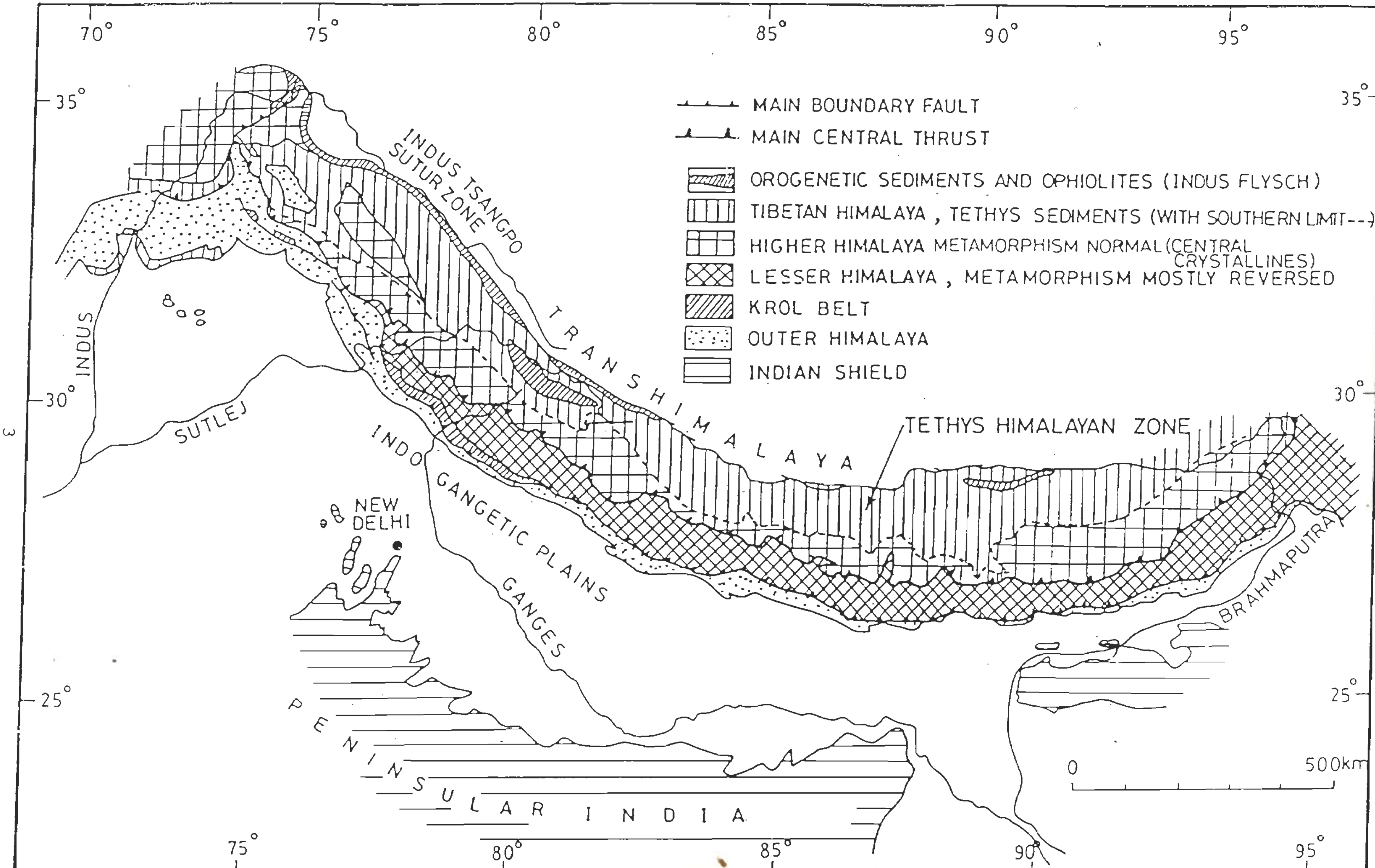

FIG.1 GENERAL GEOLOGICAL MAP OF THE HIMALAYA SHOWING TETHYAN HIMALAYAN ZONE (AFTER GANSSER, 1964)

The "Tethys" as conceived by Suess, implied subsidence and, thus, his "Tethys" became a classical example of a geosyncline (Stocklin, 1984). The concept of 'Plate Tectonics' in the oceanic realm modified the geosynclinal theory and revolutionised the idea, and Stocklin (1984) presented his theory in the following manner :

(a) "As a geosyncline, the Tethys was a narrow seaway and a giant ocean in terms of the concept of Plate Tectonics";

(b) "Previously, the Tethys was thought to have resulted from down buckling of the crust".

"But, now, it is thought to have originated from upwelling and spreading of the mantle material";

(c) "Previously, the Tethys was considered to have deep (eugeosynclinal) and shallow (miogeosynclinal) sediments underlain by unspecified crust";

"But, now, it is thought to be a specific "Ocean" feature complete with oceanic crust and oceanic sediments";

(d) "The Tethys geosyncline was conceptually symmetric".

"But, the Tethys ocean, as per Plate Tectonics model, is considered to be asymmetric with all orogenic processes operative at the northern "active margin";

(e) "According to geosynclinal concept, the orogenic zone was a unity since the birth of the Tethys".

The advocates of Plate Tectonics proposed that the orogen is a strange composite of two continental margins, which, prior to collision, were separated by thousands of kilometers and had nothing to do with each other in their original development.

The term "Tethys Himalaya" was introduced by Auden (1935; 1937) for the fossiliferous sequence occurring to the North of the Central Crystalline Axis (Fig. 1). The name "Tethyan Zone" in the Himalaya was also introduced by Auden (1937) to designate the widespread sedimentary basin to the North of the Central Crystalline rocks (Fig. 1).

Shah and Sinha (1974) suggested "Tethyan facies" for the fossiliferous Precambrian-Paleozoic-Mesozoic sequences in this region. Sediments of Tethyan facies rest normally on a basement of the Central Crystallines, which in turn, over-ride the sediments and metasediments in the Lesser Himalayan Zone to the South along a thrust which developed possibly during Oligocene-Miocene time and is known as the Main Central Thrust (M.C.T.) as shown in Fig. 1.

Thus, the Garhwal part of the Tethyan Zone of the Himalaya refers to the zone extending from Gamsali in the West to Ghatmila dhura in the East and from Malari in the Southwest to Rimkhim and Shalshal in the North. (Fig. 2)

Rocks of Lower Paleozoic marine sequence are exposed within the Tethyan Zone of the Himalaya in Kashmir, Spiti (Himachal Pradesh) and Kumaon-Garhwal (Uttar Pradesh) regions of India. Literature survey reveals that no work on the acritarch biostratigraphy has so far been carried on the Lower Paleozoic marine sequence of Kashmir, Spiti and Kumaon-Garhwal regions.

In view of world-wide occurrence of acritarchs in the Lower Paleozoic sequences and, particularly, in absence of any detailed investigation on this aspect in India, the Tethyan Garhwal Himalaya was chosen as the study area (Sumna-Rimkhim section).

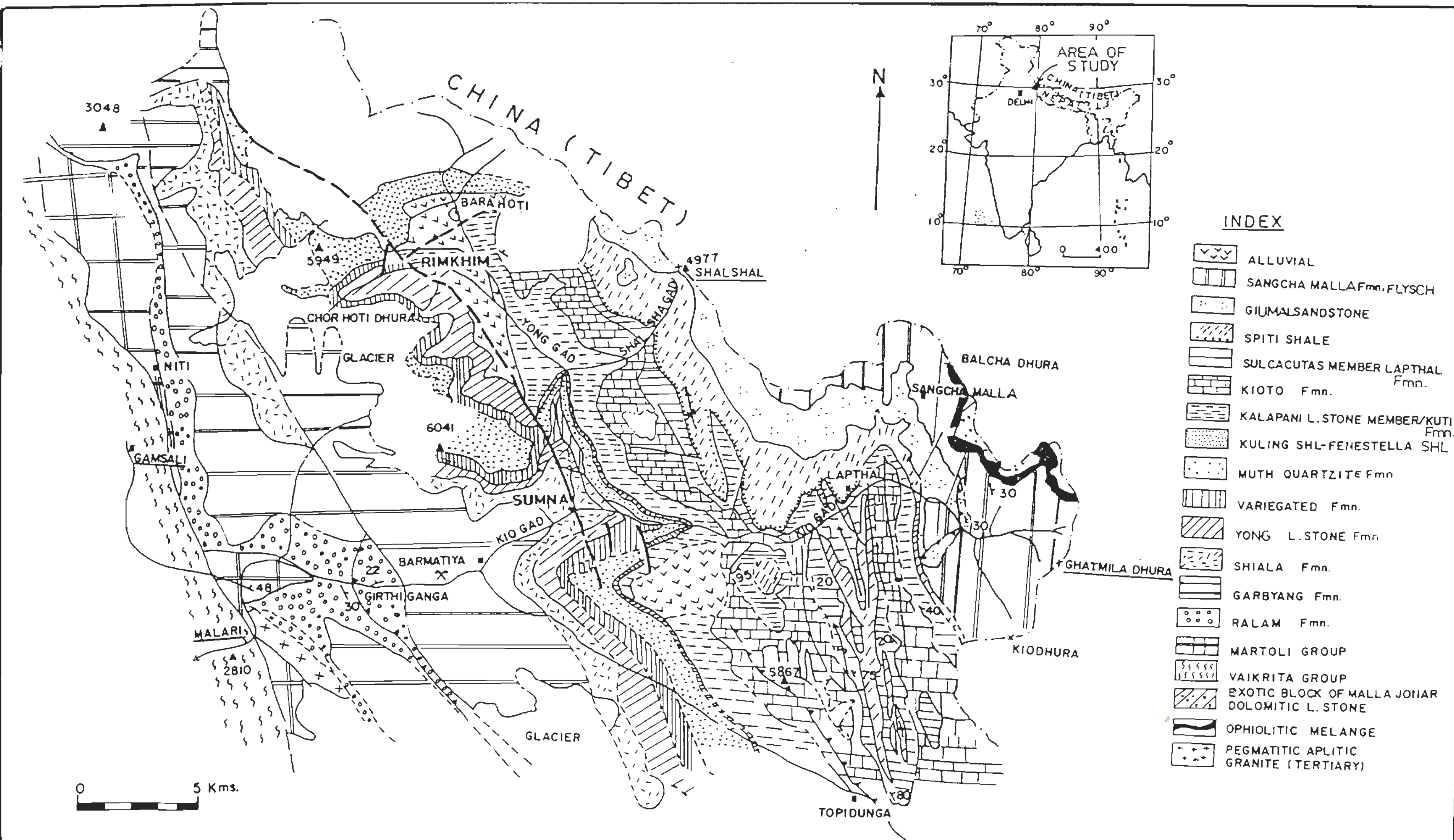

FIG: 2. GEOLOGICAL MAP OF THE MALARI-LAPTHAL AREA OF TETHYAN ZONE OF THE HIGHER GARHWALHIMALAYA. INDIA. (A.K. SINHA, 1985)

The Study Area

Location and Accessibility

Location

The present study area (Fig.2), under investigation, is the Northeastern segment of the Chamoli District of the Garhwal Division in the State of Uttar Pradesh (U.P.), India. The village of Sumna (Lat. 30°40': Long. 80°50') with no inhabitants is the base camp site for defence and security personnel as well as for Geologists. After reconnaissance survey in and around Sumna; the Sumna-Rimkhim section was found to be an ideal one, and, thus, it was chosen for detailed palynological investigations under the present doctoral programme. In addition to detailed Palynological investigations, help of Sedimentological and Chemical-sedimentological investigations carried out on the same rock-samples was also considered as an additional supporting evidence while inferring the environment of deposition. The present study area is a part of the Survey of India Topographical Sheet No. 53N/13 on 1:50,000 scale.

The Northern limit of the study area is just the international frontier line between India and China (Tibet), The Mc-Mohan line lies about 15 Kms. North of this limit. The Sumna-Rimkhim section lies on the bank of the Yong Gad (Yong river).

Accessibility

The last point approachable by road transport is Malari (Lat. 30°39' : Long. 79°53'20") village. Infrequent road transport facility exists upto Malari from Joshimath during field-season only. Since the study area lies close to the international frontier with China, prior permission is obtained from the Government of India to undertake geological field investigations in this area.

The village of Sumna (the base camp) is situated at a distance of 26 kms., North-northeast of Malari village (the last motorable point). One has to walk all along the mule track (a distance of 26 kms.) from Malari to reach Sumna.

Joshimath is a town located at a distance of 272 kms. on Rishikesh-Badrinath pilgrimage motorable road. Roads from Rishikesh to Joshimath and from Joshimath to Malari are frequently blocked due to very frequent land slides and slips especially during rainy months.

Climate

Inclemency of weather conditions at such a high altitude is a common feature. Terrain with typical rugged topography has heights ranging between 3000 to 6000 metres from MSL. Owing to heights, Alpine type of climate prevails in this area. The mean temperature during summer months is below 18°C, while the winter mean is below the freezing point. Precipitation is mainly in the form of snow. Rains are never torrential but occassional drizzling is frequent. The whole area is under a thick snow cover during the period from November to February or even upto early March. Snow gets melted on the lower reaches of the hilly terrain by the end of March but the peaks remain under perpetual ice cap. Strong, cold, biting and high velocity winds are common and hinder work very frequently especially after 10 O'Clock in the morning. Utra-violet radiation of the sun causes skin-burns on long and continued exposure. Breathing problem is felt, at times, due to high altitude in this region.

Flora and Fauna

Flora

Since the area is situated in the "Shadow-Zone" of the monsoon and having lofty Nanda Devi (7820 metres) group of peaks, scanty vegetal patches are seen infrequently on the northern slopes. Notable among them are; Birch, white and violet varieties of *Rhododendron* (Sinha, 1989). Birch forests are usually found on the sedimentary rocks commonly between 3000-4000 metres. These forests are sustained by snow during winters, and drizzling rains in summer, emerging with profuse flowers in early June.

The bark of birch, the "Bhojpatra" is like paper and was used for writing by ancient people of India (Sinha, 1989).

The meadows on the Northern slopes of Martoli and Malari area on the left bank of the Girthi Ganga river remain covered with snow till the first week of May. With the melting of the snow towards the end of May, a colourful carpet of purple *Primulas*, blue *Corydalis* and yellow *Gangea* bloom profusely and cover the vast stretches of meadow. Famous blue Poppy (*Mecanopsis aculeata*) appears in July-August (Sinha, 1989).

On the heights below 3000 metres, Deodar forests (*Cedrus deodar*) are common. Bhojpatra (*Betula alnoides*) is found to occur between heights from 3000 to 3500 metres. Only grass, shrubs and bushes are seen at about 3500 metres of height. Beyond the altitude of 4000 metres, no prominent vegetation occurs and, hence, the entire terrain assumes a barren, rugged, frost-bitten and wind-swept character.

Fauna

The common wild animals of the region are : Musk deer (*Moschus moschiferus*), barking deer (*Cerrulus muntajae*), Himalayan black bear (*Ursus torquatus*) and creatures of the goat family : thar (*Hemitragus jemlaicus*), goral (*Nemorhoedus goral*) and the sheep or bharal (*Ovis nahura*). Tibetan yak and wild horse or kyang (*Equus hemionus pallas*) are occassionally seen near Rimkhim (last security post of India). The mules (local breed of ponies) are used for transportation of luggage and field-gear etc.

Review of Literature

An attempt has been made to scan available published literature pertaining to the present study area with a view to collect only those informations which are relevant to the objectives envisaged under the present investigation.

In the process of reviewing the literature on the previous work done, it was observed that various names and age assignments have been proposed to the stratigraphic units by earlier workers from time to time. Hence, to avoid confusion and in proper understanding of the description/discussion, the following table on lithostratigraphic frame work of the study area is given below (Shah and Sinha, 1974 and Sinha, 1989). This lithostratigraphic classification has largely been adopted in the present work (Table-1).

TABLE-I

Time Unit 1	Lithounit 2	Lithology 3	Assemblage Zone 4	Fossils 5
SILURIAN	Variegated Formation	Purple limestone and shale with bands of quartzite	*Strophonella* Zone *Orthis (Dalmanella) basalis*, Favosites,	*Atrypa reticularis*, *Strophonella* Sp.?,
	Yong Limestone Formation	Leptaena rhomboidalis Green nodular biohermal and biostromal limestone massive stromatoporids	*Calostylis* Zone Streptelasma sp.	Calostylis dravidina? and
ORDOVI-CIAN	Shiala Formation	Grey to pinkish sanstone *and quartzite with bands* of limestone to the top	*Rafinesquina alternata* zone Saffordia sp., *Monotrypa* sp., Strophonema	*R.alternata*, *Leptaena* halo, Favosites sp.,
		Alternating bands of sandstone and shale	*Monotrypa* zone trachealis? Rhinidictya sp., *Asaphus*, *Lioclema* sp.	Chaemaerops, Laptaena?
		Alternating bands of greenish shale and biostromal limestone. Green splintery shale with thin bands of arenite	Rafinesquina *aranea* zone, *Orthis testudinaria* zone	Rafinesquina aranea, *R. muthensis*, *Triplecia* sp., *Skendium* sp., etc.
	Garbyang Formation	Green needle shales with occasional bands of limestone		
		Alternating bands of sandstone and shale with graded bedding	*Ecclioptens* zone	*Ecclioptens kushanensis*
CAMBRAIN		Cross-bedded calcareous sandstone		
		Greyish green graded bedded sandy shales		
		Crinoidal and oolitic limestone	Horizon bearing indeterminate trilobite fragments and lingulids	
		Brown marl		
		Brown dolomitic limestone with alternating bands of shale		
PRECAMBRIAN		Ralam Formation	Arenaceous shale	
			Dark-coloured quartzite Conglomerate alternating with quartzite	
		Martoli Formation	Graded bedded black shales; Slates and phyllites	
		Vaikrita Group	Quartzite, quartz schist, calc-silicates, kyanite and sillimanite gneisses, migmatites, etc.	

[Lithostratigraphic framework of the Tethyan Garhwal-Kumaon Higher Himalaya, Shah and Sinha, 1974 and Sinha, 1989].

However, the rock-samples of only Shiala Formation and Yong Limestone Formation (Ordovician-Silurian) yielded acritarchs which form the basis of the present work.

Thus, a review of previous work done on the Lower Paleozoic marine sequence of the present study area is presented in stratigraphic order of the rock units sampled.

Contributions of previous workers on relevant aspects only have been cited under each lithostratigraphic unit. Lithostratigraphic classification as proposed by (Shah and Sinha, 1974 and Sinha, 1989) has been followed in the present work (Table-1). However, a shift in one of the lithostratigraphic boundaries as delineated by Shah and Sinha (1974) and Sinha (1989) has been suggested on the basis of present work in Chapters 2 and 4.

The relevant aspects considered in review include nomenclature of litho-units and their description, fossil macro-or microbiota reported, biostratigraphic zones erected, age assignments and interpretations made with regard to the environment of deposition based on fossil finds & sedimentological and chemical-sedimentological data accumulated by previous workers.

Garbyang Formation (Cambro-Ordovician)

Lithostratigraphic Description

This formation was first stuided by Heim and Gansser (1939) in the Kali river valley and they designated "Garbyang Series" to the sequence after the village of Garbyang. Gansser (1964) redesignated it as "Garbyang Formation". The best exposures of this formation are located in the Girthi Ganga gorge. Shah and Sinha (1974) and Sinha (1989) gave a detailed account of various lithological units of this formation (Table 1).

Kumar *et al.* (1977) made an attempt to subdivide the Garbyang Formation in different ways. But, divisions proposed by Sinha (1989) appears quite authentic and reliable.

Fossil Biota

Shah and Sinha (1974) and Sinha (1989) reported the occurrence of tiny remnants of trilobite and some minute lingulid brachiopods. In the sandstone shaly unit, about 3 km Southwest of Sumna, a horizon with flat gastropod *Eccliopteris kushanensis* Grabau occurs (Sinha, 1989).

Characteristic trace fossils which have been recorded from this formation (Tandon and Bhatia, 1978) are : *Cruziana, Gorylhorte, Isopodichnus, Lennea, Phycodes, Planolites, Rusophycus, Scolicia, Teichichus, Lavicyclus, Aulichnites* and *Zoophycus*.

Age Assignment

Based on the records of tiny remnants of trilobite & liguilid brachiopods and crinoids in the lower part and occurrence of *Eccliopteris kushanensis* Grabau (flat grastropod) in the upper part of this formation, the previous workers (Shah & Sinha, 1974 and Sinha, 1989) have assigned Cambrian age to the lower part and Ordovician age to the upper part. Hence, this formation has been reported to range from Cambrain to Ordovician.

Sedimentological Aspect

Kumar, Singh and Singh (1977) divided the Garbyang Formation into seven divisions (Garbyang A to Garbyang G) based on distinct phases of sedimentation history marked by variation in lithology, sedimentary structures and paleocurrent patterns(Table 2). They considered the age of the entire formation to be Cambrain. They have observed and recorded the following sedimentary structures: small and large scale cross stratification, ripple cross lamination, parallel lamination, rain print, wrinkle marks & current and wave ripples. They have also taken the help of trace fossils.

Environment of Deposition

Inference with regard to environment of deposition based on fossil biota has so far not been drawn by any worker. However, Kumar *et al.* (1977) inferred the deposition of environment of this formation based on their investigations as shown in Table-2 below.

TABLE-2

Lithostratigraphic subdivisions, trace fossils and environment of deposition of the Tethyan succession of Garhwal-Kumaon Himalaya (Kumar *et al.*, 1977)

Form-ation	Member	Lithology	Sedimentary structure	Trace fossil	Environment of Deposition	Age
1	2	3	4	5	6	7
G	Garbyang G 140 m	Silty sandstone and shale	Dominance of graded rhythmites; graded bedding, ripples & ripple bedding; Extensive bioturbation with vertical burrows.	-	Transition zone shelf mud area	C
A						A
R	Garbyang F 120 m	Oolitic limestone, calcareous sandstone and shale	Large scale cross-bedding sometimes herring bone type Marly beds exhibit wavy bedding, lenticular/ flaser bedding and often tidal bedding, longitudinal cross-bedding.	-	Tidal flat	M
B						B

Form-ation 1	Member 2	Lithology 3	Sedimentary structure 4	Trace fossil 5	Environment of Deposition 6	Age 7
Y	Garbyang E 45 m	Shale and sand-stone	Sand layers graded; ripple foreset laminae lenticular and flaser bedding, often cross-bedding & channeling	*Rouaultia* de Tromelin, 1877	Intertidal transition	R
A	Garbyang D 70 m	Sandstone and shale	Low-angle cross-bedding, parallel bedding and trough cross-bedding, beach bar cross-bedding	Ichnogenus Form B	Tidal flat	I
N	Garbyang C 165 m	Limestone, cal-careous sand-stone and shale	Small ripple bedding, channeling and planes of discontinuity, small scale cross-bedding	Ichnogenus *Form* A	Sand bar/shoal	A
	Garbyang B 110 m	Dolomites, marls and gypsi-ferous shales	Large scale cross-bedding, ripple bedding	-	Supra intertidal	
G	Garbyang A 46 m	Limestone, dolomitic lime-stone and sub-ordinate shales with veins of barytes	Faint large scale cross-bedding, small ripple bedding and herring bone cross bedding.	-	Shallow tidal sea	N
Total thickness : 696 m						

Shiala Formation (Ordovician-Silurian)

Lithostratigraphic description : Heim and Gansser (1939) have named about 400 to 500 meters thick shales with intercalations of sandy limestones or crinoid breccia of brown weathering, overlying the typical Garbyang sequence at Shiala pass, as "Shiala Series". It was redesignated as "Shiala Formation" by Gansser (1964). According to Shah and Sinha (1974), the Garbyang Formation grades into Shiala Formation without any marked lithological change. Here, they observed perfect conformity between the underlying

Garbyang Formation and the Shiala Formation. They marked the lower boundary of the Shiala Formation, from where, there is a regular development of horizons of fossiliferous crinoid bearing limestone.

The main distinction in lithology between the two formations is the presence of a biostromal band in the latter. The broad lithology was described by these two workers in their 1974 publication (Table-1).

Fossil Biota

Heim and Gansser (1939) have mentioned the presence of crinoid breccia in Shiala lithology. Shah and Sinha (1974) established four biostratigraphic zones in this sequence in a section in the gorge of the Kiogad river, a few kilometers from the Sumna camp site towards West.

They mentioned that the Shiala Formation is rich in macrofauna in addition to the horizon containing indeterminate fossils. Biostratigraphic zones established by them were assigned names after the characteristic fossil brachiopod taxa. The zones from the base are: *Orthis (Dalmanella) testudinaria* Zone, *Rafinesquina aranea* Zone, *Monotrypa* Zone and *Rafinesquina alternata* Zone (Table-1). They assigned Middle to Upper Ordovician age to this sequence based on brachiopod faunal assemblage.

Banerjee *et al.* (1975) and Kumar *et al.* (1977) have stated that the Shiala as such is profusely dotted with trace fossils and some of them which are found in the rock exposures near Sumna are : *Skolites* Heldeman, 1890, Chondrites, *Lorenzinia, Planolites, Skalolithous*. Kumar *et al.* (1977) have also identified the following trace fossils in the Kiogad gorge:

Ichnogenus *Dimorphincus* Seilacher, 1955; Ichnogenus *Fuousopsis* Vassoevitch, 1932; Ichnogenus *Helminthopsis* Heer, 1977; Ichnogenus ? *tomaculum* Groom, 1902; Ichnogenus ? *Planolites* Nicholson, 1873, Ichnogenus Form.

Goel *et al.* (1987) reported the first record of indubitable conodonts from the Ordovician of Spiti and Garhwal Himalaya in the Tethyan Zone. Incidently, Goel *et al.* (1987) had collected rock-samples from the Shiala sequence of the same section i.e. the Sumna-Rimkhim Section (present work).

They based their inference with regard to age of the Shiala on the occurrence of typical Middle Ordovician (Caradocian) Conodont species namely *Amorphognathus tvaerensis* Bergstrom. This characteristic Middle Ordovician species was recorded from Europe and North America only.

Age Assignment

Workers who studied fossil macro-and micro biota of the Shiala Formation assign largely an Ordovician age to this formation. However, the age assignment and delineation of lower and upper boundaries of this formation based on the present work on acritarchs are in variance to the previous work. A detailed account to this effect has been given in Chapter 4.

Sedimentological Aspects

Kumar *et al.* (1977) did sedimentological investigations on the rock samples of this formation collected from the best developed exposures around Sumna near the confluence of the Yong-and Kio rivers. They divided the Shiala Formation into seven lithostratigraphic members, all showing gradational contacts and summarised their inferences as given in the Table-3.

TABLE-3

Formation 1	Member 2		Lithology 3	Sedimentary structure 4	Trace fossil 5	Environment of Deposition 6
S	Shiala 75 m	G	Sandy shell limestone and shale	Small ripples are usually present, Shale layers are often extensively burrowed.	-	Medium energy coastal sand area.
	Shiala	F	Shell limestone, shale and sandstone	Large scale cross-bedding with low angle discordances; parallel bedding and small ripple bedding	*Dimorphichnus* Seilacher, 1955 *Fucusopsis* Vassoievitch, 1932	Medium to high H energy coastal area.
I	Shiala 40 m	E	Shell limestone and calcareous shale	Large scale cross-bedding commonly present.	*Helminthopsis* Heer, 1877	Medium to high energy coastal area.
A	Shiala 180 m	D	Orthoquartzites and shale	Abundant ripples of various types: current ripples, ripples with rounded crests and interference ripples of tadpole type; Wrinkle marks and spring pits.	?*Planolites* Nicholson, 1873 Ichnogenus *Form* C	Medium energy sandy tidal flat/shoal complex.
L	Shiala 165 m	C	Shell limestone, intraformational conglomerate and shale	Convolute bedding, small ripple bedding and ripples are common, small channels are usually present.	? *Tomaculum* Groom, 1902	Subtidal to intertidal zone.
A	Shiala 40 m	B	Shales and limestone	Sand layers often show channeling; Ripples of wave origin.	-	Intertidal-subtidal zone.
	Shiala 140 m	A	Shales and sandstones with shell limestone	Sand layers show grading; Ripple bedding seen frequently.		Transition (Subtidal) zone.

Total thickness : 710 m.

Kumar *et al.* (1977) have not considered the Yong Limestone Foramtion, the unit first identified as an independent formation by Shah and Sinha (1974). This unit according to Shah and Sinha (1974) lies between the underlying Shiala and overlying Variegated formations. Yong Limestone Formation has been considered as a distinct and valid lithostratigraphic unit in the present work and has been dealt with in chapter-4.

Yong Limestone Formation

Lithostratigraphic Description

The Yong Limestone was referred to as "Nodular Limestone" and included in the pre-Silurian Shiala Series (Heim and Gansser, 1939) or Somna Series (Dave and Rawat, 1968). Shah and Sinha (1974) recognised its biohermal nature and considered it to be a separate lithostratigraphic unit, and named it as "Yong Limestone Formation" named after the deserted village of Yong in the Yong valley, where, one of the reefs is exposed on the mule track leading to Rimkhim (same section as that of the present work). This reef is about 750 m across and has an exposed thickness of 45 m. Yong Limestone conformably overlies the Shiala Formation. Lithostratigraphic framework of this unit is shown in Table-1.

Fossil Biota

Shah and Sinha (1974) and Khanna *et al.* (1985) described fauna and flora of this formation.

Fauna

This formation is rich in fossils with poor preservation containing largely massive stromatoporids and corals. Only fossils which could be identified by them are *Calostylis*? *dravidiana*? and *Streptelesma* sp. Shah and Sinha (1974) erected a biostratigraphic zone corresponding to this formation based on coral form *Calostylis*.

Kumar *et al.* (1977) mentioned that the limestone contains bryozoa and corals in abundance with some algal structures. They did not give details.

Flora

First fossil floral occurrence was recorded by Shah and Sinha (1974) i.e. the occurrence of branched algae (unnamed). Sinha (1989) and Khanna *et al.* (1985) recorded the occurrence of chitinozoa alongwith scolecodonts in this unit. They have just mentioned stray occurrence of acritarchs, cuticles and melanosclerites in this unit but did not give any details. Khanna *et al.* (1985) have listed 10 species of chitinozoa asssignable to 4 genera and scolecodonts to 9 taxa. They mentioned the occurrence of a solitary specimen of acritarch genus *Baltisphaeridium* in the assemblage. Illustrations of chitinozoans and scolecododnts only have been given by them.

Age Assignment

Shah and Sinha (1974), Sinha (1989) and Khanna *et al.* (1985) have assigned upper Ordovician to Lower Silurian (Caradocian to Llandoverian) age to the Yong Limestone on the basis of faunal and floral assemblage reported by them from this unit.

They delineated the lower boundary of this formation which conformably overlies the Shiala Formation, precisely lying at a point, where the grey to pinkish brachiopod *Rafinesquina*-bearing calcareous sandstone merge with the green nodular biohermal limestone-bearing mainly the coral *Calostylis*.

They stated further that this formation is successively and conformably overlain by the Variegated Formation which has a discordant relationship with the reef but is concordant with the intervening biostromal limestone indicating the outgrowth of the reef which might have provided the surface for the deposition of the overlying Variegated Formation.

Sedimentological Aspect

Shah and Sinha (1974), Sinha (1989) and Khanna *et al.* (1985) observed only imperceptible bedding features because of the domal disposition of the unit. However, it is important to note while scanning the work of Kumar *et al.* (1977), where, they have included this characteristic, unique and typical unit [as designated by Shah and Sinha (1974)] in the Variegated Formation as its lowermost member and named it as Variegated A with black nodular limestone and black clacareous shale as its lithology. Variegated Member A of Kumar *et al.* (1977) does not show any evidence of current or wave activity.

Environment of Deposition

Kumar *et al.* (1977) suggested that the succession (Variegated Member A i.e. Yong Limestone of Shah and Sinha, 1974) represents deposits of a zero-energy carbonate flat, where corals and bryozoa flourished.

TABLE-4

(Modified after Shah and Sinha, 1974)

Time Unit	Litho Unit	Lithology	Sedimentary structures	Assemblage zone	Fossils	Environment of Deposition
Silurian --?--?--? Ordovician	YONG LIMESTONE FORMATION (Variegated Member A of Kumar *et al.*, 1977)	Greyish green bio-hermal limestone. Reefal cores contain thin layers of calcarcous mud or marl. Margins are intercalated with thin shale bands merging into a biostromal limestone.	Imperceptible bedding features. Presents a domed character. No wave or current features.	*Calostylis* dravidiana Zone	Massive Stromatoporids, coral, Chitinozoa Branched algae and Scolecodonts.	Zero-energy carbonate flat, where corals and brryozoa flourished.

Variegated Formation

Lithostratigraphic Description

Heim and Gansser (1939) referred as "Variegated Silurian" to a thick succession constituting variegated shales and limestone with crinoid fragments. They mentioned that this sequence had been called as "Red Crinoidal Limestone" by Griesbach (1891). However, the "Variegated Silurian" of Heim and Gansser was redesignated as "Variegated Formation" by Shah and Sinha (1974). Best exposures can be seen only in Yong valley, North of Sumna. The beginning of this formation is taken at the base of a thick nodular limestone with minor shales, while the upper contact is gradational with the overlying Muth Formation (Shah and Sinha; 1974 and Kumar *et al.* 1977).

In general, the lower part of the Variegated Formation is represented by purplish algal limestone and phyllite, sometimes arenaceous followed by upper part mainly composed of purplish and green calcareous quartzite. The thickness of the formation varies from section to section. This formation is separated distinctly on account of colour contrast with the underlying green Yong Limestone and the Overlying white Muth Quartzite (Shah and Sinha, 1974).

Fossil Biota

This formation has been reported by previous workers to be barren so far as the occurrence of acritarchs, chitinozoans, melanosclerities and conodonts are concerned. However, occurrence of brachiopods, corals, bryozoans, algal structures and trace fossils in the formation has been reported.

Valdiya and Gupta (1972) recorded the occurrence of brachiopod species from the middle part of this formation : *Orthis* (*Dalmanella*) *bouchardi* and *Orthis* (*Dalmanella*) *basalis* var. *muthensis*. According to them, the upper limestone member of this fromation yielded coral form *Favosites spitiensis* and poorly preserved *Streplesma* (?) and broken blades of *polygnathids*.

Shah and Sinha (1974) stated that this formation is poorly fossiliferous. However, they established a characteristic brachiopod assemblage zone in the Kiogad valley section and named it as *Strophonella* Zone (Table-1).

Trace fossils recorded by Tandon and Bhatia (1978) is represented by *Chondrites* Sternberg, 1833 and occurs mainly at the shale-silt interface in Darma and Kali valleys of this region. They recorded Ichnogenus *Volkichnium* Pleiffer, 1965 with radiating burrows parallel to bedding plane.

Age Assignment

Shah and Sinha (1974) assigned Silurian age to this formation based chiefly on brachiopod assemblage.

Sedimentological Aspects

Kumar *et al.* (1977) subdivided the Variegated Formation into three lithostratigraphic members (Table-5) as Variegated A, B and C.

According to them, Variegated A constitutes 46 m thick succession of black nodular limestone with thin intercalations of black clacareous shale. They reported occurrence of corals and bryozoa in abundance in the nodular limestone. Some algal structures were also recorded by them. Variegated B is composed of 20 m thick succession of purple to brown limestone with greenish shale-siltstone intercalations. Variegated C constitutes 33 m succession and is characterised by 1 m thick carbonates intercalated with 2-3 m thick shale layers of different colours e.g., violet, brown and green.

Variegated A Member of Kumar *et al.* (1977) is in fact the Yong Limestone unit of Shah and Sinha (1974). Therefore, the Table modified after Kumar *et al.*, 1977 is being presented below:

Environment of Deposition

Kumar *et al.* (1977) stated that members Variegated B and Variegated C fail to exhibit well developed primary sedimentary structures representing low energy shallow water carbonates.

TABLE-5

(Modified after Kumar *et al.*, 1977)

Time Unit	Litho Unit	Lithology	Sedimentary structures	Assemblage zone	Environment of Deposition
S	V	Shale	No primary	-	
I	A	and	sedimentary		
L	R Member C	Limestone	structures		
U	I		observed		
R	E				
I	G				Low energy shallow
A	A				water carbonates
N	T				
	E Member B	Limestone,	-	Volkichnium	
	D	Shale and		Pfeiffer,1965	
	FORMATION	Siltstone			

Objectives of the Present Study

The published literature review on the previous work done so far reveals that there exists a very wide scope of work on the fossil microbiota of the Lower Paleozoic marine sequences of the Himalaya in general and of the Tethyan Garhwal Himalayan region in particular.

Due to proximity of the Garhwal Himalaya from the place of work i.e. the University of Roorkee, the present study area was chosen for investigations. After a critical survey of literature, it was learnt that almost no work has so far been done on the acritarchs of the Lower Paleozoic marine sequences in the Himalayan region in general and in the Tethyan Garhwal Himalaya in particular. Hence, the present study was aimed mainly at the detailed investigation on acritarchs. In addition, it was thought appropriate to include the sedimentological and chemical-sedimentological aspects also as an interdisciplinary approach in inferring the environment of deposition.

Keeping all these aspects in mind, the following objectives of the present study were envisaged :

Objectives

1. Present lithostratigraphic status of the Ordovician-Silurian sequence of the study area including sedimentological and chemical-sedimentological investigations;
2. Identification of acritarchs recovered from the rock samples collected in the field and processed in the laboratory;
3. Palynology : Taxonomy of acritarchs recovered;
4. Acritarch biostratigraphy (Palynozonation) and Age assignment to the sequence;
5. Intercontinental correlation based on acritarch assemblages;
6. To deduce the environment of deposition based on acritarchs and other associated fossil microbiotic elements with an additional support of results of sedimentological and chemical-sedimentological investigations.

Brief account of field and laboratory work done, keeping in view of the above objectives, is dealt in the beginning of the next chapter-2 on Geology.

CHAPTER 2

GEOLOGY

Introduction

As mentioned in Chapter-1, the present study area falls in the Chamoli District of Uttar Pradesh lying in the Tethyan zone of the Garhwal Himalaya.

Two visits of one month duration each, were made to the field during the months of August and September in 1992 and again in 1993. After camping at Sumna (the base camp site), reconnaissance survey was carried out and traverses were taken in and around Sumna. Sumna-Rimkhim section along the mule track was found to be an ideal one, where, the Lower Paleozoic marine sequence is largely exposed (Fig. 3).

Physiography and Structural Setting

Dhauliganga (which is a tributary of the Alaknanda river) and its tributary the Girthiganga are the two main rivers flowing in this region. These rivers are joined by a number of small streams in their entire run. At a number of confluence points, the rivers and streams such as the Yong Gad and the Kiogad make right angles (Fig. 2). This type of

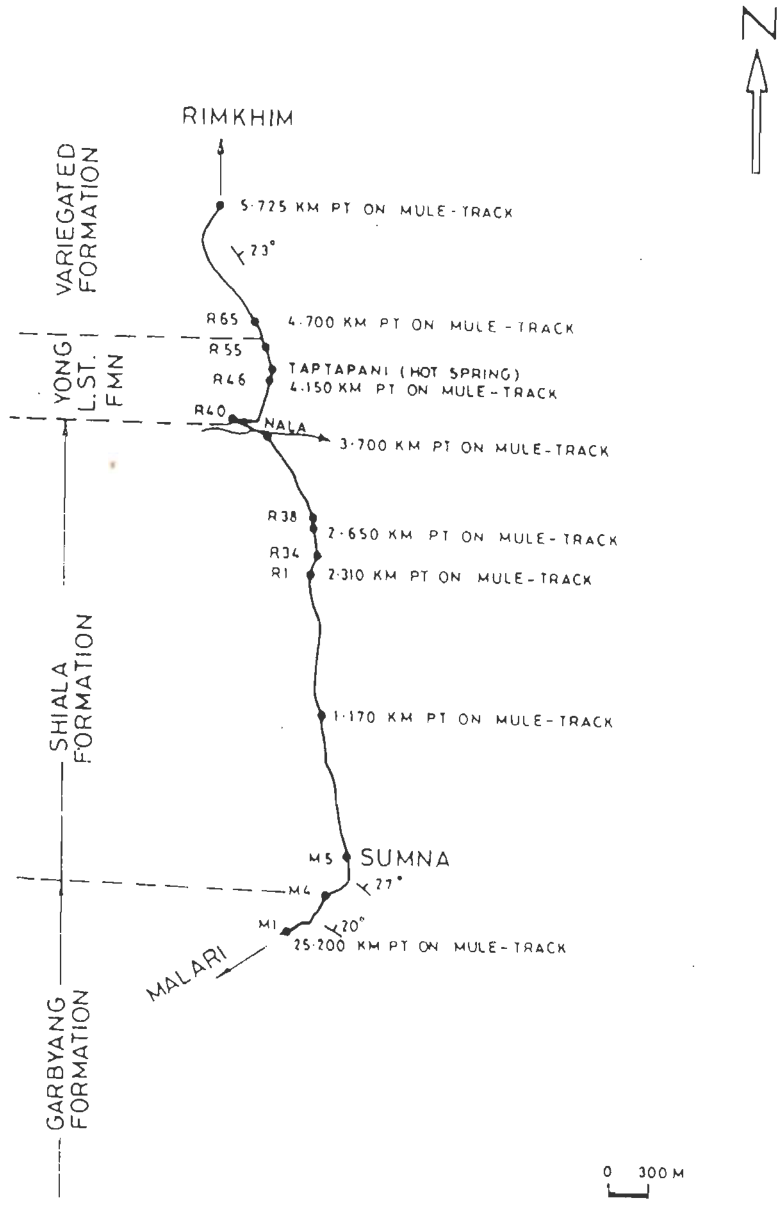

FIG. 3 SUMNA - RIMKHIM SECTION SHOWING LOCATION OF SAMPLES

drainage system has carved out two deep valleys through which the Dhauliganga and the Girthiganga flow with several narrow and steep valleys of smaller streams. The smaller streams also serve as channels for glaciers to descend during winter season. Part of glaciers are found quite intact at places during summer season also. These two main valleys, as cited above, are asymmetrical "V" - shaped with normal gradients. One side of the valley usually has steep slope. However, at times, both sides of the valley are vertical or have convex slopes making gorges.

The smaller streams have very steep gradients and make "U" - shaped valleys. Presence of "V" - shaped valleys on the walls of the high ridges is quite common. The deepest gorge in this region has been carved out by the Girthiganga and the Kiogad between Girthi Dobla and Sumna in a stretch of about 5 Kms. and is deeper than 2000 metres at places. The width of the gorge is less than 500 metres.

The morphology in the region characterised by river action is modified by the glacial moraines and avalanche debris which have dammed the rivers at places in the past. Such places exhibit sudden widening of the valley indicative of natural reservoirs, thus, created during damming. Other indications are the presence of river terraces and alluvial deposits, sometimes 100 to 150 meters above the present high flood levels.

The highest point of the study area is the Shalshal cliff (5646 metres high). However, in general, the area is typical of the Tethyan Zone of the Himalaya, with regard to topographic features.

Structural Setting

Apart from the difference in lithology and presence of well known prolific macro - and less known microfauna, the rocks of the Tethyan zone display an entirely different structural setup as compared to the rocks of the Lesser Himalaya. This manifests in the form of the absence of isoclinal folds and prevalence of the Jura type of folding (Shah and Sinha, 1974).

The regional fold axis of the Paleozoic sedimentary sequence largely is NW-SE. It gradually changes to N-S in the Mesozoic sequence. In the lower part of the Garbyang Formation, there is a predominance of gravity structure producing "tooth-paste" like feature (Shah and Sinha, 1974).

However, various types of folds are recognised in the Garhwal Tethyan Zone which are disharmonic folds, *en echelon* structure and cross-puckers. No large scale thrusting has been seen in the study area. Shah and Sinha (1974) recognised two major types of faults :

(i) essentially strike faults turning to strike slip faults occassionally (trend NW-SE to NNW-SSE)

(ii) transverse faults which trend NE-SW to E-W. The fault along Sumna-Rimkhim Section (Fig. 2) is a strike fault. In the Yong Limestone exposures, the base is green in colour and limestone is at the top which is separated by pink shale and limestone. The pink shale and limestone belong to the overlying "variegated" Formation, exposures of which, are found repeating at Yong, possibly because of faulting (Shah & Sinha, 1974).

Field Work

Seventyone rock samples at convenient intervals, as close as possible, were systematically collected along Sumna-Rimkhim section (Fig. 3). Strato-litho-petrographic column (Fig. 4) was made after careful computation and error correction of field

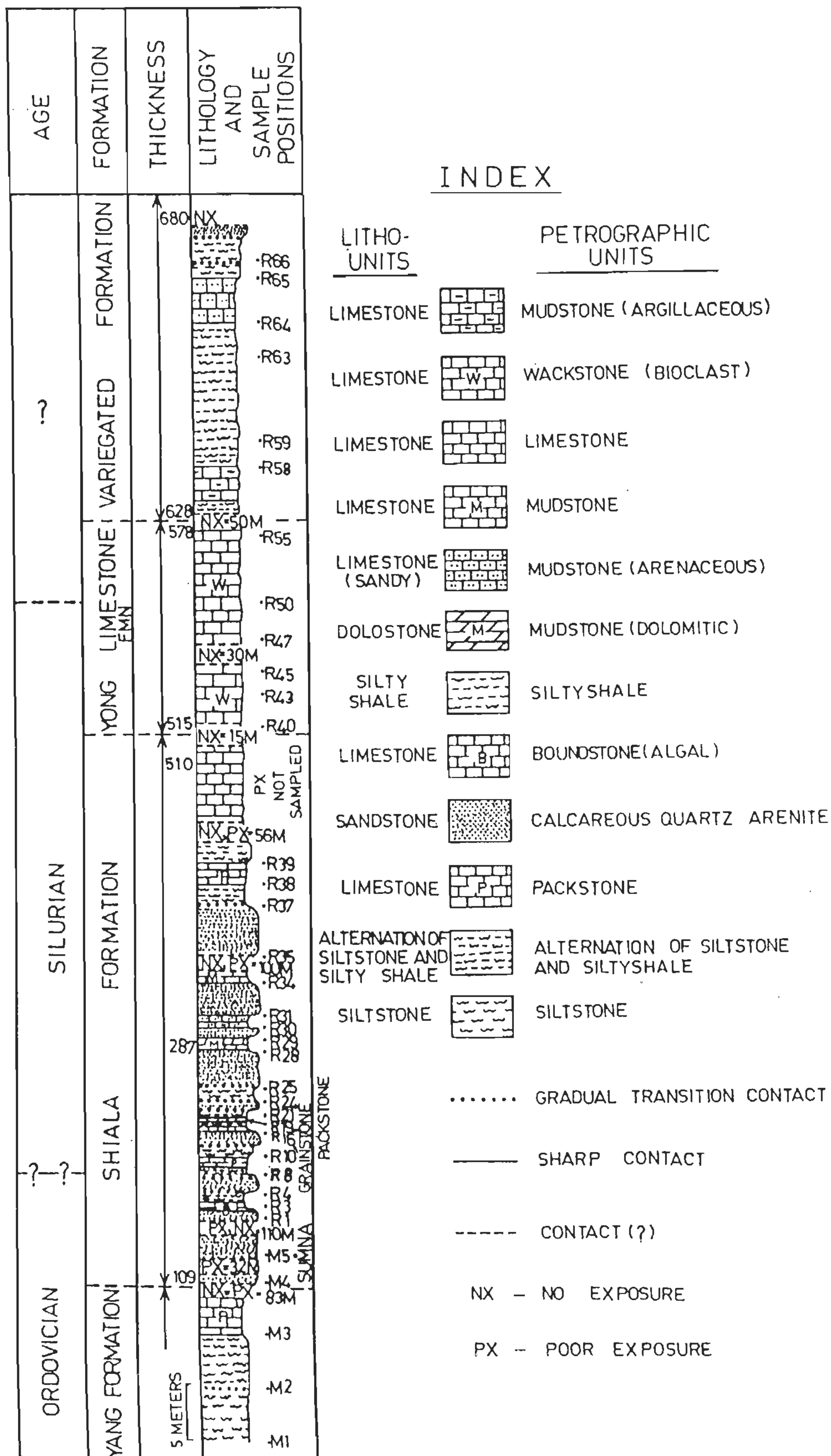

FIG. 4. INTEGRATED STRATO-LITHO-PETROGRAPHIC COLUMN OF SUMNA-RIMKHIM SECTION ALONG THE RIGHT BANK OF YONG GAD VALLEY SHOWING SAMPLE POSITIONS.

observations and data considering the aspects of topography, slope, traverse direction, attitude of exposed beds, lithology and petrographic characters. Thus, a total thickness of 680 meters of the Lower Paleozoic marine sequence was systematically sampled along this section.

In strato-litho-petrographic column (Fig. 4), NX and PX have been marked which denote expanse of strata either not exposed (NX) or poorly exposed (PX). Thus, from the base of the column, the Garbyang Formation has a total thickness of 109 meters, of which, only 26 meters are exposed and sampled. Likewise, Shiala, Yong Limestone and Variegated formations have exposed thickness of 88 meters, 33 meters and 52 meters respectively. Naturally, samples were obtained from ideally exposed segments of the entire expanse of each formation. Photographs of ideally exposed rocks of almost all the formations were taken during field visits (Plates 16, 17 and 18).

An integrated strato-litho-petrographic column (680 meters thick) shows age, name of formation (lithostratigraphic unit), thickness in meters, sample positions and names of rock types (Fig. 4).

Names of rock types (litho-units) based on megascopic characters have been given like limestone, sandstone, siltstone, siltyshale etc. Subsequently, the precise and still more suitable names of rock-types (litho-units) based on detailed microscopic (petrographic) study have been given like mudstone (arenaceous), wackstone (bioclast), boundstone (algal), grainstone (algal) and calcareous quartz arenite etc. The classifications of sedimentary rocks by Dunham (1962) and Dott (1964) have been followed while assigning the names after microscopic examination of each rock type (litho-unit).

Sedimentary structures as described by Kumar *et al.* (1977) were observed, verified and recorded in the field.

The gross lithological descriptions and lithostratigraphic details have been given in the later part of this chapter.

Laboratory Work

Each rock sample collected in the field was divided into two parts. One part was processed for palynological investigations by adopting conventional laboratory methodology. The other part of the same rock sample was treated for sedimentological and chemical-sedimentological investigations like petrography, clay mineralogy, detection and estimation of major and trace elements, identification of diagonostic minerals and silt percentage determination.

After obtaining the residue through palynological processing of each rock sample in the laboratory, four slides were prepared from each fraction but this varied with the volume of residue available. All slides are labelled with the relevant rock sample numbers in this manner : R-8(0) is slide number "one", R-8(1) is slide No. "two", prepared from sample R-8. R and M stands for rock samples taken from Sumna-Rimkhim section. Specimen coordinates are listed in the taxonomic descriptions (in Chapter-3) and also in the explanations of the plates. Leitz photomicroscope (Orthoplan No. 042230, German make) available at Keshva Dev Malviya Institute of Petroleum Exploration; Oil and Natural Gas Company Ltd., Dehradun (India) was used for palynological studies and photography of the palynoforms.

The film used in this connection was a 35x30mm Agfa Copex Pan AHU with a speed of 25 ASA/9DIN. The exposure time was maintained from 6 to 8 seconds for better contrasts of palynomorph photos. The text figures were prepared in the laboratory to verify and confirm the morphological details during precise identification of acritarch forms upto specific level. However, the same could not be included in the plates (nos. 1 to 8) due to certain unforeseen circumstances.

The data and results obtained after the laboratory investigations by adopting conventional techniques with regard to the sedimentological and chemical-sedimentological aspects have been dealt in later part of this chapter. The palynological data and results have been presented in Chapters 3 and 4.

After processing of rock samples, it was revealed that sample Nos. M1 to M5 followed up in the column by sample Nos. R1 and R2 are barren of acritarchs. Likewise, in the uppermost part of the column i.e. from sample Nos. R52 to R66 were found barren of acritarchs. However, sample Nos. R3 to R51 did yield some fossil palynoform or the other including acritarchs (Fig. 5). With this picture, which evolved after the palynological processing of samples, informal names like "Unfossiliferous sequence-A" in the lowermost part and "Unfossiliferous sequence-B" towards the uppermost part of the lithological column have been given. It is important to mention here that unfossiliferous sequences A and B mean the segment of sequence in the stratigraphic column barren of acritarchs.

In between these two unfossiliferous sequences lies the sequence of strata (from sample Nos. R3 to R51) which has been subdivided into four distinct palynozones namely I, II, III and IV based on acritarch assemblages (Chapter 4).

In the succeeding chapters and discussions, mention of these zones has been made (Fig. 5).

Lithostratigraphy

Understanding of precise and accurate lithostratigraphic status of a sequence is essential before an attempt is made to propose the biostratigraphic classification of that sequence based on fossil biota. This aspect, therefore, has been described in the following manner :

Nomenclature of Rock Types (Litho-units) and their Descriptions

A - Assignment of names broadly based on megascopic characters:

The megascopic descriptions of litho-units (in order of dominance) from the base towards the top of the lithological column and their broad names are given as under:

1. Unfossiliferous Sequence-A, Zones I and II:

Siltyshale : This is the most dominant rock type. This litho-unit has varied colours: light grey to greyish black; moderately to poorly fissile; hard and compact with occasional lenticular patches of siltstone. Shale is greenish grey in colour, moderately fissile, calcareous in nature and occasionally micaceous.

Sandstone : Sandstone, the next in order, is calcareous in nature and is greenish grey to dark grey and sometimes light brown in colour. The sand grains are very fine to fine, hard and compact, micaceous in nature. Sandstone is bedded as exhibited by the different shades of alternating colour bands of dark grey and light brown.

Limestone : Limestone is mainly light grey in colour, hard, massive, compact and fresh with well preserved megafossils, particularly, mollusca.

2. Zone III

Sandstone : It is light brown and occasionally dark grey in colour and is fine grained; calcareous; angular to subangular and compact.

Limestone : This litho-unit is mainly greenish black and rarely, at times, light brown in colour. It is hard, compact and massive. The brown variety is dull to earthy in look and is moderately hard. Occasional quartz veins are also observed.

Dolostone : It is brown in colour; hard and compact. Crystals of mineral grains are typical of this unit. It does not react with hydrochloric acid in the field and even after heating in the laboratory.

Siltyshale : It is greenish black to greyish black in colour. These siltyshales are moderately soft, in general, but at times, hard and compact beds also occur. It shows moderately to good to poor fissility. Mineral grains are of silt size and are occasionally calcareous in nature. Lenses of siltstone are commonly found in this litho-unit.

3. Zone IV and Unfossiliferous Sequence-B

Limestone : This litho-unit comprises mainly greenish black to greenish grey and occasionally greenish coloured limestone. It is hard, compact, massive and fresh. The criss-cross calcite veins with occasional brown tints are seen. Few bands are of earthy look.

Siltyshale : This litho-unit is of greenish brown to chocolate colour. However, grey coloured with earthy look, weathered and soft siltyshale is also present with poor fissility. Lenses of siltstone are generally found in this litho-unit.

Sandstone : It is light grey in colour, very fine to fine, angular to subangular with calcareous cement, moderately hard and well sorted.

B. Microscopic (Petrographic) Study of Litho-units and Diagenesis

Detailed thin section petrography has been carried out to elucidate the grain-matrix relationship, textural pattern, mineral association and cement type in order to assign precise and more suitable names to various litho-units.

Petrographic Characters of Litho-units Observed in Unfossiliferous Sequence- A, Zone I and II

Calcareous quartz arenite : This litho-unit comprises very fine sand to occasionally silt size (60-115μm), angular to subangular, moderately to well sorted quartz grains. The quartz grains are embedded in clayey matrix (5-8%) with calcareous cement (20-25%). The quartz grains are generally monocrystalline (50-60%); showing line to sutured contact fabrics and are of submature nature (Plate 10, Photomicrograph No. 1). In addition to quartz, few grains of feldspars (mainly orthoclase 4-8%) with muscovite and associated heavy minerals (less than 1%) like siderite, pyrite, zoisite, zircon, epidote are sporadically observed. Quartz overgrowths are rare. A characteristic feature of this litho-unit is the sparitisation of micritic matrix along the borders of algae primarily due to diagenesis (Plate 10, Photomicrograph

No. 2). Bryozoans which form important carbonate forming benthic organisms are also sparitised as a result of diagenetic processes. (Plate 10, Photomicrograph No. 3). The solution seams are observed which are filled by either ferrugineous or calcareous solution which is post depositional and is indicative of tranquil condition. The mica grain does not show any preferred orientation indicating intermittent clastic supply from the metamorphic country.

Bryozoans prefer clear, slightly agitated water and cannot withstand turbidity (Banerjee, 1974). They indicate a marine environment.

Banerjee (1974) suggested that micrite indicates a quiet environment that might be shallow and protected from water agitation by physical barrier, as well as algae live only in the upper, well lit part of water, i.e. restricted to depth less than 60 meters.

Siltstone and siltyshale : These are represented by silt to clay size grains of quartz, feldspar and mica. The accessory minerals are pyrite, epidote, siderite, zoisite and calcareous matter. The relict bioclasts are mainly subjected to sparitisation (algae and mollusca; Plate 12, Photomicrograph No. 2). The periphery of mollusca is rimmed by secondary carbonates, i.e. siderites but the central part is micritic (Plate 10, Photomicrograph No. 4). Sometimes, the micritised algal boundary exhibit solution channels or dissolution seams which have been filled by clayey matter (Plate 11, Photomicrograph No. 1).

Tucker *et al.* (1990) suggested that dissolution seams are more common in argillaceous limestone and develop along clay layers or at junction of clay rich and clay-poor limestone. The dissolution seams are the result of chemical compaction which requires several hundred meters of burial. The mica flakes do not show any preferred orientation.

Packstone and grainstone (algal) : These litho-units mostly contain fragments of algae and bryozoa which are micritised and subsequently sparitised. Thus, it is difficult to identify their original morphology. The micritised algal peloids are sometimes coated with glauconite, pyrite and siderite. In many places, the glauconite and pyrite form replacement texture with algal peloids (Plate 11, Photomicrograph No. 2 and 3) thus, producing a ribbon-like feature (Plate 11, Photomicrograph No. 3). However, the arenaceous population includes quartz (6-8%), feldspar (2%) and mica (1%) which is mainly angular to subangular and exhibit corroded sutured boundary with floating framework (Plate 11, Phtomicrograph No. 4). The argillaceous matter and mud is 10%, micritised/sparitised algae, bryozoans and calcareous cement/matrix are 70-75%. The nature of cement and corrosion of mineral framework suggest that the cementation took place due to slow percolating alkaline solution within the pore space of the original terrigenous framework.

Dapples (1971) in his study suggested that the percolating calcareous solution digests the pre-existing arenaceous terrigenous boundary. The accessory minerals pyrite, siderite, glauconite etc. constitute 2-3%. The quartz grains are (20-100μm) angular to subangular.

Glauconite forms under marine alkaline solutions with pH ranging from 7-8 (Greensmith, 1978).

The replacement of algal peloids by glauconite might have happened due to diagenesis. Sinha (1989) reported glauconite in his study and suggested that it represents normal salinity having reducing/suboxic environment and slow sedimentation in a depth of upto 18-72 meters. Pyrite is the indicator of aspidic euxinic, anaerobic or poorly oxygenated, low energy environment (Miller & Heller, 1994). The presence of micritic grains with pyrite may be interpreted as post depositional with incipient diagenesis in a reducing environment.

Boundstone (algal) : This litho-unit is full of cellular type algae which is fully micritised.

The micritic grains are mixed with clayey matter (Plate 12, Photomicrograph No. 1). The arenaceous population, mainly quartz and feldspar (5%) is mud supported. Few scattered grains of pyrite and glauconite (1%) are also present.

Zone III

The following litho-types are identified and are presented in order of dominance :

(a) Calcareous quartz arenite

(b) Wackstone (bioclast)

(c) Siltyshale and Siltstone

(d) Mudstone (dolomitic)

(e) Mudstone (arenaceous)

(f) Mudstone and

(g) Packstone

The litho-types calcareous quartz arenite, siltyshale, siltstone and Packstone are similar as described above in previous zones.

Wackstone (bioclast) : In this litho-unit the chief bioclasts are bryozoa, chitinozoa (?), mollusca, conodonts, melanosclerites (?), algal peloids (Plate 15, SEM Photograph No. 1) and calcitic peloids. This litho-unit constitutes 40-45% calcareous mud, bioclast 25-35%, sparitised grains 20-25% and arenaceous population 1-2%. The bioclasts are poorly sorted, mud supported and fully micritised (Plate 12, Photomicrograph Nos. 3, 4 and Plate 13, Photomicrograph No. 1). The presence of whole fossil in wackstone, encrusting bryozoans and carbonate mudstone points to relatively slow sedimentation in tranquil condition. These conditions can occur behind bioherms in open shelf, open circulation environments, where, wave energy is minimal (Wilson, 1975; Miller and Heller, 1994; Tucker *et al.*, 1990).

Stylolites and dissolution seams are common in this unit which have fine saw-toothed to dendritic appearance (Plate 13, Photomicrograph No. 2) indicating forceful formation of dissolution seam in narrow space. Dissolution seam and stylolite in limestone are indicative of chemical compaction and pressure dissolution of burial processes (Greensmith, 1978; Tucker *et al.*, 1990) and normally absent in limestone with more than 5-10% clay. Pressure dissolution is an important process for supplying carbonate for the formation of carbonate cement (Flugel, 1982). At many places, the quartz veins are interrupted by these stylolites/microfaults, which are filled with residual solutions (Plate 13, Photomicrograph No. 3). The algal peloids are rim cemented with second generation of ferruginous matter but the inner part is sparitised and showing microcracks which indicates little transportation before settlement (Plate 13, Photomicrograph No. 4).

At places, the upper cortical part of algal peloid is made up of chert with the remanant of original silica cement (Plate 14, Photomicrograph No. 1). The peloids are sand-sized grains with an average size of 100-500μm and are an important constituent of typical, shallow, low energy, restricted marine carbonate environments. Tucker *et al.*, 1990, Meijer (1971) and Flugel (1982) in their studies suggested that algal peloids are formed in lagoonal and shelf limestones.

Mudstone (dolomitic) : The euhedral to rhomb shaped crystal of dolomite is frequently seen with three sets of cleavages with calcitic inclusions. The arenaceous grains (1-2%) are digested by mud. This unit is devoid of any bioclast/algal traces, may be fully destroyed due to dolomitisation (Plate 14, Photomicrograph NO.2). Greensmith (1978) has suggested that the favourable condition for dolomitisation is in shallow warm waters and depths between 0 and 45 meters.

Mudstone (arenaceous) : This litho-unit is mainly composed of mud which is highly sparitised (Plate 15 SEM Photograph No. 3). The arenaceous population (3-4%) is mainly silica which has precipitated along the vein.

Mudstone : This is made up mainly of mud (98%) which is sparitised. The precipitation of silica (less than 1%) in a vein is also noticed. The mud deposit takes place in a low energy settings, where, mud matrix is not winnowed away (Tucker *et al.*, 1990). There is no trace of algae or bioclast in this unit.

Zone IV and Unfossiliferous Sequence-B

Following litho-units are observed in these zones in order of dominance :

(a) Wackstone (bioclast)

(b) Siltyshale & siltstone

(c) Calcarous quartz arenite

(d) Mudstone (arenaceous)

(e) Mudstone (argillaceous)

Wackstone (bioclast) : This litho-unit is different from that described earlier as having numerous fractures which are refilled by calcareous solutions (Plate 14, Photomicrograph No. 3). However, the micritic grains are frequently seen (Plate 15, SEM Photograph No. 2).

Mudstone (argillaceous) : This litho-unit is characterised by argillaceous matter mixed with calcareous (80-85%) and fine grains of arenaceous population (10%). The solution seams, branched and criss-cross veins are numerous which are filled up by calcareous solution (Plate 14, Photomicrograph No. 4).

The rest of litho-units are similar, as described, in previous zones.

Lithostratigraphic Status of the Sequence Examined in the Study Area

As mentioned in Chapter-1, under the review of literature pertaining to the previous work done, it has been stated that the lithostratigraphic classification of the Lower Paleozoic marine sequence of the study area as proposed (Table-1) by Shah & Sinha (1974) and Sinha (1989) has been critically examined and verified during the present investigation. The same scheme has been adopted in the present study except one modification with regard to the stratigraphic boundary between the Shiala and Yong Limestone formations. This boundary as delineated by Shah and Sinha (1974) and Sinha (1989) shifted downwards based on the present study on acritarch assemblages (Figs. 4 & 5) and is discussed further in Chapter-4.

However, it is necessary to give an account of each formation examined during the course of present investigation in stratigraphic order as below :

Contact of Garbyang and Shiala Formation

Field study and sample collection were carried out at the point of contact between the Garbyang and Shiala formations i.e. from 25.250 Kilometer point very near the village of Sumna, where, the beds have average dip N30°E with 100°N strike direction. At 25.400 kilometer point, gradational contact between Garbyang and Shiala formations was exactly located. Rocks of the Garbyang Formation are mainly shale, siltyshale, sandstone and limestone. Sample positions are shown in Fig. 4. Cross bedded calcareous sandstone and alternating bands of sandstone and shale were observed with megafossils in the limestone beds.

Shiala Formation

The Shiala Formation comprises a sequence of green shales with bands of quartz arenite, greenish grey to greenish black siltyshale, siltstone and occasional bands of dolomitic mudstone and limestone. The details of lithology and sample positions have been shown in Figs. 3 & 4. The limestone is mainly fossiliferous consisting of fragments of crinoids, calcareous algae, corals and shells of brachiopods etc. The strike varies from 300°N to 323°N and dip from 20°NE to 30°N45°E.

At places, along the line of traverse, it is difficult to scale the steep slopes to reach the outcrops. Likewise, there are debris covers found covering the outcrops. The stratigraphic thickness of this formation as measured during the present study in this section is 401 meters.

Yong Limestone Formation

This limestone is greenish black in colour and comprises crinoids, corals and bryozoans. The measured thickness of this formation is 63 meters taking into account of infrequent to rare occurrence of obscure exposures due to debris cover.

Variegated Formation

This formation comprises limestone and shale with bands of quartzite with a characteristic purple to chocolate brown colour. The formation is poorly fossiliferous. The fault described by Shah and Sinha (1974) was not discernible due to scree & boulder cover, at places, along the line of traverse.

Sedimentological Investigations

These investigations include microscopic (petrographic) study of the rock thin-sections, clay mineralogy and determination of silt content. The microscopic (petrographic) study has already been given earlier, in this chapter. Hence, details of investigations carried out on clay minerals and silt are presented below.

Clay Mineralogy

Twenty five samples consisting of siltyshale, sandstone, limestone and siltstone from Sumna-Rimkhim section were selected for clay mineral studies.

Clay Mineral Identification

A PW 1730 Philips X-ray diffractrometer with the following setting was adopted in the present investigations :

1. Treatment - Oriented (Air dried) & glycolated
2. Chart speed - 1 cm/minute
3. Filter used - Copper
4. 2θ Range - 4°-30°
5. Powder pack method was also used for carbonate mineralogy.

The following interpretation was drawn from the diffractogram generated from XRD:

Illite : This mineral is the most abundant in all the four zones proposed along Sumna-Rimkhim section (Figs. 6a & 6b). The crystallinity of illite is moderate to good (Figs. 6a & 6b) indicating the diagenetic alteration of continental clays like kaolinite, which is present in minor proportions.

Kaolinite : This mineral is present in subsidiary proportion in zones I and II indicating fluvial relicts under a dominating shallow marine environment of deposition. The crystallinity of kaolinite is also moderately good showing slow burial of sediments and considerable exposure to chemical weathering (Fig. 6a).

Calcite : The carbonate bands of zone I at R-9, zone III at R-40, R-45, R-48, R-52, R-54 and unfossiliferous sequence-B at R-64 indicates the presence of calcite as the main mineral constituent, which is moderately well crtystalline (Fig. 6c).

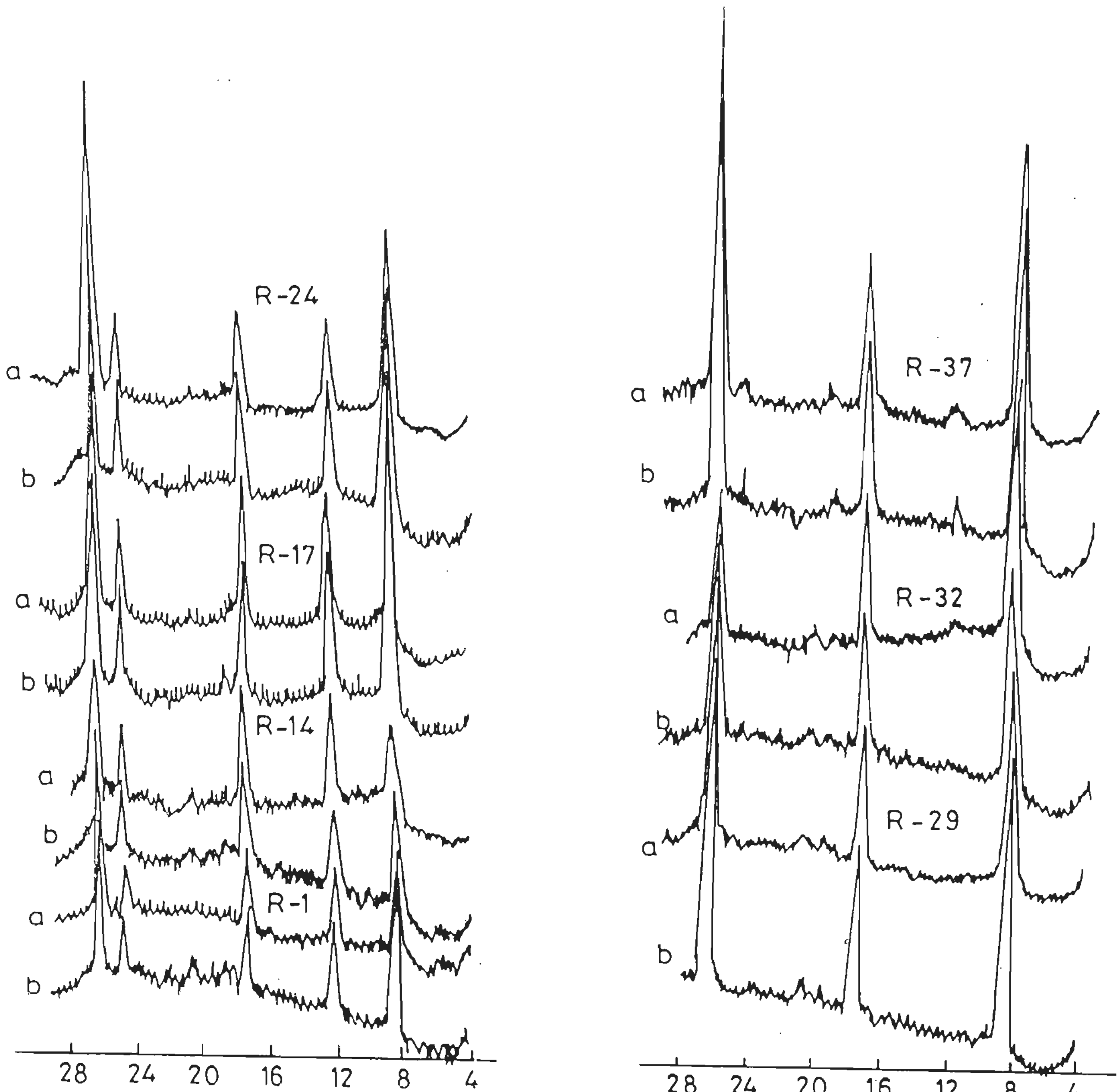

FIG. 6a X-RAY DIFFRACTOGRAMS OF CLAY FRACTION OF SELECTED SAMPLES FROM SUMNA-RIMKHIM SECTION.(a=air dried,b=glycolated)

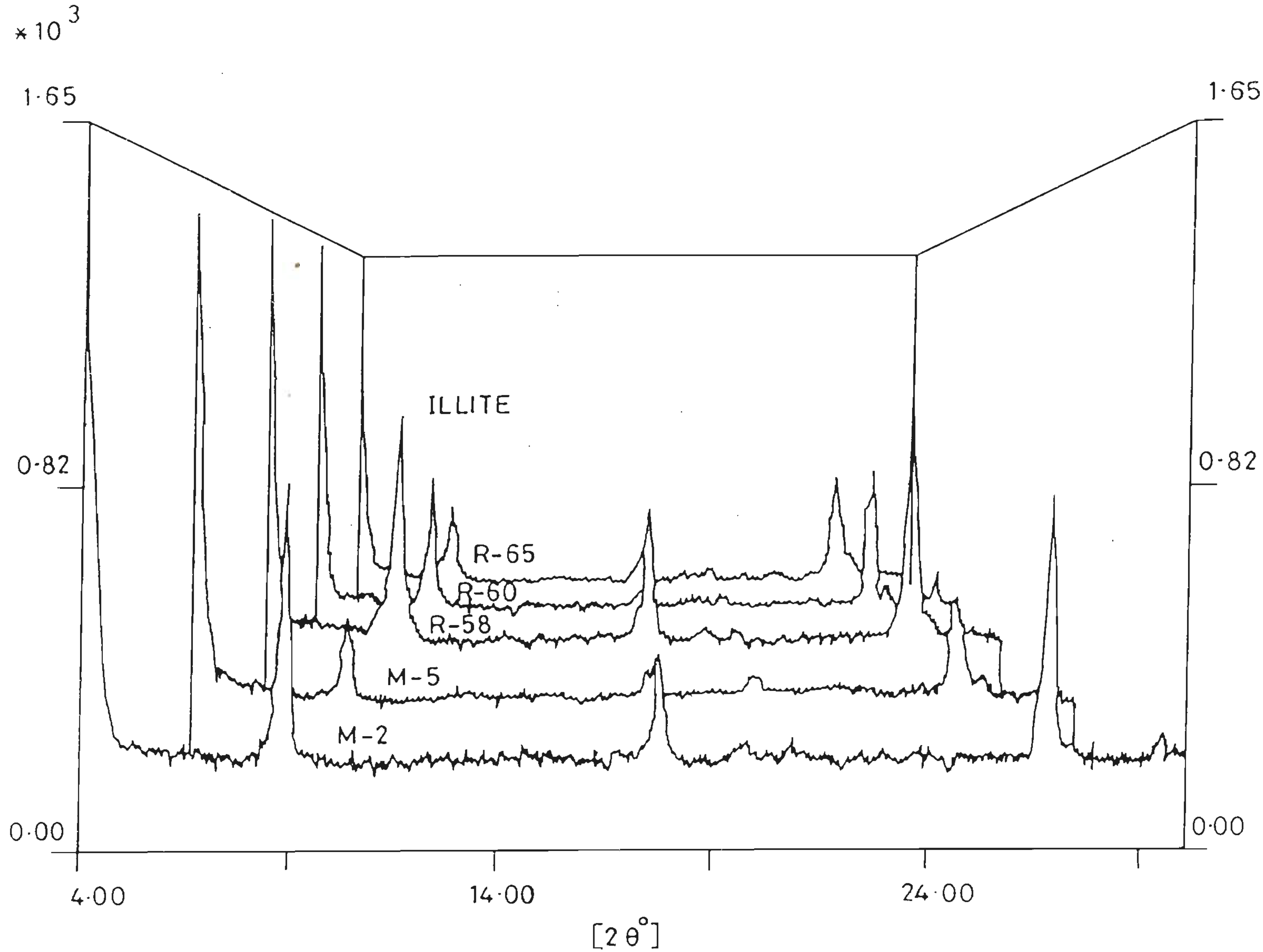

FIG. 6b XRD OF CLAY FRACTION OF SELECTED SAMPLES FROM SUMNA - RIMKHIM SECTION

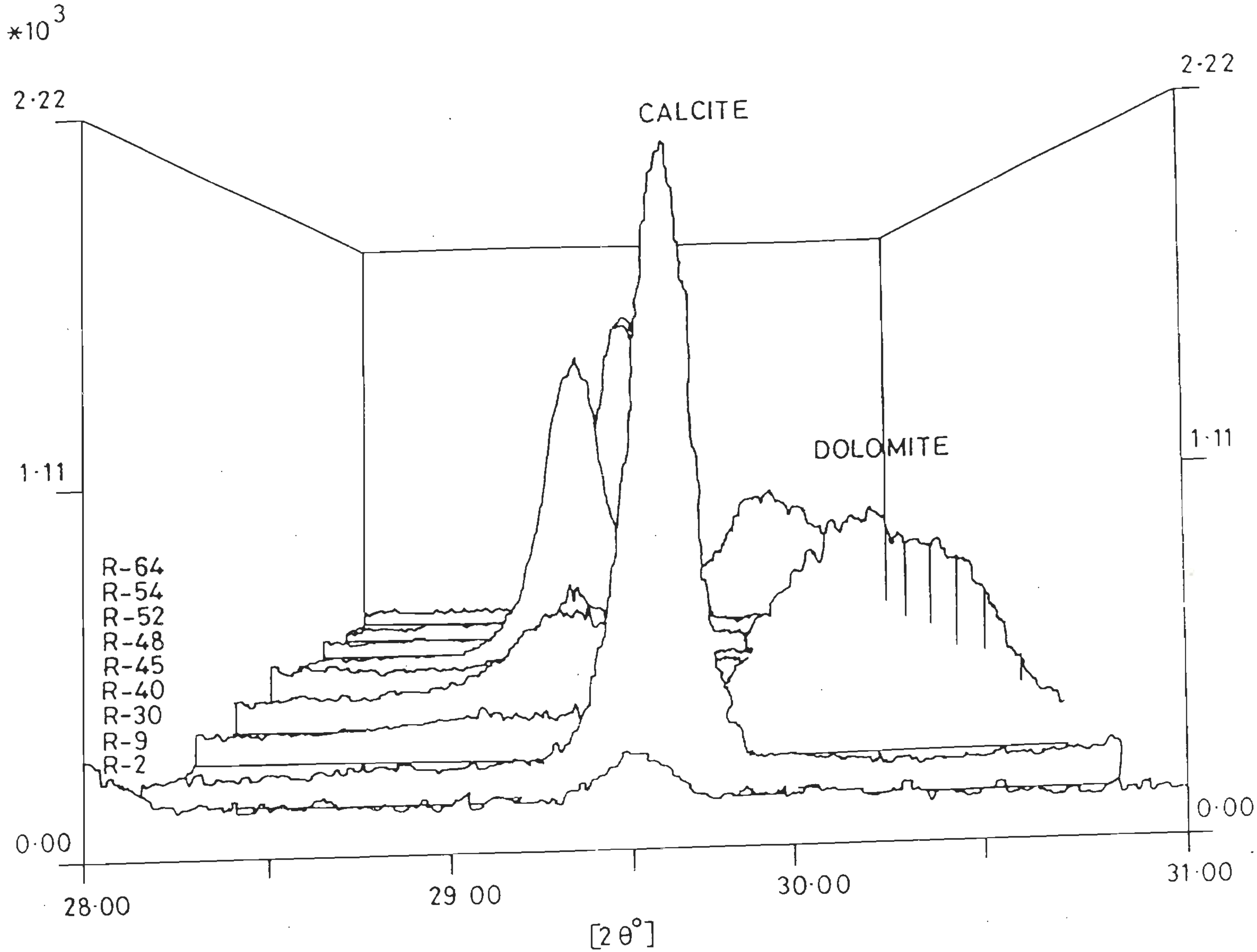

FIG. 6c IDENTIFICATION OF CALCITE AND DOLOMITE BY XRD

Dolomite : The carbonate bands of zone III at R-30 is poorly crystalline dolomite (Fig. 6c).

The clay suspensions were found only in 13 samples from clastics. No suspension was found in non-clastics. Results of clay minerals recorded are given in Table-6. It is observed that illite is present in most of the samples (Table-6) and Figs. 6a and 6b.

The abundance of clay minerals in different zones has been tabulated in Table 6. The abundance of illite and subsidiary presence of Kaolinite in unfossiliferous sequence-A, zone I and zone II indicate the dominance of shallow marine environment with signatures of fluvial regimes intermittently. Disappearance of Kaolinite in zone III and unfossiliferous sequence-B indicates absence of fluvial conditions and prevalence mainly of marine environment.

TABLE-6

Presence of clay minerals (Zone-Wise)

S.No.	Sample Nos.	Clay Mineral Present		Acritarch Zones
		Kaolinite in %	Illite in %	
1.	R - 65		100	UNFOSSILIFEROUS SEQUENCE-B
2.	R - 60		100	
3.	R - 58		100	
4.	R - 37		100	
5.	R - 32		100	ZONE-III
6.	R - 29		100	
7.	R - 24	21.4	78.6	
8.	R - 17	29.5	70.5	ZONE-II
9.	R - 14	28.58	71.40	
10.	R - 3	26.6	73.4	
11.	R - 1	27.77	72.23	ZONE-I AND UNFOSSILIFEROUS SEQUENCE-A
12.	M - 5		100	
13.	M - 2		100	

TABLE-7

Percentage of silt in siltyshale

Sample Nos.	Rock Type	Silt %	Frequency of acritarchs	Zones (as per the stratigraphic column)
R - 60	Siltyshale	43.5	Nil	Unfossiliferous Sequence-B
R - 37	Siltyshale	41.4	Infrequent	III
R - 21	Siltyshale	35.10	Prolific	II
R - 3	Siltyshale	38.0	Relatively poor	I
M - 2	Alternation of siltstone & siltyshale	41.0	Nil	Unfossiliferous Sequence-A

Silt Percentage

The frequency of population of acritarchs recoverd from various litho-units was critically examined just to check and see the relationship between the nature of entombing sediment and palynofossil contents. Thus, one litho-unit of the stratigraphic column i.e. siltyshale was chosen for this study. It was noted that even the siltyshale occurring at various levels in the stratigraphic column has varying yields of acritarchs and other associated microbiotic elements. For example, in Zones I and II the siltyshae yielded acritarchs in abundance while in Zone III the acritarch yield is infrequent and in the samples of siltyshale from unfossiliferous sequence-B did neither yield acritarchs nor any other fossil microbiota except algae and bryozoa (Fig. 5).

The above observation was found to be an interesting one which led the worker to think in terms of sediment/fossil microbiota relationship.

Thus, one sample of siltyshale from each zone and unfossiliferous sequences was chosen for silt percentage determination (Table-7).

Silt in the basal part of the section i.e., the unfossiliferous sequence-A is 41.0% and in the unfossilifereous sequence-B (top of the section), the silt is 43.5%. Such a considerable amount of silt in the litho-units has possibly hindred the preservation of palynomorphs. Silt percentage from Zone II (35.10) to Zone III (41.4) shows an increasing trend which possibly has controlled the frequency of acritarch population. The same is possibly true for Zone I.

Chemical-Sedimentological Investigations

The chemical-sedidmentological studies play an important role in reconstruction of paleoenvironments and sedimentation model. Investigations show that a few major and trace element assemblages are, in some respects, characteristic of the depositional environment of the sediments. Accordingly, 34 samples, from the present study area, were run for their major and trace element concentrations to understand the depositional environment (Table-8). Some of the important indicator elements, used in this study are Fe, Mn, B, Ga, Ca and Mg.

TABLE-8 Major and trace element concentrations

MAJOR ELEMENTS IN %

TRACE ELEMENTS IN ppm.

Sample Nos.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	S	V	Cr	Ni	Co	Ga	Rb	Sr	Ba	B
R-1	67.734	16.781	3.895	3.867	0.836	0.238	4.459	0.068	0.577	0.027	0.018	63	22	32	4	18	77	82	-	90
R-3	59.911	22.098	6.226	1.966	0.974	0.301	6.187	0.031	0.735	0.033	0.038	82	35	33	10	17	79	60	-	89
R-5	61.006	21.761	6.138	1.520	0.971	0.307	5.901	0.038	0.696	0.054	0.107	85	35	35	12	18	80	70	-	91
R-8	55.252	25.240	7.884	0.510	1.082	0.300	7.396	0.002	0.800	0.004	0.036	111	49	34	13	17	70	76	-	90
R-10	59.079	23.550	7.027	0.468	1.014	0.307	6.308	0.006	0.792	-	-	95	44	35	13	18	81	52	65	89
R-12	65.688	18.628	4.351	3.130	0.688	0.254	4.754	0.052	0.645	0.053	0.077	75	26	33	8	19	77	79	-	93
R-14	64.454	20.453	5.375	0.744	0.898	0.303	5.311	0.021	0.777	0.086	0.049	81	32	33	10	19	79	62	-	93
R-16	23.725	9.784	2.280	58.231	0.599	0.003	2.969	0.267	0.156	0.187	0.306	42	-	22	-	15	58	189	-	92
R-18	64.040	20.188	4.633	2.239	0.884	0.275	5.317	0.042	0.740	0.096	0.046	74	31	34	9	17	80	82	-	90
R-20	62.842	20.235	4.507	3.411	0.923	0.302	5.485	0.043	0.694	0.005	0.053	74	27	33	7	18	79	80	-	94
R-22	63.377	20.871	5.145	1.510	0.983	0.311	5.486	0.028	0.713	0.045	0.030	82	37	35	10	18	82	93	-	94
R-24	62.430	20.231	4.934	2.861	1.050	0.360	5.666	0.029	0.703	0.065	0.059	76	38	34	9	18	81	98	-	93
R-26	57.437	15.608	2.603	16.472	0.804	0.175	4.658	0.102	0.478	0.067	0.096	56	3	27	2	18	74	134	-	89
R-28	22.710	10.231	4.887	54.221	1.781	1.134	2.720	0.386	0.158	0.112	0.16	42	-	24	1	13	63	123	-	95
R-30	23.919	9.816	6.379	51.769	1.919	1.270	2.572	0.354	0.152	0.162	0.188	41	-	24	3	13	61	127	-	88
R-32	68.085	8.114	2.176	2.858	0.843	0.174	5.502	0.025	0.639	0.028	0.057	63	16	34	2	16	81	80	-	92
R-34	16.255	10.582	10.100	54.638	1.826	1.207	2.944	0.397	0.217	0.217	0.116	44	-	34	5	14	61	138	-	95
R-36	82.391	7.300	1.307	4.386	0.579	0.637	2.032	0.033	0.203	0.047	0.133	44	-	33	-	19	73	98	-	93
R-38	47.304	7.576	1.879	38.771	0.611	0.036	1.747	0.132	0.132	0.156	0.216	39	-	23	-	15	62	137	-	98
R-41	17.136	8.637	-	69.270	0.546	-	2.418	-	0.096	0.269	0.317	39	-	22	-	14	61	610	-	92
R-42	20.569	10.388	0.369	62.474	0.608	-	3.447	-	0.144	0.184	0340	43	-	28	-	14	63	669	-	88
R-46	17.107	6.588		73.284	0.478	-	1.271	-	0.047	0.237	0.224	38	-	21	-	14	56	676	-	92
R-50	14.583	6.124	-	76.761	0.475	-	0.836	-	0.041	0.255	0.384	37	-	21	-	15	56	795	-	90
R-56	51.599	17.829	2.639	17.278	0.917	0.182	7.461	0.018	0.461	0.046	0.071	53	2	28	2	18	73	135	-	90
R-58	57.805	22.557	3.352	3.073	1.038	0.224	9.539	0.016	0.766	0.043	0.086	77	31	33	6	17	84	90	-	88
R-60	55.663	16.112	2.166	14.891	0.774	0.118	7.965	0.042	0.474	0.128	0.165	51	-	28	1	18	75	147	-	92
R-65	62.833	15.862	2.995	6.955	0.969	0.307	7.847	0.023	0.471	0.138	0.102	50	3	30	3	17	78	126	-	90
R-67	61.895	21.844	0.437	3 .153	0.999	0.219	9.218	-	0.734	0.022	0.096	60	10	31	-	18	82	109	-	88
M-2	40.587	14.784	3.349	29.877	1.528	0.832	6.844	0.127	0.346	0.164	0.063	45	-	26	-	17	69	84	-	88
M-3	30.992	10.709	1.223	48.345	0.766	0.136	5.672	0.045	0.211	0.132	0.268	42	-	23	-	15	64	100	-	88
M-4	56.574	17.982	1.074	11.422	1.258	0.564	8.849	0.027	0.578	0.102	0.068	58	5	36	1	18	77	86	-	93

Distribution of Boron (B) and Gallium (Ga)

Boron is one of the trace elements that has long been regarded to characterise the sea water and marine sediments. Degens *et al.* (1957) showed that B & Ga occur in relatively insoluble forms of combination and, therefore, are suitable for use as environmental indicators. They observed higher content of B and lower content of Ga in marine sedidments. Harder (1970) reported higher Boron concentration ($\approx$ 1000 ppm) in evaporites than in those deposited in normal sea water (around 1000 ppm) of brackish and fresh water sediments ($<$80 ppm). Reynolds (1965) concluded that the Boron content of sea water has not changed significantly during the last two to three billion years.

A cross plot of Boron Vs. Gallium has been used by Degens *et al.* (1957) to distinguish between marine and fresh water shales of Pennsylvania. Similar data from Sumna-Rimkhim section has been plotted (Fig. 7) for each zone.

Unfossiliferous Sequence-A, Zones I, II, III and Unfossiliferous Sequence-B

The cross plot between Boron and Gallium of these zones indicate that the sediments were deposited under marine to marginal marine influence (Fig. 7). Hence, the environment of deposition in the study area is mainly marine to transitional.

Contents of major elements like Al, Si, Ca, Mg, Na and K vary with lithology. The lower Ca content is indicative of non-calcareous to feebly-calcareous nature of these sediments, which has been confirmed by petrographic studies also.

The higher percentage of Fe_2O_3 (1.223% - 10.100%) than Mno (0.045 - 0.397%) indicates marginal marine condition, while higher value of CaO (51.769% - 80.851%) over MgO (1.919% - 0.452%) indicates marine condition (Table-8).

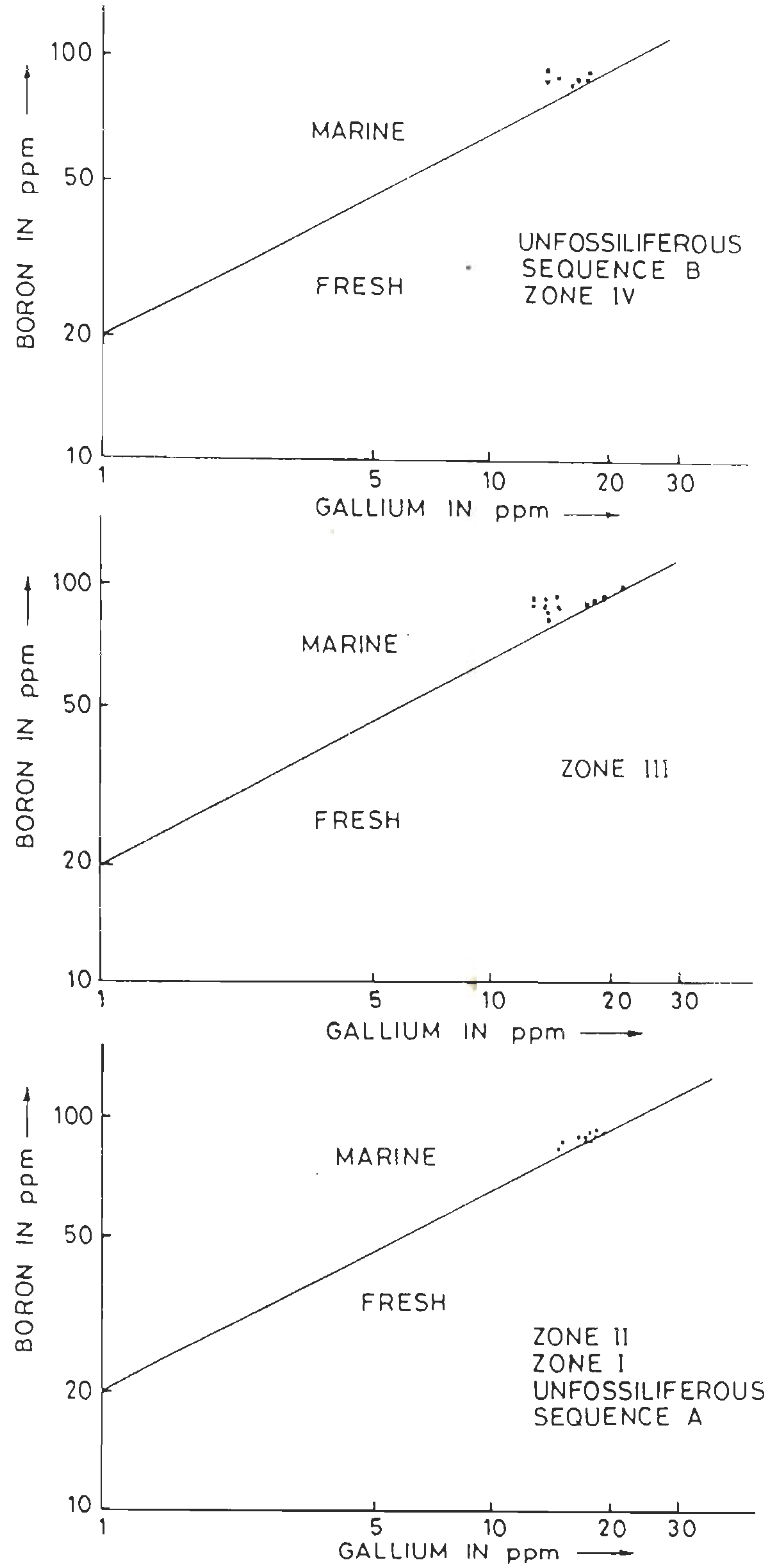

FIG.7 BORON-GALLIUM PLOTS OF SAMPLES FROM SUMNA - RIMKHIM SECTION.(THE STANDARD DIAGRAM TAKEN FROM DEGENS et al., 1957)

Discussion

The major and trace element study indicates that the sediments of Sumna-Rimkhim section were deposited in marine to transitional environment.

Fossil Microbiota, Biozonation (Palynozonation), Age and Correlation

Palynological processing of rock-samples has yielded acritarchs in abundance. In addition to acritarchs, chitinozoans, melanosclerites, scolecodonts, conodonts, bryozoans and algae were also found occurring in samples. The present study concentrates only on acritarchs as they have been reported from Ordovician-Silurian marine sedidments from almost the entire world but have not been recorded so far from India. Hence, the present study is the first detailed study on acritarchs of the Lower Paleozoic marine sequence in India. The taxonomy, biostratigraphic zonation (Palynozonation), age assignment of sequence and intercontinental correlation have been presented in Chapters 3 and 4.

Environment of Deposition

A detailed account and discussion on the inferences drawn with regard to environment of deposition based on acritarchs and other associated fossil microbiotic elements, supported by sedimentological and chemical-sedimentological studies have been presented in chapter 5. However, some of the inferences on this aspect have already been given in this chapter while dealing with the microscopic (petrographic) description of litho-units & diagenesis as well as under sedimentological and chemical-sedimentological investigations.

Finally, the entire study has been summarised with specific conclusions arrived at.

CHAPTER 3

PALYNOLOGICAL STUDIES

Introduction

Study of pollens, spores, other disseminules and associated detritus of higher plants is "Palynology", a term originally coined by Hyde and Williams in 1944 (Cross, 1962). According to Cross (1962), it also includes the study of spores, fruiting structures, fragments of algae and fungi and some elements of similar size belonging to protozoans or to other groups of animals and some of uncertain affinity.

The term "Palynomorphs" was first introduced by Tschudy for the spores and spore-like entities or fragments of larger plants and animals (Cross, 1962).

The first major study in Palynology was started in Europe in 1916 and was commonly known as "Pollenalysis".

Thiessen and his co-workers (in cross, 1962) in the United States made use of palynoforms in a big way for identification and correlation of coal-bearing sequences. The application of this science attained further refinement in Germany during the years from 1928 to 1935. The period from 1934 to 1950 received the maximum attention of Palynologists and this Science flourished to a very great extent in terms of its varied applications in diverse geological investigations in U.S.A. and other countries as well.

The third and most major development of Palynological application is in Oil Exploration which commenced at almost the same time in three different Oil company laboratories Creole, Shell and Carter (1945-47).

Application of Palynological knowledge and techniques in Geology is vast such as in age determination and correlation of rock sequences; in paleoenvironmental deductions and other allied aspects of study.

Palynoforms

1. Acritarch

Acritarchs are the microbiotic remains formed of organic compounds. Their systematic placement has not been possible because of their very simple morphology (Sarjeant and Stancliffe, 1994). Walls of acritarch are made up of organic material similar to cellulose or cutine. According to Cramer and Diez (1972), acritarchs' residue yield porphyrine derivates, when eometamorphosed. Acritarchs are apparently converted to "Kerogen" granules and lose their mirphological characteristics. However, Legault (1973) defines acritarchs as a polyphyletic group of organic-walled fossil microplanktonic organisms of undetermined biological affinities. Based on the relationship of many hystrichosphaeres with the dinoflagellates, Evitt (1963) erected the group acritarchs (from the Greek acritos= uncertain; and archae = origin) to include these hystrichosphaeres whose affinities are unknown or uncertain.

Ehrenberg (1838) was the first to record acritarch fossils. Wetzel (1933) introduced the term Hystrichosphaere and named the genus Hystrichosphaera to denote Ehrenberg's forms which were assigned erroneously and noted its indefinite biological affinities. Wetzel named a new family Hystrichosphaeridae to show animal affinities.

Deflandre (1937) corrected Ehrenberg's assignments and erected another genus, Hystrichosphaeridium. Deflandre (1947) pointed out that the order Hystrichosphaeridae was polyphyletic containing varied and often unrealted forms.

The order Hystrichosphaeridae was expanded to include a great variety of morphological types, for which, no biological affinities could be proposed. Evitt (1963) stated that the morphology of **Hystrichosphaera** and **Hystrichosphaeridium** shows that they are dinoflagellates. Hence, he amended the family Hystrichosphaeraceae and, excluded from it, those forms which do not exhibit dinoflagellate morphology.

Thus, Evitt suggested the name "acritarchs" for those forms, excluded from the hystrichosphaeres. So, this name includes a group of morphologically varied microfossils, whose affinities can not be determined. Hence, the term "acritarch" has no formal status in taxonomic nomenclature due to its polyphyletic implication, but, it is retained under "Catch-all" category (Legault, 1973).

Acritarchs are morphologically varied and their tests or vesicles may be spherical, polyhedral, cigar-shaped or irregular. Walls may be unornamented or bear appendages; spines; ridges; papillae, one-or two-layered; perforate or imperforate. Some acritarchs may be resting cysts, the opening (pylome) of which possibly served as an escape outlet for the organism.

The geologic history of the acritarchs begins from the Precambrian (Barghoorn and Tyler, 1965) to Recent. Paleozoic acritarchs are varied and numerous; certain groups emerged rapidly and disappeared and have been used as reliable stratigraphic indicators, while others lived for longer period of time. In the Mesozoic and Cenozoic, dinoflagellates displaced the acritarchs in numbers and in stratigraphic value as well (Legault, 1973).

There are a number of opinions with regard to the nature and systematics of the acritarchs. Downie and others (1963) stated that the acritarchs are heterogeneous mixture of fossil eggs, cysts or tests of unicellular or multicellular animals or plants. Eisenack (1963) stated that hystrichosphaeres inclusive of the acritarchs are a homogeneous group, in which, shelled stages alternated with naked stages and were the ancestral stock from which the dinoflagellates and particularly the armoured forms developed. Cramer and Diez (1972) believed that the acritarchs possibly had algal affinities and were largely colonial. Lister (1970) observed that the majority of Lower Paleozoic acritarchs are cysts of the unicellular phytoplanktons.

Thus, based on gross morphology, Cramer and Diez (1979) categorised acritarchs into the following three major morphological groups :-

Unit 1 : **Sphaeromorphitae** : more or less spherical forms with a smooth and little ornamented exterior vesicle surface. The most conspicuous and largest genera of this group are Tasmanites and Leiosphaerida.

Unit 2 : Those acritarchs which do not belong to the sphaeromorphs and are not acanthomorphitic acritarchs (=unit 3) either. They comprise Cymatiogalea, Cymatiosphaera, Polyedryxium, Polyplanifer, and many other genera. They termed it as heterogeneous group : **non-acanthomorphitic** acritarchs.

Unit 3 : The spiny or acanthomorphitic acritarchs (Acanthomarphitae, Netromorphitae and similar units). This is a very large group and constitutes a central body which is essentially spherical, plus one or more centrifugal processes, plus the possibility of forming an inner body or endoderm (almost thick-walled and spherical), plus occasionally some kind of an nonperiderm. Cramer & Diez (1979) estimated that two thirds of the acanthomorphitic acritarchs fall under one of these four big genera : *Baltisphaeridium*, *Micrhystridium*, *Multiplicisphaeridium* and *Veryhachium*. The remainder are unevenly distributed over more than 150 genera.

2. Chitinozoans

The word "Chitinozoa" was introduced in 1931 by the famous German micropaleontologist, Alfred Eisenack, who discovered these organic microfossils from erratic boulders drifted by the Quaternary ice cap on the Baltic sea shore. The biological significance and systematic position of chitinozoa are not satisfactorily explained so far. The actual chemical composition of the wall is still unknown.

The chitinozoans first appeared at the beginning of the Ordovician (Tremadoc) and then proliferated worldwide during 130 Ma, until the Devonian (Late Famennian). Chitinozoans are recovered exclusively from the marine deposits. They are usually abundant in fine-grained sediments, e.g. mudstone, shales, siltstone, argillaceous sandstones, limestones, phosphatic and ferruginous rocks. Their abundance ranges from a few individuals to several hundreds of specimens per gram of rock. 3000 specimens per gram of sample have been reported from the Pridoli of Western Libya. The abundance of the Chitinozoans is controlled by the primary factors like salinity, temperature, lighting, geographic situation of sea-water, food supply and hydrodynamic constraints (the chitinozoan vesicle behaves similar to mineral particles during sedimentary processes).

Chitinozoans have a fairly simple architecture with an opening located at or near the top of a cylindrical structure, so that they display a bottle or vase-like shape. The vesicle length ranges from 50μm to 2000μm. The weight of a vesicle ranges from 10^{-4} mg i.e. about 10-100 gm. of chitinozoans per ton of rock.

Chitinozoans are the most useful biostratigraphic fossils for Early Paleozoic time due to rapid morphologic changes through time. They are also the indicator of thermic changes occurring during the geological history of the deposits, where they were preserved. The increasing temperature produces a progressive darkening of the organic walls which corresponds to a new molecular equilibria i.e., increase of the carbon ratio= maturation of the organic matter. Chitinozoans give informations on the early diagenetic history of the sediments (Paris, 1990).

Few chitinozoans have been identified upto generic level from the Sumna-Rimkhim section. They have been recovered from the Shiala Formation and Yong Limestone Formation. They are *Conochitina* sp., *Desmochitina* sp. and *Ancyrochitina* sp. (Plates 8 & 9). However, the detailed study on chitinozoa is beyond the scope of the present work.

3. Melanosclerites

Melanosclerities are rod-shaped, pseudochitinous microfossils of problematic affinity. The term "Melanosclerites" was first used by Eisenack in 1942. They range from Ordovician to Middle Devonian (Eifelian). He considered them to have some affinity with hydrozoans (Cnidaria).

Melanosclerites were strongly facies controlled, occurring in sediments formed under open-ocean conditions (Nolvak, 1980). However, Cashman (1992) considered that melanosclerities could have been restricted to more shallow to open-ocean conditions. Since, melanosclerites are strongly facies controlled, and, thus, may have potential for paleoenvironmental and paleogeographical reconstructions (Cashman, 1992).

Melanosclerites are generally confused with chitinozoans as their silhouette and their size are very similar. The only way to distinguish is to check the wall structure through

SEM-studies (Plate-9). Chitinozoans have normally thin walled vesicles, whereas, melanosclerites are not hollow or display just a very small central canal (Paris. F, 1993; personal communication).

Melanosclerites have been recovered from the Yong Limestone and Shiala formations of the Sumna-Rimkhim section (Plates 8 & 9).

TAXONOMY OF ACRITARCHS

Introduction

20 genera and 67 species of acritarchs have been identified and recorded for the first time from the Ordovician-Silurian (Caradocian to Ludlovian) marine sediments of the Tethyan Garhwal Himalaya, India.

Catalogues on acritarchs (Eisenack, Cramer and Diez 1973, 1976 & 1979) and other literature on taxonomy published upto 1994 were consulted while identifying the forms upto specific level. As mentioned in Chapter 2, text-figures were also prepared in order to observe the morphological details of the forms recorded. The text-figures could not be incorporated in Plates 1 to 8 due to certain unforeseen circumstances.

Group : ACRITARCHA Evitt, 1963

Subgroup : **SPHAEROMORPHITAE** Downie, Evitt & Sarjeant, 1963

Genus : *Bavlinella* Shepeleva, 1962

Type species : *Bavlinella faveolata* Shepeleva, 1962

Bavlinella sp.

(Pl. 8, Fig. 15)

Description : Cyst spherical, dark brown, matured, measuring 57μm at maximum diam.; cyst wall reticulates with few exinal folds; pylome indiscernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Bavlinella*. Due to less number of forms in the Tethyan assemblage, it has been identified upto generic level and, for the time being, mentioned as *Bavlinella* sp.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(2): 106.8x29.5

Genus : *Lophosphaeridium* (Timofeev) Lister, 1970

Type species : *Lophosphaeridium rarum* Timofeev, 1959

Lophosphaeridium parvum Stockmans & Williere, 1963

(Pl. 8, Fig. 17)

Description : Cyst globular, subcircular to oval, measuring 24μm in diam.; cyst wall ornamented with number of conical processes, cones with broad base and pointed tips, solid, cylindrical, measuring upto 1μm in height; cyst wall in between the processes psilate; pylome indiscernible.

Comparison : The present specimen closely compares with *Lophosphaeridium parvum* Stockmans & Williere (1963) described from the Borehole of the Lust Brewery, (Tarannonian) of Belgium.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(1): 108.5x41.7

Distribution elsewhere : Tarannonian: Belgium (Stockmans & Williere, 1963); Lower Silurian: Belgium (Martin, 1965 &1968).

Lophosphaeridium sp. cf. *L. parvum* Stockmans & Williere, 1963

(Pl. 4, Fig. 1)

Description : Cyst globular, highly matured, measuring 18μm in diam.; cyst wall rigid, covered by sparsely distributed processes; processes simple with acuminating tips and broad base, upto 1-2μm high, 12-15 processes at the periphery; pylome indiscernible.

Comparison : The Tethyan specimen referable to *Lophosphaeridium* sp. closely compares with *L. parvum* Stockmans & Williere,1963 (p. 472, pl. 3:27) described from the Lust Brewery (Tarannonian) of Belgium. However, the present form differs from holotype due to its smaller size range.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-22(1):94x59

aff. *Lophosphaeridium* sp.

(Pl. 2, Fig. 2)

Description : Cyst subspherical, brownish black, matured; vesicle wall rigid, ornamented with closely placed coni with broad base, coni height measure less than 1μm; wall in between coni punctate; pylome indiscernible due to close ornamentation.

Comparison : The present form is morphologically comparble with generic circumscription of *Lophosphaeridium*. Due to less number of forms in the Tethyan assemblage, it has been identified upto generic level and for the time being, mentioned as *Lophosphaeridium* sp.

Occurrence in study area : Calcareous quartz arenite of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-5(1): 101x51

Lophosphaeridium sp.

(Pl. 3, Fig. 4) and (Pl. 8, Fig. 13)

Description : Cyst circular, peripheral margin roughened, measuring 40-42μm at maximum diam.; cyst wall bears varied type of sculptural elements, sculptural elements include solid, short, cylindrical processes and spines upto 1.5μm in height, sparsely distributed; 8-9 sculptural elements present on peripheral margin; cyst wall structured by fine reticulation; pylome indiscernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Lophosphaeridium*. But, conspicuous with known species of the genus due to its varied sculptural elements. Specimens are less in number, therefore, these forms are only compared with *Lophosphaeridium* instead assigning to new species.

Occurrence in study area : Siltstone of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-12(1): 99.8x61.6; R-12(1): 92.1x65

Genus : *Leiosphaeridia* (Eisenack) Turner, 1984

Type species : *Leiosphaeridia baltica* Eisenack, 1958

Leiosphaeridia viswanathiae (Maithy & Shukla) Viswanathiah *et al.*, 1980

(Pl. 8, Fig. 6)

Description : Cyst dark brown, highly matured, circular to oval in shape, peripheral margin undulating due to compressions, measuring 35μm in diam.; cyst wall structured by minute puncta and few irregular folds.

Comparison : The Tethyan specimen closely compares with *Leiosphaeridia viswanathiae* (Maithy & Shukla, 1977) Viswanathiah *et al.*, 1980 (pl. 3, Fig. 22) described from the Su Ket Shale of M.P.,India. However, the specimens from this area are relatively smaller in size range.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(2): 104.7x46.5

Subgroup : *ACANTHOMORPHITAE* Downie, Evitt & Sarjeant, 1963

Genus : *Aremoricanium* Deunff, 1955

Type species : *Aremoricanium rigaudiae* Deunff, 1955

Aremoricanium sp. cf. *A. simplex* Loeblich & MacAdam, 1971

(Pl. 8, Fig. 9)

Description : Cyst subcircular to spherical, 48μm in diam.; cyst wall rigid, ornamented by rare, low, indistinct processes and grana; a prominent neck like extension, measuring 3μm in diam., terminates in a circular pylome; a number of discontinuous ridges observed along the peripheral margin.

Comparison : The Tethyan form broadly compares with generic circumscription of *Aremoricanium* Deunff, 1955. However, it is not comparable to any known species of the genus due to solitary record in this area. Hence, it is referred to the *Aremoricanium* sp. with nearest comparble to *A. simplex* Loeblich & MacAdam.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(1): 94.7x23.8

Distribution elsewhere : Mountain Lake Member of the Bromide Formation (Middle Ordovician, Llanvirnian-Llandeilian): Oklahoma (Loeblich & MacAdam, 1971).

Genus : *Baltisphaeridium* (Eisenack) Eiserhardt, 1989

Type species : *Baltisphaeridium longispinosum* Eisenack, 1931

Baltisphaeridium accinctum Loeblich & Tappan, 1978

(Pl. 2, Fig. 6)

Description : Cyst spherical, dark, highly matured, measuring 48μm in diam.; cyst wall psilate to punctate with number of thin cylindrical processes, processes simple, hollow and long, measuring upto 4μm in height; about 25 processes observed along the periphery; pylome indiscernible.

Comparison : The above specimen closely compares with *B. accinctum* Loeblich & Tappan, 1978 (pl. 2, Fig. 1) described from the Vaureal Formation (Ashgillian) of Quebec, Canada.

Occurrence in study area : Siltyshale of the Shiala Formation : Tethyan Garhwal Himalaya, India; R-8(1): 100.5x27.5

Distribution elsewhere : Vaureal Formation (Ashgillian): Quebec, Canada (Loeblich & Tappan, 1978).

Baltisphaeridium archaicum Cramer & Diez, 1972

(Pl. 3, Fig. 5)

Description : Cyst subspherical, deformed into subrectangular shape due to compression, measuring upto 30μm in diam., cyst wall ruptured, structured with fine grana, 4-5 long processes emerge out from the vesicle wall, processes simple, slender, flexible distally, processes hollow with granulate surface, measuring upto 24μm in height; pylome circular.

Comparison : The Tethyan specimen compares with *B.archaicum* Cramer & Diez, 1972 described from the Belfast Bed (Lower Llandoverian) of Ohio.

Occurrence in study area : Siltyshale of the Shiala Formation : Tethyan Garhwal Himalaya, India; R-8(2): 94.1x36

Distribution elsewhere : Belfast Bed (Lr. Llandoverian): Ohio (Cramer & Diez, 1972).

Baltisphaeridium citrinum (Downie) Stockmans & Williere, 1974

(Pl. 2, Figs. 7 & 8)

Description : Vesicle ellipsoidal, measuring 25-29μm at maximum diam.; pylome distinct, circular to subcircular; cyst wall ornamented with capitate spines with rounded as well as pointed tips, measuring 1-1.5μm high, 26-32 spines at periphery; cyst structure punctate, occassional exinal folds conforming with cyst periphery present on the cyst wall.

Comparison : The Tethyan specimens closely compare with *Baltisphaeridium citrinum* (Downie) Stockmans & Williere (1974) described from the Wenlock Shales (Wenlockian) of England.

Occurrence in study area : Siltyshale of the Shiala Formation : Tethyan Garhwal Himalaya, India; R-21(5): 93.1x31.5; R-21(5): 106.4x65.6

Distribution elsewhere : Wenlock Shale (Wenlockian): England (Stockmans & Williere, 1974).

Baltisphaeridium longispinosum subsp. *delicatum* Turner, 1984

(Pl. 7, Fig. 6)

Description : Cysts spherical, highly matured, measuring upto 44μm in diam.; cyst wall thick, reticulate with sparsely distributed long processes, processes hetromorphic, long and delicate, cylindrical, hollow, acuminating tips in bifurcated one, processes upto 20-30μm in height, with plugged base and granulate surface; pylome circular.

Comparison : The Tethyan speicmens assigned to *Baltisphaeridium longispinosum* subsp. *delicatum* resemble to those described by Turner, 1984 (pl. 6, Fig. 1,7) from the Ordovician Caradoc Series (Late Costonian-Onnian; Early Caradoc) of England. The recovered forms in this assemblage have reticulate cyst wall, whereas, Turner's specimens are smooth.

Occurrence in study area : Calcareous quartz arenite of the Shiala Formation : Tethyan Garhwal Himalaya, India; R-5(2): 100.5x33.5

Distribution elsewhere : Caradoc Series (Ordovician): England (Turner, 1984).

Baltisphaeridium longispinosum var. *longispinosum* Eisenack, 1959

(Pl. 7, Figs. 1 & 5)

Description : Cysts spherical, matured, often ruptured, 35-63μm in size at maximum diam.; cyst wall rigid, laevigate, sculptured by long and slender processes, processes septate(?) with granulose surface, gradually tapering at distal end, height upto 26-32μm and width 2-4μm at base; pylome distinct, subcircular.

Comparison : The studied specimens closely compare with *Baltisphaeridium longispinosum* var. *longispinosum* Eisenack, 1959 (pp. 195, pl. 15:1) described from the Chasmops-Limestone, Boda, Oland of lower Caradocian.

Occurrence in study area : Calcareous quartz arenite of the Shiala Formation : Tethyan Garhwal Himalaya, India; R-5(2): 103x33.5; R-5(1): 99.7x27.8

Distribution elsewhere : Middle Ordovician to upper Llandoverian: Baltic (Eisenack, 1959); Ordovician; Sweden (Staplin, Jansonius & Pocock, 1965).

Baltisphaeridium sp.

(Pl. 3, Fig. 6)

Description : Cysts subcircular to oval, with undulated periphery, dark brown, measuring

36μm in diam.; cyst wall laevigate, exinal surface with few occassional irregular pits and folds; two processes opposite to each other emerge from cyst wall, processes hollow, cylindrical, measuring 12μm in height, 2-3μm in breadth, smooth with rounded(?) tips; pylome indiscernible.

Comparison : The morphological characters of the recovered form is conspicuous from the known species of *Baltisphaeridium* in having only two distinct processes.

Occurrence in study area : Siltyshale of the Shiala Formation : Tethyan Garhwal Himalaya, India; R-8(1): 105.5x28.7

Baltisphaeridium sp.

(Pl. 3, Fig. 12)

Description : Cyst spherical, measuring 54μm (including processes); cyst wall thin, shagrinate, sculptured by close placed, long process; processes simple, hollow, non-branching, homomorphic, communicating freely with the vesicle cavity, few of these hair-like and sinuous with acuminate distal terminations; processes upto 18μm in height; exinal folds on cyst wall present; pylome indiscernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Baltisphaeridium*. Due to solitary form in the present assemblage, it has been identified upto generic level, and for the time being, mentioned as *Baltisphaeridium* sp.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(1): 91.2x34

Genus : *Baltisphaerosum* (Eisenack) Turner, 1984

Type species : *Baltisphaerosum christoferi* (Kjellstrom) Turner, 1984.

Baltisphaerosum bystrentos (Loeblich & Tappan) Turner, 1984

(Pl. 2, Fig. 13)

Description : Cysts spherical, measuring 39μm in diam.; cyst wall thin, structured with prominent irregularly spaced grana; sculptural elements with long processes; processes flexible, simple, slender and hollow, few with acuminating tips, processes wall granulose, height of processes smaller than cyst diameter with plugged base; excystment by median split.

Comparison : The examined forms compare with *Baltisphaerosum bystrentos* (Loeblich & Tappan) Turner, 1984, (pl. 3,Figs.1,2, 5) described from the Caradoc Series, England. However, the Tethyan forms have less number of processes with plugged base.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(2): 95x31.3

Distribution elsewhere : Llandeilo (Bromide Formation): Oklahoma (Loeblich & Tappan, 1978).

Genus : *Buedingiisphaeridium* (Schaarschmidt) Sarjeant & Stancliffe, 1994

Type species : *Buedingiisphaeridium permicum* Schaarschmidt, 1963

Buedingiisphaeridium tremadocum Rasul, 1979

(Pl. 1, Fig. 11)

Description : Cysts spherical, highly matured, small, measuring upto 14μm in diam.; excystment by distinct equitorial rupture; cyst wall thin, ornamented with closely distributed conical tubercles, tubercle base solid and broad with long, narrow pointed tips, communicating with test wall, tubercles upto 1.5-3.5μm high and 1-3μm wide at base, about 21 tubercles at peripheral margin.

Comparison : The present specimen resembles with *Buedingiisphaeridium tremadocum* Rasul, 1979 (pp. 64, pl. 1, Fig. 12, 13) of the Tremadoc Series of the Shineton Shales, Shropshire, England.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 105.3x50.5

Distribution elsewhere : Shineton Shales (Tremadoc): Shropshire, England (Rasul, 1979).

Genus : *Cheleutochroa* (Loeblich & Tappan) Turner, 1984

Type species : *Cheleutochroa gymnobrachiata* Loeblich & Tappan, 1978.

Cheleutochroa diaphorosa Turner, 1984

(Pl. 1, Fig. 8)

Description : Cysts subcircular to oval, dark brown in colour; measure upto 18μm in diam.; cyst wall granulate; a number of heteromorphic processes emerge out from the central body, two types of processes observed-one simple with acuminate tips, other bifurcate distally, few bifurcating at half of total length, second order bifurcation rare; process wall thin, delicate, psilate, hollow throughout the length, processes height usually equal or slight greater than the vesicle diam., breadth upto 1.6μm, about 26 processes present at the equator; pylome discernible.

Comparison : The above illustrated forms closely compare with *Cheleutochroa diaphorosa* Turner, 1984 (pl. 7, Fig. 3) described from the Ordovician (Caradoc Series) of Shropshire, England. The Tethyan specimens have distinct pylome and more number of processes in comparison to Shropshire one.

Remarks : *Cheleutochroa diaphorosa* and *Multiplicisphaeridium irregulare* are morphologically identical. Both are differentiated by cyst wall structure and ornamentation. The wall structure in previous one is granulate whereas in later one laevigate.

Occurrence in study area : Calcareous quartz arenite of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-15(1): 106x50.8

Distribution elsewhere : Ordovician Caradoc Series (Actonian-Onnian): Shropshire, England (Turner, 1984).

Genus : *Diexallophasis* Loeblich, 1970

Type species : *Diexallophasis denticulata* (Stockmans & Williere) Loeblich Jr., 1970

cf. *Diexallophasis* sp.

(Pl. 1, Fig. 5)

Description : Cyst inflated to oval, deformed and broken, dark brown, measuring 30μm at maximum diam.; vesicle wall double-layered, granulate; processes formed by the outer layer, tabular with sharp base, appears to be plugged proximally; processes two types : one unbranched, smooth and hollow; the other ones bifurcate and multifurcate, height upto 15μm, few processes emerging from central wall, the outer surface of the processes bear fine spines, upto 1μm high, processes 6 in number, communicate freely with the central body, vesicle wall ruptured; pylome indiscernible.

Comparison : The present forms are morphologically comparble with generic circumscription of *Diexallophasis*. It differes from the known species of *Diexallophasis* in having smaller size range. Due to less number of forms in the present assemblage, it has been referred to as *Diexallophasis* sp.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation: Tethyan Garhwal Himalaya, India; R-47(1): 107.3x64.3

Genus : *Filisphaeridium* (Staplin, Jansonius & Pocock) Sarjeant & Stancliffe, 1994

Type species : *Filisphaeridium setasessitante* (Jansonius) Staplin, Jansonius & Pocock, 1965

Filisphaeridium henryi (Paris & Deunff) Sajeant & Stancliffe, 1994

(Pl. 1, Fig. 16)

Description : Cysts spherical to subspherical with spinose peripheral margins, measures 20μm at maximum diam.; cyst wall bear numerous hollow, homomorphic, smooth processes that taper rapidly to acuminate tips, each processes interior open to the vesicle cavity, processes 2.5-4μm high; no excystment structure visible.

Comparison : The present form closely resembles with *Filisphaeridium henryi* (Paris & Deunff) Sarjeant and Stancliffe, 1994 (pp 31-32, p. 2:14) described from the Calymene Shales of France.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0); 103.3x36.2

Distribution elsewhere : Llanvirnian: Brittany (Paris & Deunff, 1970); Llanvirnian: Montagne Noire, France (Rauscher, 1974).

Genus : *Helosphaeridium* Lister, 1970

Type species : *Helosphaeridium clavispinulosum* Lister, 1970

Helosphaeridium citrinipeltatum (Cramer & Diez) Dorning, 1981

(Pl. 2, Fig. 4)

Description : Cysts small, spherical,peripheral margins roughened due to outward projection of sculptural elements, measuring 14μm; vesicle hollow, wall densely covered with small solid peltate sculptural elements distributed in well spaced pattern; pylome indiscernible.

Comparison : Present forms resemble *Helosphaeridium citrinipeltatum* (Cramer & Diez) Dorning, 1981 (p. 166-167, pl. 35:58, 59) described from the Alger Shale (Upper Llandovery) of Ohio. The size range of the Tethyan specimens are comparatively smaller than those of Alger Shale.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5): 92.6x64

Distribution elsewhere : Waldron Formation (grapt. z. top 30 and base 31): Indiana and Kentucky (Cramer & Diez, 1972).

Helosphaeridium sp. cf. *H. clavispinulosum* Lister, 1970

(Pl. 8, Fig. 14)

Description : Cyst ellipsoidal, measuring 14 μm at axis; vesicle hollow, cyst wall ornamented with small cones; coni with broad base and sharp pointed tips, 0.5-1 μm high, spacing of cones constant; rupture along periphery; pylome indiscernible.

Comparison : The Tethyan specimens referable to *Helosphaeridium* closely compare with *Helosphaeridium clavispinulosum* Lister, 1970 (pl. 8: 8, Fig. 18g, 27b) described from the Lower Elton Beds (Ludlovian) from Herefordshire. However, the present forms differ from holotype in being smaller in size range and exceptionally broad bases of coni.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5); 94.1x73

Distribution elsewhere : Lower Elton Beds (Ludlovian): England (Lister, 1970)

Genus : *Micrhystridium* (Deflandre) Sarjeant & Stancliffe, 1994

Type species : *Micrhystridium inconspicuum* (Deflandre) Deflandre & Sarjeant, 1970.

Micrhystridium ? diornamentum Rasul, 1979

(Pl. 3, Figs. 2, 3 & 10)

Description : Cyst globular with spherical outline, dark brown and matured, measuring 12-16μm in diam.; cyst wall thin structured by fine grana, a number of varied sculptural element emerge from the cyst wall, one type consists of numerous, closely spaced small, hair-like, smooth and hollow spines; the other kind comprises few exceptionally long, and hollow processes which taper at distal ends; long processes widely spaced, upto 8 to 12μm high about 8-10 in numbers along the peripheral margins; pylome distinct, circular, situated at the center of body, occasional exinal folds on cyst wall present.

Comparison : The Tethyan specimens compare with *Micrhystridium*? *diornamentum* Rasul, 1979 (Pl. 1, Fig. 4, pp. 55-56) described from the Tremadoc Series of the Shineton Shales, Shropshire, England. The specimens referable to this species are conspicuously distinct from the generic circumscription of the *Micrhystridium* as this bears two orders of spines, variable in their morphology. Therefore, Sarjeant & Stancliffe, 1994 has provisionally retained it in *Micrhystridium* with interrogation.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103.5x40.8; R-8(0): 102.6x40; R-8(0): 95.8x38.5

Distribution elsewhere : Shineton Shales (Tremadoc): England (Rasul, 1979).

Micrhystridium equispinosum Turner, 1984

(Pl. 4, Fig. 14)

Description : Cysts subspherical to polygonal, small measuring 8-10μm in diam.; cyst wall microgranulate, ornamented with a number of processes, processes simple, hollow and homomorphic, open to the vesicle cavity; processes have slightly expanded bases and taper rapidly to slender, somewhat flexible acuminate distal terminations, some solid towards the tip, height varies from 2-4μm, surface of the vesicle as well as processes are granulate without much differentiation; Pylome present, poorly discernible, subcircular to oval in shape.

Comparison : The recovered specimens closely compare with *Micrhystridium equispinosum* Turner, 1984 (pp. 119-120; pl. 15, Fig. 1) described from the Caradoc Series from Shropshire, England. However, the present form differs from the holotype by its microgranulate cyst wall.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103.5x41

Distribution elsewhere : Caradoc Series: Shropshire, England (Turner, 1984).

Micrhystridium exiguum Rasul, 1979

(Pl. 4, Fig. 2)

Description : Cyst body very small, spherical in outline, measuring 5-6μm in diam.; cyst wall thin, sculptured by numerous spinate processes, spines short, smooth, hollow and thorny the bases of the processes narrow with average height upto 3μm; about 35-40 processes present on the peripheral margins; pylome indiscernible.

Comparison : The Tethyan specimens show close resemblence to *Micrhystridium exiguum* Rasul (1979) described from the Tremadoc Series of the Shineton Shales of Shropshire, England.

Remarks : Sarjeant & Stancliffe (1994) restricted the generic circumscription of *Micrhystridium* having upto 35 processes. He further questioned the genuinity of the forms having more than 35 processes classed under *Micrhystridium*. The number of processes in the Tethyan specimens varies from 30-40. It is very difficult to separate the forms having less than or more than 35 processes on the morphological ground. So, the forms having process more than 35 are also placed here under *Micrhystridium* in the identification of Tethyan acanthomorphs.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 95x35.2

Distribution elsewhere : Shineton Shales (Tremadocian): Shropshire, England (Rasul, 1979).

Micrhystridium parinconspicuum Deflandre, 1945

(Pl. 1, Figs. 6 & 15)

Description : Cysts globular with subcircular to oval shape, dark brown and matured, 10-14μm at maximum diam.; cyst wall sculptured by sparsely distributed, stout processes; processes equally distributed over the cyst, each processes have broad bases and terminate into sharp pointed tips, height of spines varies from 3-7μm, spines hollow with granulate surface, communicating with cyst; cyst wall in between the sculptural elements microgranulate; pylome distinct and subcircular.

Comparison : The Tethyan specimens closely compare with *Micrhystridium parinconspicuum* Deflandre, 1945 (p. 65-66, pl. 3, Fig. 8-13) recorded from the Limestone of Roquemaillere (Silurian) of France.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 104.9x63.3; R-8(0): 106.4x68.5

Distribution elsewhere : Silurian: France (Deflandre, 1945); Shineton Shales (Tremadocian): Great Britain (Downie, 1958); Tarannonian: Belgium (Stockmans & Williere, 1963); Wenlock Shales (Wenlockian): England (Downie, 1959).

Micrhystridium robustum Downie, 1958

(Pl. 3, Fig. 11)

Description : Cysts spherical, measuring 10-12μm in diam.; cyst wall microgranulate, surface ornamented by long, unbranched hair-like processes, hollow, cylindrical with acuminating tips, about 7 processes at equatorial margin, 6-8μm high; pylome indiscernible.

Comparison : The studied specimens closely compare with *Micrhystridium robustum* Downie, 1958 (p. 344, pl. 17:5, Fig. 3b) described from the Shineton Brook, Shropshire (Up. Tremadocian) of England.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5): 94x54.8

Distribution elsewhere : Shineton Shales (Lower Tremadocian) : England (Downie, 1958); Arenigian: Montagne Noire, France (Rauscher, 1974).

Micrhystridium shinetonense Downie, 1958

(Pl. 1, Fig. 4)

Description : Cyst spherical, dark brown, matured, measuring 11μm in diam; cyst wall microgranulate with sparsely placed solid spinose processes; processes simple, tapering at distal ends, bases broad and not communicating with cyst body, height varies from 3-7μm, few long flexible processes are also present, about 8 processes at periphery; pylome indiscernible.

Comparison : The Tethyan specimens resemble with *Micrhystridium shinetonense* Downie, 1958 (p. 342, fig. 5a-h) described from the Shineton Shales (Tremadocian) of Shropshire, England.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0); 107.2x59

Distribution elsewhere : Tremadocian : Shropshire, England (Downie, 1958); Tarannonian: Belgium (Stockmans & Williere, 1963); La Vid Formation, Siegenian/Emsian (Part): NW Spain (Cramer, 1963).

Micrhystridium sp. cf. *M. shinetonense* Downie, 1958

(Pl. 1, Fig. 12)

Description : Cysts spherical, measuring upto 13μm in diam., cyst wall psilate to microgranulate, sculptured with outwardly projected long spinose processes; processes mainly homomorphic, simple, flexible, measuring 2-6μm high, rarely bifurcating distally with acuminating tips, about 8 processes observed over the surface; pylome indiscernible.

Comparison : The Tethyan specimen referable to *Micrhystridium* closely compares with *M. shinetonense* Downie, 1958 (p. 342, Fig. 5a-h) described from the Shineton Shales (Tremadocian) of shropshire, England. But, the present form differs from the holotype in having distally bifurcating processes.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0); 103.2x60.4

Micrhystridium sp.

(Pl.1, Fig. 14)

Description : Cyst spherical, dark brown, matured, measruing 15μm in diam.; cyst wall microgranulate; processes simple, broad base, pointed tips, hollow, 1-1.5μm high and distributed in a regular fashion over cyst wall; pylome poorly discernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Micrhystridium*. But, differs from known species of genus in having processes with broad base.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5): 103.6x44.5

Micrhystridium sp.

(Pl. 1, Fig. 9)

Description : Cyst subspherical to subtriangular, 12μm in diam.; cyst wall microgranulate, ornamented with homomorphic processes; processes simple, 2-3μm high, hollow, bases broad, taper abruptly into hair-like processes, tips acuminate; pylome present, outline poorly discernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Micrhystridium*. But, differs from known species of genus in having processes with broad base, thin and slender distal ends.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 99.1x63.6

Genus: *Multiplicisphaeridium* (Staplin) Staplin, Jansonius & pocock, 1965

Type species : *Multiplicisphaeridium ramispinosum* Staplin, 1961

Multiplicisphaeridium cladum (Downie) Lister, 1970

(Pl. 1, Fig. 10)

Description : Cyst spherical, dark brown, matured, measuring 14μm in diam; cyst wall psilate; processes distributed in regular fashion, processes hollow, freely connected with the vesicle, about ten in number at periphery, height 9-10μm, stout with rapidly widening bases, rarely bifurcate or trifurcated, pinnae bear short pinnulae of the first order; pylome poorly discernible.

Comparison : The Tethyan specimen closely compares with *Multiplicisphaeridium cladum* (Downie, 1963; pl. 92: 5, Fig. 3a) Lister, 1970 described from the Wenlock Shales (Middle Silurian), England. The recovered specimens in present assemblage are relatively smaller in size range.

Remarks : *M. cladum* (Downie, 1963) Lister, 1970 and *M. ramispinosum* Staplin, 1961 are morphologically similar. *M. cladum* have relatively stout processes with rapidly widening bases.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 104.6x52.3

Distribution elsewhere : Coalbrookdale Beds: England (Downie, 1963); Rochester Shale: Ontario, New York (Cramer, 1970).

Multiplicisphaeridium ornatum Pothe de Baldis, 1971

(Pl. 4, Fig. 9)

Description : Cyst ellipsoidal, dark brown, matured,30μm at max. diam.; cyst wall rigid, minutely punctate; cyst wall bears varied type of sculptural element, it includes solid, short, few hollow, distally bifurcated cylindrical processes, others conical and spine like upto 1μm high; pylome indiscernible.

Comparison : The Tethyan specimen closely compares with *Multiplicisphaeridium ornatum* Pothe de Baldis, 1971 described from the Capo Formation (Upper Silurian) of Argentina. However, the studied forms have punctate vesicle wall in comparison to Capo Formation one.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-3(1): 107.6x26.3

Distribution elsewhere : Capo Formation (Up. Silurian): Argentina (Pothe de Baldis, 1971).

Multiplicisphaeridium osgoodense (Cramer & Diez) Eisenack *et al.*, 1973

(Pl. 1, Fig. 1)

Description : Cyst polygonal, dark, matured, measuring 24μm at max. diam.; cyst wall ornamented with five branched and one simple processes, processes long, slender, flexible, bifurcated one or more times about half way the total process length, most processes bear pinnae of the third order, measuring upto 26μm high, processes hollow and its wall ornamented with rare grana; cyst wall in between the processes psilate; pylome indiscernible.

Comparison : The present form closely compares with *Multiplicisphaeridium osgoodense* (Cramer & Diez, 1972) Eisenack *et al.*, 1973 (pl. 33:26) described from the Osgood Formation (Upper Llandoverian) of Bardstown. However, the Tethyan forms have less number of processes and rare presence of grana on its surface.

Occurrence in study area : Wackstone (bioclast) of the yong Limestone Formation : Tethyan Garhwal Himalaya, India; R-47(2): 92x37.8

Distribution elsewhere : Osgood Shale (Upper Llandoverian): Kentucky (Cramer & Diez, 1972)

Multiplicisphaeridium thusuii (Thusu) Eisenack, 1976

(Pl. 1, Fig. 13)

Description : Cyst subspherical, dark brown, matured, measuring 14 μm in diam.; cyst wall smooth, ornamented with heteromorphic long processes, some processes strong with broad base, few are thin and slender, hollow communicate freely with the vesicle, distal ends multifurcate into radiating spinules, height upto 3-4 μm; pylome indiscernible.

Comparison : The Tethyan specimens closely compare with *Multiplicisphaeridium thusuii* (Thusu, 1973) Eisenack, 1976 (p. 814, pl. 105: 8, 12) described from the Rochester Formation, (Wenlockian) Canada.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 104.1x63.4

Distribution elsewhere : Rochester Formation (Wenlockian): Canada (Thusu, 1973).

Multiplicisphaeridium variabile (Lister) Dorning, 1981

(Pl. 3, Fig. 8a & b)

Description : Cysts polygonal, measuring upto 15μm at max. diam.; a number of exceptionally long, thin and flexible processes emerge from the cyst wall, processes slender, simple, hollow, bifurcate upto third order distally, branches flexuous, tapering to a point, the height of branched processes upto 16μm, others upto 8μm; surface of the processes also ornamented with sparsely distributed fine hair-like spinules, upto 10 spinules on each process; cyst wall in between the processes laevigate; pylome indiscernible.

Comparison : The Tethyan specimens closely compare with *Multiplicisphaeridium variabile* (Lister, 1970) Dorning, 1981 (pl. 11:4-7, Fig. 25d) described from the Lower Elton Beds (Ludlovian) of Shropshire.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation: Tethyan Garhwal Himalaya, India; R-47(1): 94.6x60

Distribution elsewhere : Maplewood Shales (Middle Silurian): New York (Fisher, 1953); Wenlockian to Gedinnian: Sahara (Jardine & Yapaudjian, 1968); Lower Elton Beds (Ludlovian): England (Lister, 1970).

Multiplicisphaeridium sp.

(Pl. 8, Fig. 10)

Description : Cyst spherical to ovate, dark and matured; measuring 36μm in diam.; vesicle wall puncted with irregular pits; processes bifurcating at distal ends and rarely trifuracating, 10-13μm in height, 1-1.5μm in width; pylome poorly discernible.

Comparison : The Tethyan form broadly compares with generic circumscription of *Multiplicisphaeridium* but, it is not comparable to any known species of the genus due to its typical processes pattern and cyst wall ornamentation.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(1): 99.6x42

Genus : *Oppilatala* Loeblich Jr. & Wicander, 1976

Type species : *Oppilatala vulgaris* Loeblich Jr. & Wicander, 1976

Oppilatala ? indianae (Cramer & Diez) Priewalder, 1987

(Pl. 1, Fig. 2)

Description : Cyst subspherical to polygonal, dark brown, matured, measuring 24μm in diam.; cyst wall psilate; four long and slender processes emerge from the main body, processes flexible, simple as well as branched,branching irregular at distal ends, branched processes bear pinnae upto fourth order; one branched process also emerges from centre of the vesicle; processes hollow, presence of vela on branched processes rare; height upto 30μm of branched processes, simple process upto 24μm high, pylome poorly discernible, appears to be subtriangular in shape.

Comparison : The present form closely compares with *Oppilatala? indianae* (Cramer & Diez) Priewalder, 1987 described from the Racine Formation of lower Ludlovian. The Tethyan specimens referable to this species differs from the holotype in having smaller processes, height and a pylome(?).

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation: Tethyan Garhwal Himalayan, India; R-47(2); 94x30.9

Distribution elsewhere : Racine Formation (Ludlovian to Skala): Illinois (Cramer & Diez, 1972); Moccasin Springs Formation (Ludlovian): Missouri (Cramer & Diez, 1972).

Genus : *Ordovicidium* Tappan & Loeblich Jr., 1971

Type species : *Ordovicidium elegantulum* Tappan & Loeblich Jr., 1971

Ordovicidium nudum (Eisenack) Loeblich Jr. & Tappan, 1978

(Pl. 2, Figs. 9 & 14)

Description : Cyst subspherical, matured, measuring 35-50μm at maximum diam. (excluding processes); cyst wall psilate; processes twelve in numbers, height about 1/4 to 1/5 of vesicle diameter; processes homomorphic, cylindrical, trifurcate, hollow, psilate, tips acuminate, no peteinos along the processes stem, angular proximal contact with the vesicle, width of stem varies from 3-5μm; Pylome indiscernible.

Comparison : The Tethyan specimen closely compares with *Ordovicidium nudum* (Eisenack) Loeblich Jr. & Tappan, (1978) originally described by Eisenack, 1959 (p. 203, pl. 17: 4-6) from the Reval Stage of Llandeilian.

Occurrence in study area : Siltstone, siltyshale and calcareous quartz arenite of the Shiala Formation : Tethyan Garhwal Himalaya, India; R-11(2): 103.6x59; R-17(2): 95.5x41.3.

Distribution elsewhere : Middle Ordovician : Baltic erratics and Estonia (Eisenack, 1959); Questionable identification: Upper Tarranonian,? Wenlockian; Belgium (Martin, 1968).

Genus : *Peteinosphaeridium* (Staplin, Jansonius & Pocock) Eisenack, 1969

Type species : *Peteinosphaeridium trifurcatum* Staplin, Jansonius & Pocock, 1965

Peteinosphaeridium sp.

(Pl. 2, Fig. 12)

Description : Cyst subspherical, sturdy, measuring 36μm in diam.; cyst wall reticulate; sculptural elements with short and solid processes, proccesses stems thick, width 3-4μm, distally multifurcate; simple rupture at periphery observed; pylome indiscernible.

Comparison : The examined form is morphologically comparable with generic circumscription of *Peteinosphaeridium,* but differs from known species of the genus in having very small processes.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(2): 92x65.5

Genus : *Solisphaeridium* (Staplin *et al.*) Eisenack *et al.*, 1979

Type species : *Solisphaeridium stimuliferum* (Deflandre) Pocock, 1972

Solisphaeridium nanum (Deflandre) Turner, 1984

(Pl. 1, Fig. 7)

Description : Vesicle spherical to subspherical, dark brown, matured, measuring 15μm in diam. (without processess); cyst wall laevigate; variable number of processes emerge from the cyst wall which are simple, hollow, homomorphic with smooth surface, somewhat flexible with relatively wide bases, tapering to slender acuminate distal terminations and are proximally open, no difference between the vesicle and process wall; processes upto 2-8μm high; pylome indiscernible.

Comparison : The forms assigned to mentioned species closely compares with *Solisphaeridium nanum* (Deflandre) Turner, 1984 (pl. 476, Fig. 1, 16) described from Calcaire de la Roquemaillere (Wenlockian) of France. However, the present form is relatively smaller in size range.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5): 93.4x66.2

Distribution elsewhere : Wenlock Shales: Welsh borderlands (Downie, 1959); Upper Devonian: Belgium (Stockmans & Williere, 1960); Caradoc & Arening: Montagne Noire (Rauscher, 1974).

Solisphaeridium sp.

(Pl. 1, Fig. 3)

Description : Vesicle spherical, measuring 13μm in diam, cyst wall thin, smooth, wall covered with numerous firm spines; spines hollow and solid, short and slender, taper continuously towards the closed tips, few spines have a tendency to reduce their cavity through secondary deposition of wall material and few communicates freely with the vesicle; height varies from 1-3.5μm; pylome indiscernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Solisphaeridium*. But, differs from known species of genus in having thin cyst wall.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103.7x66.1

Genus : *Vulcanisphaera* (Deunff) Rasul, 1976

Type species : *Vulcanisphaera africana* Deunff, 1961

Vulcanisphaera imparilis Rasul, 1976

(Pl. 2, Fig. 10 & 11)

Description : Cysts polygonal, often hexagonal to octagonal, 36-48μm at max. diam.; cyst wall laevigate, sculptured by long cylindrical processess, individual processes emerge from each corner of the polygonal cyst, processes shaft like, distally hollow, flat tips, length of shaft varies from 4 to 12μm bearing granules, shaft 6-8 in numbers; pylome indiscernible.

Comparison : The present forms closely compare with *Vulcanisphaera imparilis* Rasul, 1976 (pl. 1, Fig. 4-6, 12) described from the Tremadocian of England.

In the Tethyan specimens the processes are comparatively lesser in number than those of Tremadoc of England.

Occurrence in study area : Siltstone of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-11(3): 92.5x42.5; R-11(2): 105.5x35.6

Distribution elsewhere : Tremadocian: England (Rasul, 1976)

Genus : *Stelliferidium* Deunff *et al.*, 1974

Type species : *Stelliferidium striatulum* (Vavrdova) Deunff *et al.,* 1974

Stelliferidium redonense (Paris & Deunff) Deunff *et al.,* 1974

(Pl. 4, Fig. 24)

Description : Cyst spherical, matured, symmetrical; measuring 39μm in diam.; cyst wall covered with number of small spines and spinules, spines small, conical, tapering, emerging from all along the periphery, closely spaced, solid, height upto 2μm; pylome indiscernible.

Comparison : This form of the Tethyan assemblage closely resembles *Stelliferidium redonense* (Paris & Deunff, 1970) Deunff *et al.,* 1974 (pl. 2: 28) described from the base of the calymene shales (Llanvirnian) of France.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-10(1): 105x39.4

Distribution elsewhere : Llanvirnian : Brittany (Paris & Deunff, 1970).

Subgroup : **POLYGONOMORPHITAE** Downie, Evitt & Sarjeant, 1963

Genus : *Coryphidium* Vavrdova, 1972

Type species : *Coryphidium bohemicum* Vavrdova, 1972

Coryphidium miladum Cramer & Diez, 1976a

(Pl. 4, Figs. 5 & 6)

Description : Cyst subsqure with rounded corners, dark brown and matured; measuring 24-32μm diam.; cyst wall structure psilate, processes are solid, small, measuring 1-2μm high, few bifurcate distally, many conical at tips, few blunt with broad base; pylome indiscernible.

Comparison : The Tethyan specimen closely compares with *Coryphidium miladum* Cramer & Diez, 1976a (p. 205, pl. 23:9) described from the Kasba Tadla Basin (Late Arenigian) of Morocco.

Occurrence in study area : Alternation of siltstone and siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-17(2): 97x50.7; R-12(1): 104.8x27.9.

Distribution elsewhere : Late Arenigian; Cis-Saharian, Morocco (Cramer & Diez, 1976a)

Genus : *Dorsennidium* (Wicander) Sarjeant & Stancliffe, 1994

Type species : *Dorsennidium patulum* Wicander, 1974

Dorsennidium rhomboidium (Downie) Sarjeant & Stancliffe, 1994

(Pl. 2, Fig. 3)

Description : Cyst subquadrate in outline, drak brown, matured, measuring 14μm at maximum breadth; cyst wall laevigate; processes of two orders, 4 major processes emerging one from each corner, several minor processes arising perpendicular to plane of major processes, processes hollow, acuminating tips, height varies from 3.5-10μm; pylome indiscernible.

Comparison : The Tethyan specimens resemble *Dorsennidium rhomboidium* (Downie 1959, p. 62-63, pl. 12, Fig. 10), Sarjeant and Stancliffe (1994) described from the Wenlock Shale, Shropshire, England.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 107.7x31.2.

Distribution elsewhere : Wenlock Shale (Wenlockian): England (Downie 1959, 1963); Upper Devonian: Belgium (Stockmans & Williere, 1960); Arenigian: Montagne Noire, France (Rauscher, 1971).

Dorsennidium minutum (Downie) Sarjeant & Stancliffe, 1994

(Pl. 5, Figs. 1, 2, 6, 9 & 10)

Description : Vesicles subquadrate in outline, dark brown and matured, measuring 5-15μm (maximum length); cyst wall scatterly microgranulate; vesicle sides concave, four long and slender spines each one arise from the corner of vesicles, spines hollow, simple, acuminating closed tips, height varies from 3-7.5μm; few spines (at least two) emerging from another plane of the vesicle, measuring 4-6μm in height; pylome generally circular, indiscernible in others.

Comparison : The Tethyan specimens compare with *Dorsennidium minutum* (Downie) Sarjeant & Stancliffe, 1994 (pl. 17:4, Fig. 3c) described from the Shineton Shales (Tremadoc) of England. The forms having circular pylome has been also retained here.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 102.9x62.3; R-8(0): 103.7x65; R-8(0): 105.2x28.7; R-8(0): 104.3x69.7; R-8(0): 104.8x50.4.

Distribution elsewhere : Tremadocian: Shineton Shales (Downie, 1958); Tremadocian: Montagne Noire, France (Martin, 1972).

Dorsennidium europaeum (Stockmans & Williere) Sarjeant & Stancliffe, 1994

(Pl.5, Fig. 8)

Description : Cyst tetrahedral in shape, 14μm from one edge to the base of the opposite "point"; processes emerge from each corner, ornamented with same equal "points" of 8μm; three of these correspond with the angles of the triangle, the fourth one is the ornament of one of the faces; pylome indiscernible.

Comparison : The Tethyan specimen closely compares with *Dorsennidium (Veryhachium) europaeum* (Stockmans & Williere, 1960, p. 3, pl. 2, Fig. 25) Sarjeant & Stancliffe, 1994 described from Tournai, Belgium (Frasnian). However, the present specimen differs from holotype by its smaller size range.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103.8x66.8

Distribution elsewhere : Klabava Shales (Arenigian): Bohemia (Vavrdova, 1972); Rose Hill and Tuscarora Formation (upper Lower Silurian): Pennsylvania (Beju, 1972).

Dorsennidium sp.

(Pl. 5, Fig. 11)

Description : Vesicle quadrangular with straight to convex sides, measuring 15μm at maximum breadth; cyst wall psilate to punctate; wall sculptured by long processes, processes emerging one from each corner, hollow, simple, acuminating tips and terminate to hair-like at distal ends, few processes also emerging out on the plane perpendicular to previous one; pylome distinct, circular in outline.

Comparison : The present form is morphologically comparable with generic circumscription of *Dorsennidium*. Only solitary form is recovered in the present assemblage, so it has been identified upto generic level and, for the time being, mentioned as *Dorsennidium* sp.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 106.1x29.2

Genus : *Goniosphaeridium* Eisenack, 1931

Type species : *Goniosphaeridium polygonale* (Eisenack) Eisenack, 1969

Goniosphaeridium splendens (Eisenack) Turner, 1984

(Pl. 3, Fig. 9)

Description : Vesicle polygonal in outline, dark brown and matured, measuring 20μm in length; cyst wall psilate; vesicle hollow, processes variable in number, hollow, smooth, simple, conical, homomorphic, the interior of which open into the vesicle cavity, the processes taper gradualy to acuminate tips, the vesicle and process wall undifferentiated, processes upto 2-5μm high; pylome indiscernible.

Comparison : The present specimen closely compares with *Goniosphaeridium splendens* (Eisenack) Turner, 1984 (pl. 13, Fig. 3, 4, 5) described from the Caradoc Series of Shropshire, England.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5); 93.2x50.8

Distribution elsewhere : Caradoc Series: Shropshire, England (Turner, 1984).

Genus : *Impluviculus* Loeblich & Tappan, 1969

Type species : *Impluviculus milonii* Deunff, 1968

Impluviculus sp.cf. *I. stellum* Rasul, 1979

(Pl. 8, Figs. 1 & 2)

Description : Cysts polygonal, stellate in outline, measuring 8.5-9μm at maximum diameter; cyst wall microgranulate to psilate; processes smooth and hollow with broad base and long acuminating hair-like tips, each process emerges from each polygonal corner, 9 in number, height upto 3-5μm, few hair-like protuberance also present over the cyst wall; pylome indiscernible.

Comparison : The Tethyan specimens referable to *Impluviculus* closely compares with *I. stellum* Rasul, 1979 (p. 68, pl. 3, Fig. 11) described from the Shineton Shales of the Tremadoc Series, England. The present forms differ from Rasul specimens in being psilate to microgranulate cyst wall instead of strongly and disparsedly tubercular in later one.

Remarks : *I. stellum* is morphologically similar to *Micrhystridium robustum* Downie (1958) except previous one is polygonal in shape and later one spherical.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 104x59.3; R-8(0): 104.4x66.2

Distribution elsewhere : Shineton Shales (Tremadoc): England (Rasul 1979).

Genus : *Neoveryhachium* (Cramer) Sarjeant & Stancliffe, 1994

Type species : *Neoveryhachium carminae* Cramer, 1964

Neoveryhachium sp.

(Pl. 5, Figs. 4, 5 & 7)

Description : Cyst quadrangular, sides convex, 12μm at maximum length; cyst wall finely granulate to psilate; a single spine arises from each of the four corners of vesicle, spines height ranging from 2-5μm, simple, hollow with acuminating tips; spines separated by the endeilyma from the vesicle interior, some spines are also present on the surface of the vesicle, two processes arise near to the pylome; pylome circular in outline.

Comparison : The present form is morphologically comparable with generic circumscription of *Neoveryhachium*. But, differs from known speices of genus in having a circular pylome.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation and siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-47(0): 93.8x52.8; R-8(0): 98.7x37.6; R-8(0): 98.7x37.6

Genus : *Orthosphaeridium* (Eisenack) Kjellstrom, 1971

Type species : *Orthosphaeridium rectangulare* Eisenack, 1963

aff. *Orthosphaeridium* sp.

(Pl. 7, Fig. 3)

Description : Cyst subspherical to fusiform, dark brown, longitudinally elongate, measuring 60μm (including processes); cyst wall thick, ornamented with number of small, solid spines with round tips; processes at both poles homomorphic, long, slender, simple, distally rounded tips with 18μm length, processes interior separated from the vesicle cavity by a solid proximal plug; processes wall ornamented with spines identical to those on vesicle wall; pylome poorly discernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Orthosphaeridium.* It differs from the known species of *Orthosphaeridium* in having spines on processes wall. Due to solitary form in the present assemblage, it has been referred to as *Orthosphaeridium* sp.

Remarks : The present form differs from *Leiofusa granulacutis* (Loeblich, 1970) in having spines on cyst and process wall rather than grana on processes and cyst wall.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation : Tethyan Garhwal Himalaya, India; R-50(1):111x57.3

Genus : *Polygonium* (Vavrdova) Sarjeant & Stancliffe, 1994

Type species : *Polygonium gracile* (Vavrdova) Jacobson & Achab, 1985

Polygonium delicatum Rasul, 1979

(Pl. 3, Fig. 7)

Description : Cyst spherical to hexagonal in outline, dark brown, matured, often ruptured, measuring 48μm maximum length, cyst wall thin and sculptured with very long, hollow, smooth, tapering, filamental type processes measure upto 48μm in length, few, sculptural elements present at central body; cyst wall in between the processes psilate; pylome indiscernible.

Comparision : The present species closely resembles with *Polygonium delicatum* Rasul, 1979 (pl. 1, Fig. 11) from the Tremadoc Series of the Shineton Shales of Shropshire, England.

Occurrence in study area : Calcareous quartz arenite of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-15(1): 102x58.

Distribution elsewhere : *Clonograptus tenellus* Bed (C7) to *Shumardia pusilla* Bed (C5): Shropshire, England (Rasul, 1979).

Polygonium gracile (Vavrdova) Jacobson & Achab, 1985

(Pl. 4, Figs. 15, 16, 17 & 20)

Description : Cysts polygonal, hollow, measuring 10-15μm at maximum length; cyst wall finely granulate with nine to eleven hollow, solid, simple, homomorphic, distally acuminate processes; processes distributed more than one plane about the vesicles, processes broad-based proximally and no difference between spines and vesicle wall; pylome generally indiscernible, circular in others.

Comparison : The present specimen closely compares with *Polygonium gracile* (Vavrdova 1966; p. 413; pl. 1, Fig. 3) Jacobson & Achab, 1985 (p. 192, pl. 1, Fig. 3) described from the Lower Ordovician of Czechoslovakia.

Occurrence in study area : Siltyshale of the Shiala Formation and wackstone (bioclast) of the Yong Limestone Formation : Tethyan Garhwal Himalaya, India; R-8(0): 102.5x51.4; R-12(1): 96x46.5; R-47(1): 91.5x37.2; R-8(1): 92.4x42.5.

Distribution elsewhere : Vaureal Formation (Ashgillian) : Canada (Jacobson & Achab, 1985; Ordovician: France (Rauscher, 1974); *Polygonium* sp. cf. *P. gracilis* has been reported from Ludlovien to lower Gedinnien sequence of the Algerian Sahara (Jardine, *et al.*, 1974).

Polygonium sp. (Vavrdova) Sarjeant & Stancliffe, 1994

(Pl. 4, Fig. 23).

Description : Cyst Polygonal, hollow, measuring 24μm in length and 18μm breadth; cyst wall ornamented with hollow, long, simple and bifurcated processes with broad base and gradually tapering distal end; Cyst wall in between the processes smooth; pylome distinct, circular.

Comparison : The above studied form is morphologically comparable with generic circumscription of *polygonium*. It differs from the known species of *Polygonium* in having few distally bifurcated processes.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation: Tethyan Garhwal Himalaya, India; R-43(2): 101.7x32.1.

Genus : *Stellechinatum* Turner, 1984

Type species : *Stellechinatum celestum* (Martin) Turner, 1984

Stellechinatum celestum (Martin) Turner, 1984

(Pl. 5, Fig. 13)

Description : Cyst polygonal to star shaped, dark brown, matured; central body measures 12μm in length and 10μm breadth; each corner of the polygon associated with a long, hollow, simple and conical processes, measures 8μm high, acuminating tips and open into the vesicle cavity; surface of the vesicle as well as processes are spinose without much differentiation, measures less than 1μm high; process not arranged symmetrically; pylome indiscernible.

Comparison : The Tethyan specimen closely compares with *Stellechinatum celestum* (Martin, 1969) Turner, 1984 (pl. 14, Fig. 3, 4) described from the Ordovician Caradoc Series (Trannon-Early Ludlow.) of England.

Remarks : *S. celestum* is differentiated by *Veryhachium celestum* Martin, 1968 by rare occurrence of spines on cyst & process in *S. celestum* while later one is densely covered with spines.

Occurrence in study area: Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5): 111x33.7.

Distribution elsewhere : Thimensart Formation (Ludlovian) : Belgium (Martin, 1968); Arenigian/Llanvirnian; France (Martin, 1972); Caradoc Series: Shropshire, England (Turner, 1984).

Stellechinatum sp.

(Pl. 7, Fig. 4)

Description : Cyst polygonal to star shaped; body surface ornamented with grana and sparsely distributed spines, measuring 1 to less than 1μm in height; a single process arises from each corner of the polygone, processes 8 in number, long, hollow, height ranging from 10-12μm, simple with acuminating tips and ornamented with spines; processes open into the vesicle cavity, and arranged symmetrically; pylome circular.

Comparison : The present form is morphologically comparable with generic circumscription of *stellechinatum*. However, it differs from the known species of the genus in having very small size range of cyst.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation: Tethyan Garhwal Himalaya, India; R-47(3): 108x49.4.

Genus : *Tetradinium* Vavrdova, 1973

Type species : *Tetradinium arenigum* Vavrdova, 1973

Tetradinium sp.

(Pl. 4, Figs. 10, 11, 12 & 13)

Description : Cysts squarish to subquadrangular in outline, with convex sides and pointed corners, measures 6 to 10μm in diam.; cyst wall laevigate; two processes emerge from each corner of the cyst, in some form processes emerge out irregularly from the cysts; processes simple, homomorphic, distally pointed, hollow, measuring 2-5μm, freely communicating with vesicles interior; pylome indiscernible.

Comparison : The above studied forms are morphologically comparable with *Tetradinium* by its quadrangular shape with two processes at each corner. However, the studied forms are conspicuous from other known species of the genus in having some additional and irregularly arranged processes on cyst wall. Hence, these forms are identified upto generic level only and mentioned as *Tetradinium* sp.

Occurrence in study area : Siltyshale of the Shiala Formation and wackstone (bioclast) of the Yong Limestone Formation : Tethyan Garhwal Himalaya, India; R-21(5): 96.6x26.7; R-21(0): 108x52.5; R-21(5): 93x31.3; R-47(0): 99.7x59.3.

Genus : *Triangulina* Cramer, 1964

Type species : *Triangulina alargada* Cramer, 1964

Triangulina sp.

(Pl. 4, Fig. 3 & 4)

Description : Cyst triangular, two layered; inner body dense, triangular and smooth, measuring 7-10μm, outer wall thin, psilate; processes three in number, one at each corner of the triangular cyst; processes stout, thick, cylindrical with closed distal ends, measuring 3-7μm in height, processes never communicate to the inner body and distinctly separated from the inner body; pylome indiscernible.

Comparison : The present forms are morphologically comparable with generic circumscription of *Triangulina* and the studied forms differ from known species of genus in smaller size range. Therefore, it has been identified upto generic level & for the time being mentioned as *Triangulina* sp.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103.5x68.4; R-8(0): 103.3x40.1.

Genus : *Veryhachium* (Deunff) Sarjeant & Stancliffe, 1994

Type species : *Veryhachium trisulcum* (Deunff) Deunff ex. Downie, 1959

Veryhachium calandrae Cramer, 1970

(Pl. 5, Fig. 16)

Description : Cyst appears subpolygonal in outline, often ruptered, dark brown and matured, measures 36μm at maximum length; cyst wall microsculptured; processes emerging one from each corner, solid, simple & bifurcated distally, measures 14-30μm; surface of processes ornamented by vela; pylome poorly discernible.

Remarks : *Veryhachium calandrae* Cramer, 1970 (p. 106, pl. 6, Fig. 99) is considered invalid by Sarjeant & Stancliffe, 1994; since the text fig. and plate 6, Fig. 99 of Cramer, 1970 show no correspondence in morphology and neither was designated as the holotype.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation : Tethyan Garhwal Himalaya, India; R-50(1); 111.6x63.3

Distribution elsewhere : Ordovician : ohio (Cramer, 1970); Ordovician-Silurian : France (Lefort & Deunff, 1974).

Veryhachium downiei Stockmnans & Willire, 1962

(Pl. 2, Fig. 5)

Description : Cysts triangular with nearly straight to convex sides, measuring 15μm at maximum breadth; cyst wall smooth occassional exinal folds; wall sculptured by small and long processes, processes emerging one from each corner, hollow, simple, acuminating tips and few terminate to hair-like at distal ends, processes upto 5-10μm high; pylome distinct and circular in outline.

Comparison : The present specimen resembles with *Veryhachium downiei* Stockmans & Williere, 1962 (pp. 47-48; pl. 2-20-22) described from the Borehole of 1' Asite d' alienes, Tournai, Belgium of Frasnian.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103x63.1

Distribution elsewhere : Lower Caradocian : Belgium (Martin, Michot & Vanguestaine, 1970); Up. Silurian: Plourach: Brittany, France (Deunff & Paris, 1971); Iyadar Formation (Lr. Llandoverian): Libya (Deunff & Massa, 1975).

Veryhachium lairdii (Deflandre) Deunff ex. Downie, 1959

(Pl. 5, Fig.17)

Description : Cyst rectangular with straight sides, hollow, measurs 19μm length and 14μm breadth; cyst wall microgranulate with exinal folds; processes emerging one from each side of vesicle, processes hollow, short, simple, microgranulate and open into the vesicle cavity, process widen gradually towards the base and merge with vesicle, measures 2-7μm high; pylome indiscernible.

Remarks : Sarjeant & Stancliffe (1994) considered *V. lairdii* as a taxonomic junior synonym of *V. valiente*.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5): 98.3x29

Distribution elsewhere : *V. lairdii* has been recorded globally from Ordovician, Silurian and Devonian rocks (Turner 1984).

Veryhachium longispinosum Jardine *et. al.*, 1974

(Pl. 5, Fig. 15)

Description : Cyst rectangular with straight sides, hollow, compressed & ruptured, measures 10μm length and 8μm breadth; cyst wall thin, laevigate to shagrinate with few exinal folds; thin and long four processes each one arise from the corner of veside, processes hollow, flexible, terminate to hair-like distally with acuminating tips, measures upto 3-10μm high and open into the vesicle cavity, all the processes arising in the same plane, processes wall finely granulate; pylome distinct and circular.

Comparison : The above illustrated form closely compares with *Veryhachium longispinosum* Jardine *et al.*, 1974 (p. 116, pl. 1:1) described from the Borehole Gueddich (Upper Ordovician) of the Algerian Sahara. The Tethyan specimen has distinct pylome and finely granulate processes wall in comparison to Algerian Sahara one.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 105.1x37.2

Distribution elsewhere : Upper Ordovician : Sahara, Algeria (Jardine, *et al.*, 1974)

Veryhachium oklahomense Loeblich, 1970

(Pl. 5, Fig. 3)

Description : Cyst rectangular to nearly square in outline, hollow with concave and convex sides, light brown, measurs 14μm at maximum length; cyst wall thin, micrograpulate to smooth; wall sculptured by long processes, processes drawn out one from each corners of vesicle, processes thin, flexible, distally hair-like and occassionally solid, proximal side hollow, freely communicate with central body, few process also arises on the plane perpendicular to previous one, height measures upto 3-5μm; pylome indiscernible.

Comparison : The above specimen closely compares with *Veryhachium oklahomense* Loeblich, 1970 (pp. 742-743, pl. 63:F, G) described from the Upper Ordovician Sylvan Shale of Oklahoma.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 106x30.5

Distribution elsewhere : Sylvan Shale (Ashgillian): Oklahaoma (Loeblich, 1970).

Veryhachium reductum (Deunff) Downie and Sarjeant, 1965

(Pl. 4, Fig. 7)

Description : Cyst vesicle inflated triangular, measurs 7μm at maximum length; cyst wall ornamented with number of small processes, processes emerge from each corner with hollow, pointed tips measures upto 3-4.5μm few long, simple and flexible processes emerging from cyst wall, measures 7μm in height, cyst wall in between the processes psilate; pylome indiscernible.

Comparison : The present specimen closely compares with *Veryhachium reductum* (Deunff, 1959) Downie & Sarjeant, 1965 described from the Kermeur Sandstone (Caradocian) of Bretagne.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 102.4x69

Distribution elsewhere : Bir Ben Tartar Formation (Llanvirnian & Llandeilian): Libya (Deunff & Massa, 1975); Tarannonian: Belgium (Stockmans & Williere, 1963).

Veryhachium valiente Cramer, 1964.

(Pl. 5, Fig. 14)

Description : Cyst rectangular, hollow, often ruptured, dark brown, matured, measurs 18μm at maximum length; cyst wall psilate; wall sculptured by long & slender processes, processes emerging one from each corner (one broken in present form), hollow, simple, generally acuminating tips distally, proximally wide, measures 14μm high and freely communicate with central body; pylome poorly discernible.

Comparison : The Tethyan specimen closely compares with *Veryhachium valiente* Cramer, 1964 (p. 311, pl. 12.3) described from the La vid Shale Member (Up. Ludlovian to Emsian) of NW Spain.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 105.2x28.7

Distribution elsewhere : La Vid Formation (Up. Ludlovian to Emsian): NW Spain (Cramer, 1964); Silurian and Ordovician: Belgium (Martin, 1965).

Veryhachium sp. cf. *V. wenlockium* (Downie) Downie & Sarjeant, 1964

(Pl. 4, Fig. 8)

Description : Cyst appears tetrahedral, measuring 6μm at maximum length; cyst wall smooth to finely punctate, few occassional pits and exinal folds; processes emerging one from each corners, processes hollow, thin, long and acuminating tips, measures 6μm in height; pylome indiscernible.

Comparison : The Tethyan specimen referable to *Veryhachium* closely compares with *V. wenlockium* (Downie) Downie and Sarjeant, 1964 (P. 62, pl. 12, Fig. 9,-11) described from the Wenlock Shale (Wenlock) of Shropshire, England. However, the present form appears to be tetrahedral in shape.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103.4x69.6

Distribution elsewhere : Wenlock Shale (Wenlockian) : England (Downie, 1959); Rochester Formation (Wenlockian): Ontario, Canada (Thusu, 1973).

Veryhchium sp.

(Pl. 5, Fig. 12)

Description : Vesicle subquadrate with convex corners, occassionally ruptured, measures 7μm at maximum length; cyst wall psilate to finely microgranulate; processes emerging one from each corner of the vesicle, processes hollow, simple, acuminating and closed tips distally, height varies from 3-7μm; pylome poorly discernible, circular in outline.

Comparison : The present form is morphologically comparable with generic circumscription of *Veryhachium,* but conspicuous with known species of the genus due to its sculptural elements and smaller cyst size range. Due to less number of specimen, these forms are only compared with *Veryhachium* instead assigning to new species.

Distribution in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 109.8x62.2

Veryhachium sp.

(Pl. 2, Fig. 1)

Description : Cyst triangular, measuring 6μm at maximum length; cyst wall smooth; processes emerging one from each corner, flexible, long, simple, acuminating tips, measuring 6μm in height; pylome indiscernible.

Comparison : The morphological characters of the recovered form are conspicuous from the known species of the *Veryhachium* in having thin, long, flexible processes and very small cyst size range.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 107.5x37.7

Genus: *Villosacapsula* Loeblich & Tappan, 1976

Type species : *Villosacapsula setosapelliculum* Loeblich, 1970

Villosacapsula sp. cf. *V. entrichos* (Loeblich Jr.) Sarjeant & Stancliffe, 1994

(Pl. 8, Fig. 4)

Description : Cyst triangular, dark, matured, measuring 21μm at maximum length; cyst wall microsculptured with short conical spines; one small solid, tapering process emerging from one side of the cyst corner, 5μm in height; pylome indiscernible.

Comparison : The Tethyan specimen referable to *Villosacapsula* closely compares with *V. entrichos* Loeblich, 1970 (p. 740-741, pl. 34:F) described from the Bromide Formation (Llandeilan) of Oklahoma. However, the present form differs from the type species by relatively smaller size range.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103.3x30

Distribution elsewhere : Mountain Lake Member, Bromide Formation (Middle Ordovician): Oklahoma (Loeblich, 1970).

Villosacapsula sp. cf. *V. setosapelliculum* Loeblich, 1970

(Pl. 8, Fig. 3)

Description : Cyst inflated triangular in outline, dark, matured, measures 14μm at maximum length with slightly convex outward sides; cyst wall ornamented with short-scattered microspines and few exinal folds; short and flexible processes emerging one from each corner of cyst, measures upto 1.5-4μm; pylome indiscernible.

Comparison : The Tethyan specimen referable to *Villosacapsula* closely compares with *V. setosapelliculum* Loeblich, 1970 (p. 743, pl. 36:B) described from the Sylvan Shale (Upper Ordo.) of Oklahoma. However, the present forms differ from the type species by relatively smaller size range.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 103.3x69.3

Distribution elsewhere : Sylvan Shale (Up. Ordovician): Oklahoma (Loeblich, 1970).

Subgroup : **HERKOMORPHITAE** Downie, Evitt & Sarjeant, 1963

Genus : *Cymatiosphaera* (Wetzel), Deflandre, 1954

Type species : *Cymatiosphaera radiata* (O. Wetzel) Sarjeant, 1985.

Cymatiosphaera sp. cf. *C. celtica* Deunff, 1958

(Pl. 4, Fig. 21)

Description : Cyst spherical, dark brown, matured, measuring 10μm at maximum diam; cyst wall finely granulate and divided into number of subpolygonal areas by low membranes supported at corners of polygons by spines not extending beyond membrance, spines 14 in numbers, membrances undulatory in plan view, measuring 6μm; pylome indiscernible.

Comparison : The Tethyan specimen referable to *Cymatiosphaera* closely compares with *S. celtica* Deunff, 1958 (Taf. 6, Fig. 54) described from the Veryhach, presquile de crozon (Ordovician), Bretagne. However, the present forms differ from the type species by more number of spines.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 104.4x59.4

Distribution elsewhere : Ferner im Silurium Belgiens.

Cymatiosphaera sp.

(Pl. 8, Fig. 5)

Description : Vesicle spherical, dark brown, matured, measuring 36μm in diam.; vesicle wall rigid and granulate; the periphery of cyst surrounded by thin membrane, membrane divided into several (3 visible in present form) areas by ridges originating from the periphery of the vesicle, the length of membrane measures 6μm; pylome poorly discernible, circular in outline.

Comparison : The present form is morphologically comparable with generic circumscription of *Cymatiosphaera*. Only solitary form is recovered in the Tethyan assemblage. So, it has been identified upto generic level and for the time being mentioned as *Cymatiosphaera* sp.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(1): 94.2x44.4

Genus : *Cymatiogalea* (Deunff) Deunff, Gorka & Rauscher, 1974

Type species : *Cymatiogalea margaritata* Deunff Zardin, 1961

Cymatiogalea sp.

(Pl. 8, Fig. 16)

Description : Cyst globular, dark bronw, matured, measures 21μm in diam.; cyst wall punctate; the external surface of vesicle divided into polygonal network, the network connects with straight lines; pylome indiscernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Cymatiogalea* sp. Only solitary form is recovered in the Tethyan assemblage. So, it has been identified upto generic level and for the time being mentioned as *Cymatoigalea* sp.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5): 95.2x36.5

Subgroup : DIACROMORPHITAE Downie, Evitt & Sarjeant, 1963

Genus : *Acanthodiacrodium* Timofeev, 1958

Type species : *Acanthodiacrodium dentiferum* Timofeev, 1958

Acanthodiacrodium rotundatum Gorka, 1967

(Pl. 4, Fig. 19)

Description : Cyst ellipsoidal with rounded poles, measuring 14μm at maximum length without processes; cyst wall granulate, ornamented with a number of processes at each pole, processes hollow, simple with acuminating tips and wide bases; pylome indiscernible.

Comparison : This form of the Tethyan assemblage closely resembles with *Acanthodiacrodium rotundatum* Gorka, 1967 (p. 4.5, Pl. 2 : 6-7) described from the Silexites Zbilufka (Up. Tremadocian) from Poland.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-21(5): 93x48.3

Distribution elsewhere : Upper Tremadocian: Poland (Gorka, 1967)

Acanthodiacrodium simplex Combaz, 1967

(Pl. 6, Fig. 18)

Description : Cysts slightly elliptical, measuring 13μm at maximum length· cyst wall shagrinate to granulate with occassional exinal folds; cyst wall bears one process at each pole, processes long, slim and acuminating tips, measures 7μm in height, process wall ornamented with vela; occassionally a thin, small process observed at one pole which measures 1.4μm high; pylome indiscernible.

Comparison : The recovered specimen closely compares with *Acanthodiacrodium simplex* Combaz, 1967 (p. 14, pl. 3:44-47) of the El Gassi Sandstone Formation, Algeria (Lower Tremadocian).

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 102.4x39.6

Distribution elsewhere : Upper Acadian and Tremadocian: Montagne Noire, France, (Martin, 1972); Tremadocian: Montagne Noire, France (Rauscher 1971, 1974)

Genus : *Dasydiacrodium* (Timofeev) Deflandre & Deflandre-Rigaud, 1962

Type species : *Dasydiacrodium eichwaldi* Timofeev, 1959

Dasydiacrodium sp.

(Pl. 3, Fig. 1)

Description : Cyst elongated with subrounded sides, measuring 16μm at long axis (without processes); the equitorial part of cyst microgranulate and poles ornamented with dissimilar processes, processes hair-like, hollow, acuminating tips, measures upto 2-4μm in height; eleven in number at one pole, at other pole five long, hollow and simple processes with wide base; pylome indiscernible.

Comparison : The examined forms are morphologically comparable with generic circumscription of *Dasydiacrodium*. It differs from the known species of *Dasydiacrodium* in having microgranulate equitoral part. The recovery of only one specimen precludes the erection of a new species and has been referred to *Dasydiacrodium* sp.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation: Tethyan Garhwal Himalaya, India; R-47(0): 92.8x38

Dasydiacrodium sp. cf. *D. longicornutum* Gorka, 1967

(Pl. 4, Fig. 18)

Description : Cyst slightly elongated with rounded sides, oftenly ruptured, dark, matured, measuring 10μm in length; cyst wall appears to be microgranulate; poles ornamented with simple, pointed and hair-like, hollow processes, five processes on one pole, two at other, height upto 2-4μm; pylome indiscernible.

Comparison : The present form is referable to *Dasydiacrodium*, closely compares with *D. longicornutum* Gorka, 1967 (pp. 6-7, pl.2.5) described from the Silexites of Wysoczki from upper Tremadocian of Poland. However, the present form differs from holotype in relative smaller size range of cyst body.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 105.1x38

Distribution elsewhere : Up. Tremadocian: Poland (Gorka, 1967).

Subgroup : **NETROMORPHITAE** Downie, Evitt & Sarjeant, 1963

Genus : *Dactylofusa* (Brito & Santos) Cramer, 1970

Type Species : *Dactylofua maranhensis* Brito & Santos, 1965

Dactylofusa oblancae (Cramer & Diez) Cramer, 1970

(Pl. 6, Fig. 8)

Description : Cyst elongately fusiform, measuring 20μm in length, breadth 4μm; cyst hollow; cyst wall covered by a very large number of equally spaced echinate sculptural elements arranged in ten parallel rows, the lineation of these rows of elements is parallel to the longitudinal axis of the vesicle; at each pole there is a hollow, short process of a length and width about less than 1μm; pylome indiscernible.

Comparison : The present specimen resembles *Dactylofusa oblancae* (Cramer & Diez, 1968) Cramer, 1970 (p. 567, pl. 3:3) described from Oblanca de Luna, Leon of Ludlovian age.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation : Tethyan Garhwal Himalaya, India; R-47(0): 93.6x51.2

Distribution elsewhere : Ludlovian : NW Spain (Cramer & Diez, 1968)

Genus : *Deunffia* (Downie) Cramer, 1970

Type species : *Deunffia monospinosa* Downie, 1960

Deunffia brevispinosa Downie, 1960

(Pl. 6, Fig. 7)

Description : Vesicle flask shaped, oval; assymetric, hemispheric, measuring 30μm including spine; central body 18μm at maximum diam.; cyst wall psilate with irregular exinal folds; single process emerges from the main body, process 12μm long, 1μm wide, hollow with pointed tips, surface bears sparsely distributed fine grana; pylome indiscernible.

Comparison : The Tethyan specimen resembles *Deunffia brevispinosa* Downie, 1960 (pl. 1, Figs. 4-6) described from the Buildwas shales, Wenlockian (early Upper Silurian) of England.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(1): 100.5x59.9

Distribution elsewhere : Buildwas Shales (Wenlockian): England (Downie, 1960); Hughley Shales & Buildwas Shales: Welsh Borderland (Hill, 1974).

Deunffia monacantha Deunff, 1951

(Pl. 6, Fig. 19)

Description : Vesicle spherical, dark, highly matured, measuring 24μm (excluding process); assymetrical, hemimorphic; a single, unipolar process emerges from the main body, 29μm high, 0.2μm wide, hollow, pointed tips, few grana on the spine; pylome indiscernible.

Comparison : The specimen recovered from the Tethyan sediments closely compares with *Deunffia monacantha* Deunff (pl. 1, Fig. 18, 24) described from the Schistes du Veryhach (Caradocian- early Late Ordovician) of France.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(2): 92.2x64.3

Distribution elsewhere : Caradoc: France (Deunff, 1951).

Deunffia monospinosa Downie, 1960

(Pl. 6, Figs. 1-5)

Description : Vesicles ellipsoidal to subtriangular in outline, measuring upto 6-9μm at maximum diam.; cyst wall psilate to microgranulate; cyst hemimorphic with single unipolar process; process simple, height varies from 7-8μm and terminating in a hair-like tip; other pole smooth; pylome indiscernible.

Comparison : The Tethyan specimens resemble with *Deunffia monospinosa* Downie, 1960 (Taf. 1, Fig. 8) described form the Buildwas Shales (Wenlockian) of Shropshire, England. However, the compartments in the process are not clearly visible in the specimens of present assemblages assigned to *D. monospinosa* Downie.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 102.6x69.4; R-8(0): 99.9x63.9; R-8(0): 99.4x63.1; R-8(0): 94.7x47.9; R-8(0): 106.4x48.7

Distribution elsewhere : Llandovery: Wales (Hill, 1974); Buildwas Shales (Wenlockian): Shropshire, England (Downie, 1960)

Genus : *Domasia* (Downie) Hill, 1974

Type species : *Domasia trispinosa* Downie, 1960

Domasia algerensis (Cramer) Hill, 1974

(Pl. 6, Fig. 22)

Description : Vesicle fusiform, measuring 6μm (excluding processes), base tapering, resulting into a short pointed posterior/distal process; Vesicle wall thin, laevigate to finely granulate; two processes emerge at anterior side, processes thin, long and of unequal length measures upto 6-8μm long and 0.5μm broad, process wall oftenly bears small grannules; pylome indiscernible.

Comparison : The present specimen closely compares with *Domasia (=Leiofusa) algerensis* Hill, 1974 (p. 15, pl. 1, Fig. 16-17) described from the Welsh Borderland of Silurian (Middle to late) Tarannon .

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 100.6x34.3

Distribution elsewhere : Silurian: Welsh Borderland (Hill, 1974).

Domasia limaciforme (Stockmans & Williere) Cramer, 1970

(Pl. 6, Fig. 14)

Description : Cyst triangular in outline, small, measuring 14μm in length including processes; the long side of triangle is convex; cyst wall thin, psilate, a single process emerge from each corner, the two proximal processes small, thin and horn shaped, the third one is at distal side with sharp pointed tips.

Comparison : The Tethyan specimen closely resembles *Domasia limaciforme* (Stockmans & Williere, 1963) Cramer, 1970 (pl. 1:14, fig. 6) described from the Borehole of the Lust Brewery (Tarannonian) of Belgium. However, the specimens recovered in the present assemblage are relatively smaller in size than those known from elsewhere.

Occurrence in study area : Alternation of sillstone and siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-39(0): 107.2x69.9

Dsitribution elsewhere : Tarannonian; Belgium (Stockmans & Williere, 1963), Silurian: Belgium (Martin, 1965); Llandoverian-Tarannonian, Wenlockian: Belgium (Martin, 1968); Rochester Shale (Wenlockian); Canada (Thusu, 1973).

Domasia trispinosa Downie, 1960.

(Pl. 6, Figs. 20 & 21)

Description : Cyst subcircular to elongatedly ellipsoidal in outline, ruptured, dark brown, matured, hollow, measuring 10μm at maximum diam.; cyst wall psilate; vesicle symmetry axis longitudinal, hemimorphic and the long aixs of the body is parallel with the axis of the vesicle; posterior pole is characterised by a single, reduced process measuring 15μm in height, two processes at anterior pole, measures upto 2.5 - 8.5μm; pylome poorly discernible.

Comparison : The eaxmined forms compare with *Domasia trispinosa* Downie, 1960

(Taf. 1, Fig. 7) described from the Buildwas Shales (Wenlockian), Shropshire, England.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 97x27.6

Distribution elsewhere : Buildwas Shale (Wenlockian): England (Downie, 1960); Llandovery: Welsh Borderland (Hill, 1974).

Domasia sp.

(Pl. 6, Fig. 23)

Description : Cyst elongated triangular, measures 17μm maximum length and 6μm breadth; cyst wall microgranulate, single spine at posterior side merges into the cyst, length measuring 6μm, two small spines at anterior side, measruing 1μm is length; pylome indiscernible.

Comparison : The present forms are morphologically comparabale with generic circumscription of *Domasia*. It differs from the known species of *Domasia* in having elongated traiangular shape of the cyst. For this reason, and because of the rarity of specimens, this form is not assigned to any published taxon.

Occurrence in study area : Wackstone (bioclast) of the Yong Limestone Formation: Tethyan Garhwal Himalaya, India; R-47(0): 94.7x40.4

Genus : *Eupoikilofusa* Cramer, 1970

Type species : *Eupoikilofusa striatifera typica* Cramer & Diez, 1972

Eupoikilofusa sp.

(Pl. 6, Fig. 15)

Description : Cyst fusiform, measuring 8μm at longitudinal axis, (excluding process); cyst wall laevigate to microgranulate; two processes emerges at both poles of almost equal height, measuring 6μm, processes hollow, pointed distally, width upto 2-4μm; pylome poorly discernible.

Comparison : The present form is morphologically comparable with generic circumscription of *Eupoikilofusa*. Due to monotypic form in the Tethyan assemblage, it has been identified upto generic level and for the time being mentioned as *Eupoikilofusa* sp.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 104.8x36.1

Genus : *Geron* Cramer, 1967

Type species : *Geron guerillerus* Cramer, 1966

Geron sp. cf. *G. amabilis* Cramer, 1969

(Pl. 6, Figs. 6 & 10)

Description : Cyst spherical, measruing upto 6 - 8.5μm in diam.; cyst wall ornamented with scattered microspines with occassional exinal folds; process one in number, parallel in the longitudinal body axis, originating from the very short ectodermal skirt, process stiff, elongate-conical, distally closed and further extending to become hair-like tip; there is a distinct darkening of the ectoderm at the basal portion of the process; height of the process varies from 9 - 11μm; pylome indiscernible.

Comparison : The recovered specimen referable to *Geron* closely compares with *G. amabilis* Cramer, 1969 (p. 223-225, pl. 1:8, fig. 5) described from the Furada Formation, province of Oviedo (Lr. Sil/Ludlovian), NW Spain. However, the present form differs from the type species by relatively smaller size range.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 97x40; R-8(0): 106x67.7

Distribution elsewhere : Ludlovian : NW Spain (Cramer, 1969).

Geron sp.

(Pl. 6, Figs. 11 & 12)

Description : Cyst spherical, dark, matured, measuring 10μm in diam; cyst wall ornamented with closely spaced numerous microspines and processes; processes one to three in number, originating from the very short ectodermal skirt, process stiff, elongate-conical, distally closed and further extending to become hair-like tip; height varies from 3-8μm; pylome indiscernible.

Comparison : The above described from of the *Geron,* though illustrated the generic characteristic of the genus, but differs from known species of the genus in having closely spaced microspines on the cyst. The recovery of few specimens precludes the naming of a new species.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 100.1x34.5; R-8(0): 107.4x49.6

Genus : *Leiofusa* (Eisenack) Cramer, 1970

Type species : *Leiofusa fusiformis* Eisenack, 1934

Leiofusa algerensis Cramer, 1970

(Pl. 6, Fig. 16)

Description : Cyst fusiform, longitudinally elongate, measuring 10μm at longitudinal axis; cyst wall psilate; process of the anterior pole, simple and thick, measuring 10μm, the process of the posterior pole though simple but thin with hair-like distal ends, measuring 10μm long. an additional reduced process present near the posterior pole, measuring 3μm high; pylome indiscernible.

Comparison : The present specimen closely compares with *Leiofusa algerensis* Cramer, 1970 (pp. 72-74, pl. 1: 11, 17) described from the Alger Shale of late Llandoverian age from Ohio.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 105.5x37.6

Distribution elsewhere : Silurian: Risha area, Jordan (Basha, 1992); Rochester Shale (Wenlockian): Niagara Escarpment, Ontario and New York (Cramer, 1970); Rochester Formation (Wenlockian): Ontario, Canada (Thusu, 1973).

Leiofusa bernesgae Cramer, 1964a

(Pl. 4, Fig. 22) and (pl. 6, Figs. 24 & 25)

Description : Cysts elongately fusiform, measuring 14μm at longitudinal axis: cyst wall psilate; processes at each pole hollow, simple and curved, measuring 10μm; an additional process emerges from cyst wall in some forms; pylome circular in most of the forms.

Comparison : The Tethyan specimens closely compare with *Leiofusa bernesgae* Cramer, 1964a (p. 37a, pl. 2:10) described from the San Pedro Formation (Lower Gedinnian) of Spain.

Remarks: Combaz, Lange & Pansart (1967) indicate the range of this species to be Ludlovian to Emsian.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 104.3x70.6; R-8(0): 94.1x55.5; R-8(0): 104.7x65.5

Distribution elsewhere : San Pedro Formation (Ludlovian): NW Spain (Cramer, 1964a); Undivided Llandoverian to lower Gedinnian: Sahara (Jardine & Yapaudjian, 1968); St. Clair Formation (Upper Wenlockian to early Lower Ludlovian): Missouri (Cramer & Diez, 1972).

Leiofusa elenae Cramer, 1964a

(Pl. 7, Fig. 2)

Description : Cyst elongately fusiform, dark brown, matured, measuring 63μm (including process); cyst wall psilate; process at each pole processes solid, thick and blunt, measuring 6μm long & 3μm wide; pylome circular.

Comparison : The Tethyan specimen resembles with *Leiofusa elenae* Cramer, 1964a (text fig. 33, no. 12) described from the San Pedro Formations in the Province of Leon (Ludlow to early Late Silurian) of NW spain.

Occurrence in study area : Calcareous quartz arenite of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-15(1): 100.7x49.8.

Distribution elsewhere : Upper portion of the San Pedro Formation (Ludlovian to basal Gedinnian) : NW spain (Cramer, 1964a); Waldron Formation (grapt. Z. top 30 & base 31): Kentucky (Cramer & Diez, 1972).

Leiofusa parvitatis Loeblich, 1970

(Pl. 6, Fig. 9 & 17)

Description : Cyst fusiform, hollow, length varies from 7-10μm and width 3-7μm; cyst wall psilate to microgranulate; bipolar, processes simple, long, hollow, flexible acuminating tips distally, the process interior opens to the vesicle cavity, height varies from 6 - 12μm; pylome indiscernible.

Comparison : The Tethyan specimen closely compares with *Leiofusa parvitatis* Loeblich, 1970 (pp. 724-725, pl. 18: F, G) described from the Maplewood Shale (Middle Silurian) of New york.

Occurrence in study area : Siltyshale of the Shiala Formation Wackstone (bioclast) of the Yong Limestone Formation : Tethyan Garhwal Himalaya, India; R-8(0): 106.7x32.6; R-47(0): 94.8 x 47.8

Distribution elsewhere : Maplewood Shale (Middle Silurian) New York (Loeblich, 1970).

Leiofusa, sp.

(Pl. 6, Fig. 13)

Description : Cyst fusiform, elongate, measring 7μm at its longitudinal axis; cyst wall psilate, with thin exinal folds, processes simple, processes two in number, emerging from opposite poles, hollow, acuminating tips, freely communicating with vesicle, measuring 3μm, few small processes emerge from the vesicle surface; pylome indiscernible.

Comparison : The above described form of the *Leiofusa,* though illustrates the generic characteristic of the genus but differs from known species of the genus in having very small processes on the main body wall and being exceptionally small in size. Only two specimens were recovered. New species was not erected.

Occurrence in study area : Siltyshale of the Shiala Formation: Tethyan Garhwal Himalaya, India; R-8(0): 105x50.2

CHAPTER 4

ACRITARCH BIOSTRATIGRAPHY (PALYNOZONATION), AGE AND CORRELATION

Stratigraphic distributions of selected acritarch species recorded from the Early Paleozoic sediments, representing the Ordovician and Silurian rocks of the Sumna-Rimkhim section in the Tethyan Garhwal Himalaya, are shown in Fig. 5.

The stratigraphic distributions of these forms reveal that some age marker forms show their first and last occurrence at a particular stratigraphic level. Thus, the first and last occurrence levels (F.A.Ds and L.A.Ds) of stratigraphically significant forms, and their quantitative distributions enable in establishing four distinct acritarch assemblage zones in the present section (Fig. 5). The base and the top of these assemblage zones are marked at the first occurrence and/or last occurrence level of age marker species. The acritarch assemblage zones of the present study area have been correlated with other areas in the world (Fig. 8). The acritarch zones delineated in the Ordovician-Silurian section of the study area are as follows in descending stratigraphic order:

Zone IV : *Leiofusa algerensis-Multiplicisphaeridium osgoodence* Assemblage Zone.

Zone III: *Domasia limaciforme-Dactylofusa oblancae* Assemblage Zone.

FIG. 8 STUDY AREA AND OTHER OVERSEAS REGIONS WITH WHICH CORRELATION HAS BEEN DONE

Zone II : *Domasia trispinosa-Deunffia monospinosa* Assemblage Zone.

Zone I : *Baltisphaeridium longispinosum* var. *longispinosum-Multiplicisphaeridium ornatum* Assemblage Zone.

The salient features of each zone are described below in the ascending stratigraphic order with discussion on their age.

Zone I : *Baltisphaeridium longispinosum* var. *longispinosum-Multiplicisphaeridium ornatum* Assemblage Zone.

Reference section . Shiala Formation between 2.310-2.320 km. points of Sumna-Rimkhim section, Tethyan Garhwal Himalaya.

Definition . Common occurrence of *Baltisphaeridium longispinosum* var. *longispinosum, Multiplicisphaeridium ornatum, Baltisphaeridium* sp. cf. *B. scitulum, B. longispinosum* subsp. *delicatum, B. archaicum* and *Filisphaeridium henryi.*

Base . The base of this zone could not be ascertained precisely as the rocks below the stratigraphic level representing the sample number R-2 are mainly unfossiliferous (Fig. 5). Thus, the base may be little below this level within the Shiala Formation.

Top . The last occurrence of *Baltisphaeridium longispinosum* var. *longispinosum, B. archaicum* and/or first occurrence of *Geron* sp. cf. *G. amabilis.*

Significant accessory forms . *Deunffia monacantha, Baltisphaeridium longispinosum* subsp. *delicatum, Coryphidium miladum, Ordovicidium nudum, Baltisphaerosum bystrentos,* *Polygonium gracile, Filisphaeridium henryi, Cymatiosphaera* sp., *Peteinosphaeridium* sp., *Lophosphaeridium parvum* and *Bavlinella* sp.

Correlation and age . The characteristic forms of this assemblage zone are *Baltisphaerosum bystrentos, Baltisphaeridium archaicum, B. longispinosum* subsp. *delicatum, Deunffia monacantha* and *Baltisphaeridium longispinosum* var. *longispinosum.*

The occurrence of *Baltisphaeridium longispinosum* subsp. *delicatum* has been reported from the Caradoc Series (Caradoc) of Shropshire, England (Turner, 1984). *Baltisphaeridium archaicum* has been recorded from the Belfast Bed (Lower Llandoverian) of Ohio (Cramer & Diez, 1972) and from the Upper Ordovician-Lower Silurian sediments of Saudi-Arabia, Tunisia and Libya.

Occurrence of *Baltisphaerosum bystrentos* has been reported from Llandeilo, Mountain Lake Member, Bromide Formation, Oklohoma (Loeblich and Tappan, 1978) and Ordovician Caradoc Series (Caradocian) of Shropshire, England (Turner, 1984).

The *Deunffia monacantha* is considered as the marker taxon in the early Caradocian sequence of Veryhach and Kerglentin in Brittany (Deunff 1951, 1955, 1959 and Henry, 1969). Henry and Thadeu (1971) have also reported this species from the Late Ordovician sediments of Portugal.

The *Baltisphaeridium longispinosum* var. *longispinosum* has been reported from the Middle Ordovician and upper Llandoverian of the Baltic region (Eisenack 1951, 1959, 1962). This form has also been recorded from the Ordovician of Sweden (Staplin *et al.*, 1965); Russia (Timofeev, 1959) and upper Arenigian & Caradocian of Poland (Gorka, 1969).

The other recovered species of this assemblage zone of Tethys are also globlly recorded from the rocks of the Late Ordovician and Early Silurian. Hence, Late Ordovician to Early Silurian (Caradocian to early Llandovery) age is inferred for this zone.

Zone II : *Domasia trispinosa-Deunffia monospinosa* Assemblage Zone.

Reference section . Shiala Formation between 2.320 - 2.355 km. points of Sumna-Rimkhim section, Tethyan Garhwal Himalaya.

Definition . Dominant occurrence of *Domasia trispinosa*, subdominant presence of *Deunffia brevispinosa, Domasia algerensis* and *Deunffia monospinosa* together with common occurrence of *Solisphaeridium nanum, Geron* sp. cf. *G. amabilis* and *Baltisphaeridium citrinum.*

Base . The first occurrence of *Geron* sp. cf. *G. amabilis,* and/or last occurrence of *Baltisphaeridium longispinosum* var. *longispinosum* and *B. archaicum.*

Top . The last occurrence of *Deunffia brevispinosa,* and/or first occurrence of *Baltisphaeridium citrinum.*

Significant accessory forms . Common occurrence of *Neoveryhachium* sp., *Micrhystridium robustum, Baltisphaeridium citrinum, Filisphaeridium henryi, Leiofusa bernesgae, Micrhystridium parinconpicuum* and *Geron* sp.

However, *Filisphaeridium henryi, Acanthodiacrodium simplex, Ordovicidium nudum, Veryhachium longispinosum* and *coryphidium miladum* are found to be absent in this zone.

Restricted forms . *Geron* sp. cf. *G. amabilis, Triangulina* sp., *Dactylofusa* sp., *stelliferidium redonse, Domasia trispinosa, D. algerensis, Deunffia brevispinosa, Multiplicisphaeridium cladum* and *M. thusuii* etc.

Correlation and age . The acritarch assemblage of this zone is mainly dominated by the polygonomorphs (*Veryhachium, Neoveryhachium* and *Dorsinnidium*), netromorphs (*Domasia and Deunffia*) and acanthomorphs (*Multiplicisphaeridium* and *Micrhystridium*).

Domasia trispinosa has been reported from Buildwas Shales (Wenlockian) of England. However, this form has also been reported from the Llandovery and lower Wenlock of the Welsh Borderland (Hill, 1974); Rochester Shale of New York, Ontario and Pennsylvania; Osgood Shale of Indiana, Ohio & Kentucky and Rose Hill Formation of Pennsylvania (Cramer & Diez, 1979). Similarly, Domasia algerensis has been recorded from the Llandovery and lower Wenlock of the Welsh Borderland (Hill, 1974).

Deunffia monospinosa is recorded together with *Domasia algerensis* from the type area of the Llandovery and the Welsh Borderland as well as from Rochester Shale, Osgood Shale and Alger Shale. *Deunffia brevispinosa* has similar distribution in time and space like other netromorphs of this zone described above. The base of the Idwian Stage (Middle Llandoverian) in England is marked at the first occurrence of *D. trispinosa*. Similarly, the base of the Telychian Stage (Upper Llandoverian) is defined at the first occurrence of *Deunffia monospinosa* & other forms of this genus (Cramer & Diez, 1979). Ten selected species of *Deunffia* and *Domasia* make their first occurrence at or near the Llandoverian-Wenlockian boundary sediments in Shropshire (Hill, 1974). The base of the Wenlockian Stage (Hill, 1974) is marked at the first occurrence of *Deunffia brevispinosa* and other forms of *Deunffia*.

Downie (1963) illustrated the Wenlockian acritarchs and opined that the *Domasia* and *Deunffia* disappear at the top of the early Wenlockian Buildwas Beds. Cramer *et al.* (1979) observed the presence of *Domasia* and *Deunffia* in the Hoegklint Limestone of Gotland of early Wenlockian age.

Martin (1969) recorded the *Domasia trispinosa* and other related forms in abundance in the upper Llandoverian and their acme in Wenlockian. Therefore, *Domasia trispinosa* and its acme (Martin, 1969) has been precisely correlated with the Silurian type area as described by Hill (1974). Lister (1970 and 1970a) and Lister & Downie (1974) studied the acritarchs from the Ludlow sequence in Great Britain and stated that *Deunffia* and *Domasia* did not extend above the Wenlockian Stage.

Sheshegova (1975) studied the Silurian sediments of the Tuva region and outlined an acritarch zonation scheme for the Llandoverian and Ludlovian rocks and concluded that the *Deunffia monospinosa* and *Domasia trispinosa* had the restricted occurrence in the Llandoverian and the early Wenlockian of Tuva.

Thusu (1973) correlated the Buildwas Beds of England with the Illion Shales (Wenlockian) and recorded the species of *Deunffia* and *Domasia* together with other acritarchs. According to him, the netromorphs of Buildwas assemblages are identical to those of Illion Shales of England. Cramer & Diez (1972) and Thusu (1973) studied the acritarchs from the Rochester Formation (Wenlockian). The Rochester acritarchs are closely comparable with the acritarch association of the Illion Shales of Utica (New York) and West Virginia, and to the Buildwas Beds in Britain. Thusu (1973) concluded that the two species of the genus *Deunffia,* viz. *Deunffia ramusculosa* and *Deunffia furcata,* probably made their first occurrence in Wenlockian in the Southern part of Ontario. He (op. cit.) also observed the absence of *Deunffia* and the presence of *Domasia* in the Wenlockian of Gotland and Belgium. However, both the genera are recorded in the Hoegklint Formation of early Wenlockian age (In Cramer *et al.*, 1979).

Geron amabilis has been recorded from the Furada Formation (Ludlovian) of Northwest Spain (Cramer, 1969). The acme of the *Geron* ranges from the base of the upper

Llandoverian to the early Ludlovian which is much coincident with that of *Neoveryhachium carminae* (Cramer & Diez, 1979).

Leiofusa parvitatis has been described from the Maplewood Shale (Middle Silurian) of New York (Loeblich, 1970). *Multiplicisphaeridium cladum* has been reported from Wenlock Shale, Buildwas & Coalbrookdale Beds of England (Downie, 1963) and Rochester Shale of New York (Cramer, 1970) which are Middle Silurian in age. *M. thusuii* and *M. cladum* have been reported from Rochester Formation (Wenlockian) of Canada (Thusu, 1973) and Rochester Shale of New York (Cramer, 1970) respectively. Similarly, *Baltisphaeridium citrinum* has been recorded from the Ordovician of Belgium, Silurian of Poland and Wenlockian of England (Downie, 1963). Thus, the review of the stratigraphic distribution and ranges of these acritarch species, which are also very much common in the Early Paleozoic Tethyan sediments, suggest that these forms are characteristic of Early Silurian assemblages in the Eastern as well as in Western Europe. The restricted occurrence of *Geron* in the present assemblage further suggests a Llandoverian to Wenlockian age.

Suggested age . Llandoverian to Wenlockian.

Zone III : *Domasia limaciforme - Dactylofusa oblancae* Assemblage Zone (Poor in acritarch content).

Reference section . Shiala and Yong Limestone Formation; between 2.355-4.155 Km. points of Sumna-Rimkhim section, Tethyan Garhwal Himalaya.

Definition . Common occurrence of *Domasia limaciforme* and *Dactylofusa oblancae;* and dominant presence of *Leiofusa algerensis, L. parvitatis* and *Stellichinatum celestum.*

Base . The last occurrence of *Deunffia brevispinosa* and/or first occurrence of *Baltisphaeridium citrinum*.

Top . The last occurrence of *Leiofusa algerensis, Veryhachium* sp. cf. *V. wenlockium* and *Stellichinatum celestum.*

Significant accessory forms . *Leiosphaeridia viswanathiae, Deunffia monospinosa, Tetradinium* sp., *Cymatiosphaera* sp., *Domasia limaciforme* and *Dactylofusa oblancae.*

Restricted forms . *Deunffia monospinosa, Cymatiosphaera* sp., *Domasia limaciforme* and *Stellichinatum celestum.*

Correlation and age . The characteristic forms of this assemblage zone are *Stellichinatum celestum, Veryhachium* sp. cf. *V. wenlockium* and *Leiofusa algerensis.*

Stellichinatum celestum has been quite abundantly reported from the Silurian of Belgium (Martin, 1969), upper Llanvirnien of Bohemia (Burmann, 1970), Ordovician and ? Silurian of Algeria (Jardine *et al.*, 1974), probable Caradoc of Indiana (Colbath, 1979), Naninne and Jonquoi formations of Belgium of lower Ludlovian (Martin, 1968).

Veryhachium sp. cf. *V. wenlockium* is recorded from Wenlock beds of England (Downie 1959, 1963). Thusu (1973) recorded this species from the Silurian of Canada and U.S.A. This species has also been reported from the matrix of echinoid *Myriastiches gigas* from England suggesting a lower Ludlovian age (Lister & Downie, 1967). The *Leiofusa algerensis* is also recorded from the Silurian rocks in Jordan (Basha, 1992). Thus, the presence of species of *Domasia* and *Deunffia* in the present assemblage zone suggests a

Wenlock age, since, the species of these two forms do not extend beyond the Wenlockian (Cramer & Diez, 1979).

Remarks . The acritarch contents of *D.limaciforme-Dactylofusa oblancae* Assemblage Zone is poor to moderate. However, it contains a rich assemblage of chitinozoans and melanosclerites. The chitinozoan assemblage includes forms such as *Desmochitina* sp., *Ancyrochitina* sp., and *Conochitina* sp. which are very common in the Silurian sediments. The specific identification could not be made, as it is beyond the scope of the present work.

Suggested age . Wenlockian to lower Ludlovian.

Zone IV : *Leiofusa algerensis - Multiplicisphaeridium osgoodense* Assemblage zone.

Reference section . Yong Limestone Formation; between 4.155-4.175 km. points of Sumna-Rimkhim section, Tethyan Garhwal Himalaya.

Definition . Dominance of species nominated together with common occurrence of *Oppilatala ? indianae*, *Stellichinatum celestum*, *Veryhachium* sp. cf. *V. wenlockium* and *Multiplicisphaeridium variabile*.

Base . The last occurrence of *Leiofusa algerensis*, *Veryhachium* sp. cf. *V. wenlockium* and *Stellichinatum celestum*.

Top . The top of this zone could not be ascertained as the strata above sample no. R-51 are devoid of acritarchs.

Significant accessory forms . *Leiofusa algerensis, L. bernesgae, L. parvitatis, Veryhachium* sp. cf. *V. wenlockium, Dorsinnidium* sp., *Dasydiacrodium* sp., *Multiplicisphaeridium osgoodense, Oppilatala ? indianae* and *Multiplicisphaeridium variabile.*

However, *Multiplicisphaeridium osgoodense* and *Polygonium gracile* are found to be absent in this zone.

Correlation and age . The age marker acritarch species of this zone, such as *Oppilatala ? indianae, Multiplicisphaeridium variabile* and *Leiofusa bernesgae* are reported globally in the Late Silurian rocks. *Oppilatala ? indianae* has been described from the Racine Formation (Ludlovian to Skala) of Illinois and Moccasin & Springs Formation (Ludlovian) of Missouri (Cramer & Diez, 1972).

Multiplicisphaeridium variabile has been recorded from the Maplewood Shales (Middle Silurian) of New York (Fisher, 1953), La vid Formation (Middle siegenian to Emsian) Northwest Spain (Cramer, 1964), lower Ludlovian matrix of echinoid in England (Lister & Downie, 1967), Wenlockian to Gedinnian in Sahara (Jardine & Yapaudjian, 1968) and Lower Elton Beds (Ludlovian) of England (Lister, 1970).

Leiofusa bernesgae has been recorded in abundance from the Ludlovian succession of Argentina (Pothe de Baldis 1971, 1975), Bolivia (Cramer *et al.*, 1974), North Africa and Iberia (Cramer & Diez, 1979). This species has also been described from the St. Clair Formation (Upper Wenlockian to lower Ludlovian) of Missouri (Cramer & diez, 1972).

Suggested age . Lower Ludlovian.

The sediments overlying the Yong Limestone Formation belong to the Variegated Formation and the samples from this Formation are observed to be devoid of acritarchs. However, the Muth Quartzite section which overlies the Variegated Formation has yielded rich assemblages of brachiopod (*Pentamerifera* sp.) of the Late Silurian age and some corals (Goel *et al.*, 1987). The record of Late Silurian brachiopod in the top horizon of the Muth Quartzite sequence suggests Ludlovian age for the Variegated Formation.

Discussion

The acritarch studies of the Sumna-Rimkhim section of the Tethyan Himalaya in the Garhwal region have provided the new impetus to the stratigraphy of this region and revised the earlier date assigned to the Shiala Formation.

The recognition of acritarch assemblage zones and record of stratigraphically potential species suggest Silurian age of the Shiala Formation which was earlier dated as Ordovician.

Thus, the Early Paleozoic sediments of Sumna-Rimkhim section of the Tethyan Garhwal Himalaya ranges in age form Ordovician to Late Silurian (Caradocian to Ludlovian).

CHAPTER 5

ENVIRONMENT OF DEPOSITION

Introduction

Detailed stuides on acritarchs has led to the erection of four distinct biostratigraphic zones (Palynozones), which in turn helped in precise age determination of strata and also in stratigraphic correlation of the Lower Paleozoic marine sediments exposed along the Sumna-Rimkhim section of the Tethyan Garhwal Himalaya.

It was envisaged as one of the objectives of the present study to work out the enviornment of deposition of the sedimentary basin into which these sediments were deposited.

In the process of paleoenvironmental or paleoecological interpretations, it is always better if all the informations, observations, data obtained after field and laboratory investigations are put together and then the inferences with regard to the depositional environment of the basin are drawn in an integrated manner. This is because of the fact that a particular group of fossil microbiota does not provide all the desired information or the data base for interpretation. There is always some kind of limitation or the other with each group of fossil microbiota.

Hence, an attempt has been made, under the present study, to draw inferences with regard to the environment of deposition and, hence, acritarchs and other associated palynomorphs like chitinozoa and melanosclerites were also considered.

Owing to limitations, it was, therefore, felt necessary to undertake detailed sedimentological and chemical-sedimentological investigations on the same rock samples which yielded acritarchs, chitinozoans and melanosclerites to obtain additional data, to support further, the inferences with regard to the environment of deposition.

A discussion has been given incorporating all the findings to present the depositional environment from the base to the top of the stratigraphic column sampled. The integrated study, thus, has helped in the preparation of an estimated paleobathymetric trend of the basin of sedimentation during Llandeilo (?) to Downtonian (?) in this part of the Tethyan Garhwal Himalaya (Table-9).

The interpretations made on the aspect of environment of deposition are based on the following investigations undertaken:

(1) Acritarchs,

(2) Chitinozoans and melanosclerites,

(3) Sedimentology.

(1) Acritarchs

It is well established that the acritarchs can be used to recognise and decipher marine strata. Acritarchs indicate planktonic habitat. Their small size and great abundance suggest them to be phytoplankton.

AGE	FORMATION	ZONE	BROAD LITHOLOGY AND IMPORTANT SAMPLE POSITIONS	FOSSIL PALYNOFORMS: ACRITARCHS	FOSSIL PALYNOFORMS: MELANOS-CLERITES	FOSSIL PALYNOFORMS: CHITINO-ZOANS	ALGAE	BRYOZOA	PETROGRAPHY	GLAUCONITE	CLAY MINERALS: (%) KAO-LINITE	CLAY MINERALS: (%) ILLITE	BORON/GALLIUM	SILT PERCENTAGE
?	VARIEGATED FORMATION	UNFOSSILIFEROUS SEQUENCE B ?	R66 SILTY SHALE, LIMESTONE, SILTSTONE AND SANDSTONE	ABSENT	ABSENT	ABSENT	PRESENT	PRESENT	WACKSTONE (BIOCLAST)	PRESENT	00	100	EXCLUSIVELY MARINE	43·5
	YONG LIMESTONE FORMATION	ZONE-IV 6 METERS	R52, R51, R48, R47 LIMESTONE	ABUNDANT	PROLIFIC	ABUNDANT	PRESENT	PRESENT	WACKSTONE (BIOCLAST)	PRESENT	—	—	EXCLUSIVELY MARINE	L.st. (NO SILT)
SILURIAN	SHIALA FORMATION	ZONE-III 52 METERS	SANDSTONE, LIMESTONE, DOLOSTONE, SILTY SHALE AND SILTSTONE	DECREASE IN CONTENT	PROLIFIC	ABUNDANT	PRESENT	PRESENT	SIDERITE DOLOMITE	PRESENT	00	100	DOMINANTLY MARINE	41·4
		ZONE-II 14 METERS	R25, R24 SILTY SHALE, LIMESTONE SILTSTONE AND SANDSTONE	PROLIFIC	PRESENT	PRESENT	PRESENT	PRESENT	MICRITE, SIDERITE, PYRITE	PRESENT	26·49	73·51	MARINE TO TRANSITIONAL	35·10
–?–?–?–		ZONE-I 2 METERS	R8, R7, R3, R2 SANDSTONE, LIMESTONE AND SILTY SHALE	RELATIVELY POOR	ABSENT	ABSENT	PRESENT	PRESENT	MICRITE, SIDERITE PYRITE	PRESENT	26·6	73·4	-DO-	38·0
ORDOVICIAN	GARBYANG FORMATION	UNFOSSILIFEROUS SEQUENCE-A ?	SILTY SHALE, SILTSTONE SANDSTONE AND LIMESTONE	ABSENT	ABSENT	ABSENT	PRESENT	PRESENT	PRESENCE OF MICRITE SIDERITE	PRESENT	27·77	72·23	MARINE WITH FLUVIAL INFLUX	41·00
			M1								00	100	MARINE	

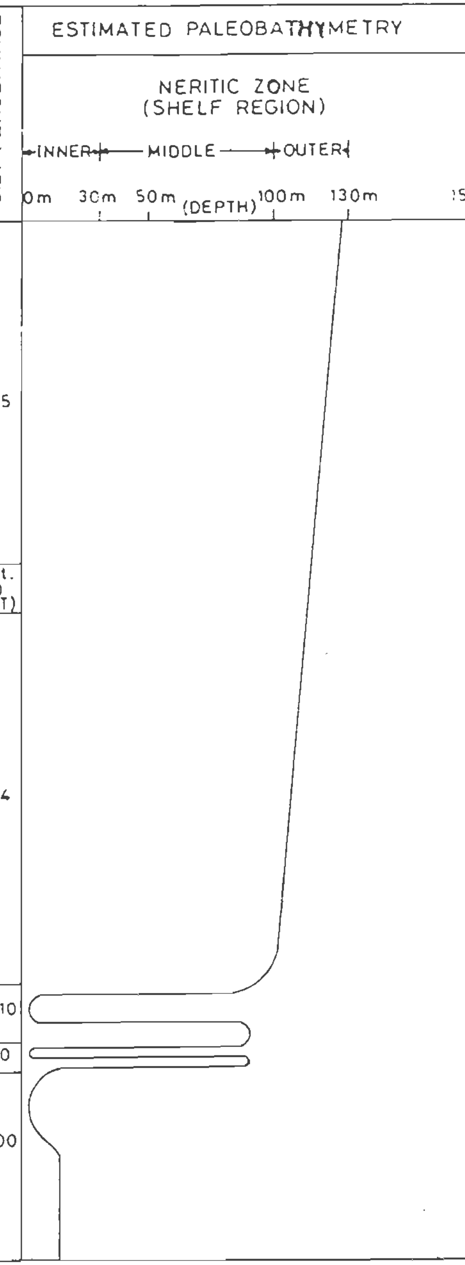

TABLE-9 ESTIMATED PALEOBATHYMETRY OF LLANDEILO (?) TO DOWNTONIAN (?) SEQUENCE OF SUMNA-RIMKHIM SECTION, TETHYAN GARHWAL HIMALAYA. (NOTE: Thickness of zone is the segment of sequence well exposed and sampled.)

Jacobson (1979) recognised three morphological classes of acritarchs indicating environment of deposition. The classes are:

(i) *Leiosphaerid* class representing near shore, shallow water environment,

(ii) *Peteinosphaerid-Dicommopalla* class indicating a shoal habitat, and

(iii)*Baltisphaerid-Veryhachid-Polygonium* class characteristic of open sea environment.

Williams (1978) also supports the view of Jacobson (1979).

Smith and Saunders (1970) made an important contribution on the "paleoenvironments and their control of acritarch distribution: Silurian of East-Central Pennsylvania". They made the following observations:

(i) "Most of the acritarchs being planktonic, their distribution in sediments must be influenced by the strength and direction of prevailing currents present in the areas of deposition, especially in transitional areas".

(ii) "The degree of preservation of acritarch forms is strongly dependent on the depositional environment. In general, the best preserved and delicately spined forms occur in thicker shale zones of the open marine facies while nearer shore and shallow water conditions are indicated by relatively greater proportions of sandstones containing fewer and more fragmented acritarchs".

Tappan (1980) put forward the following views:

(i) "that diversity of acritarchs decreases rapidly towards shore in the marine environment, the more complex taxa being typically offshore in occurrence".

(ii) "rock lithology similarly suggests this relationship, as acritarch diversity is greatest in fine grained siltyshales and siltstones and in rocks of considerable carbonate content".

Vidal (1976) observed that the varied abundances of acritarchs in certain strata, independent of facies, result from suddenly appearing algal blooms.

There are three principal physical and chemical ecological parameters operative in a marine ecosystem. They are depth, temperature and salinity.

Depth

Wall (1965) suggested that highly diverse and heterogeneous assemblages of acritarchs accumulate offshore. He observed that genera like *Domasia* and *Veryhachium* and most of their species characterise open marine condition.

As stated earlier, occurrence of *Baltisphaerid-Veryhachium-Polygonium* class also represents open sea area (Jacobson, 1979). Likewise, acanthomorphitic acritarchs are restricted to deeper waters (Tappan, 1980). Worsley (1982) suggested that relatively high sedimentation rates and possibly high energy regimes of deposition may be reasonable explanations for the low acritarch abundance in sediments and, in turn, is characteristic of shallow marine to coastal depositional environments.

Eupoikilofusa striatifera, Veryhachium wenlockium, V. lairdii and *Polygonium nanum* are the characteristic forms representing open marine environment (Jacobson, 1979; Dorning, 1981a; Al-Ameri, 1983).

Dorning (1981a) described typical offshore shelf assemblages comprising dominant species like *Diexallophasis denticulata, Veryhachium wenlockium, Oppilatala ramusculosa, Eupoikilofusa* and *Domasia.*

While working in Oslo region (Norway), Smelror (1987) has deciphered the following acritarch forms from the middle part of the Saelabonn Formation characterising shallow marine environment: *Leiosphaeridia* sp., *Micrhystridium* sp., *Lophosphaeridium* sp., *Veryhachium rhomboidium, Multiplicisphaeridium* sp., *Oppilatala* sp., *Veryhachium europeaum.*

Temperature

Cramer (1971) and Cramer and Diez de Cramer (1972) observed that the assemblage of *Deunffia, Domasia* and *Neoveryhachium* characterise warm waters.

Salinity

Brosius and Bitterli (1961) observed that *Veryhachium, Micrhystridium* and *Domasia* assemblages are abundant in normal marine salinity conditions (about 35 parts per thousand) and exhibit highest diversity. Presence of corals in sediments also represent normal marine salinity.

(2) Chitinozoa and Melanosclerites

A large majority of workers has favoured a planktonic or epiplanktonic mode of distribution of chitinozoans.

Paris (1990) has drawn following conclusions on the chitinozoan paleoenvironment:

(i) Chitinozoans are exclusively marine microfossils which occur in shallow, shelf and slope sediments.

(ii) The distal deposits (slope and outer shelf) yield abundant chitinozoans, whereas, passive elements of the plankton (e.g. spores, fragments of tracheids etc.) are extremely rare or lacking.

(iii) The geographic distribution of many chitinozoan species is more than those of benthic or neritic fauna.

(iv) Some chitinozoan taxa are distributed throughout the paleoclimatic belts. All these observations well support a pelagic mode of distribution for the chitinozoa which occurred much far from the shore when compared with land derived microfossils (spores).

Melanosclerites are rod-shaped, pseudochitinous microfossils of problematic affinity. Melanosclerites appear to be strongly facies controlled, occurring in sediment formed under open-ocean conditions (Nolvak, 1980). However, Cashman (1992) suggests that some melanosclerites could have been restricted to relatively shallower, but, in more open-ocean area.

(3) Sedimentology

The sedimentological study was carried out for elucidating the environment of deposition. The relevant references cited have already been given in chapter 2. Following aspects were chosen for this purpose:

(i) Petrography (ii) Silt percentage

(iii) Clay-mineralogy and (iv) Chemical-sedimentology

Petrography

A number of minerals and a few fossil micro-biota were encountered while examining the thin sections. Some characteristic minerals are:- micrite, glauconite, pyrite, siderite, dolomite. The micro-biota include:- algae, bryozoa and conodonts.

The presence of micrite indicates a quiet environment that may be shallow (60 meters), whereas, glauconite, pyrite & siderite suggest aspidic euxinic, anaerobic, reducing or poorly oxygenated, low energy environment. Glauconite represents exclusively marine environment and slow sedimentation in depths of 18 to 72 meters.

The presence of dolomite indicates a shallow warm water condition between 0 and 45 meters of depth and peloids indicate a shallow (shelf), low energy carbonate marine environments.

Bryozoans are benthic organisms and indicate exclusively shallow tranquil, marine condition of environment. Algae are aquatic plants and are generally restricted by depth, less than 60 meters i.e., indicating shallow marine environment of the photic zone.

Silt Percentage

This study indicates that as the silt percentage in siltyshale increases, the frequency of population of acritarchs declines.

Clay Mineralogy

Only two clay minerals viz. Kaolinite and illite have been identified. This study suggests that the sediments of Sumna-Rimkhim section were deposited under dominantly shallow marine environment with signatures of intermittent fluvial regimes.

Chemical-sedimentology

The major and trace elements study indicates that the sediments of Sumna-Rimkhim section were deposited largely in marine to intermittently transitional environment.

Discussion on the Environment of Deposition

The sediments investigated represent deposits of a single sedimentation basin which existed right from the Late Precambrian times until Cretaceous (? Lower Eocene). This basin forms the part of the Tethyan geosyncline which is supposed to have existed on the northern limits of the Himalaya (Kumar *et al.*, 1977). The rate of sedimentation kept pace with the sinking of basin of deposition.

Samples processed for acritarchs, sedimentological and chemical sedimentological studies come from the Sumna-Rimkhim section of the Tethyan Garhwal Himalaya in the Chamoli District (U.P.).

It is appropriate to initiate the discussion on depositional environment beginning from the basal part of the stratigraphic column i.e. near the contact of the Garbyang and Shiala formations. The basal part of the section has been called as the Unfossiliferous Zone-A.

Unfossiliferous Zone-A (from Sample nos. M-1 to R-2 in the Column)

This zone comprises siltyshale, sitstone, sandstone and limestone and is devoid of any type of fossil macro- or microbiota except algae which are observed in thin-sections of rocks.

Study of macro-fossil biota and trace fossils is not covered under the scope of the present study. Therefore, attention was paid on the study of palynomorphs only. However, as cited in chapter 1, the earlier workers have stated that the Garbyang rocks are largely devoid of identifiable macro-fossils. There are scanty reports about the occurrence of doubtful, fragmentary and tiny gastropods, trilobites and lingulid brachiopods.

Absence of fossil palynomorphs except algae observed in thin-section only indicates near shore area of deposition. Presence of siderite mineral indicates reducing conditions. The presence of micrite in minor amount is indicative of depths maximum upto 6om. Illite is found to be 100% at the base of this zone characterising marine conditions. But, Illite percentage shows a reducing trend upwards in this zone which indicates fluvial influx in the upper part. Presence of glauconite in the litho-units also indicates marine environment of deposition with depths ranging between 18 to 72 meters. Boron/Gallium plot also supports the marine conditions. Siltstone and siltyshale are the dominant lithology of this zone. Normally, this lithdogy is expected to provide good preservation medium for biota.

However, absence of fossil acritarchs and other microbiotic elements is possibly due to prevalence of high energy, turbid waters, high sedimentation rate and intense agitation in the depositional basin.

Based solely on sedimentological study, the depositional area for the accumulation of sediments in this zone (Unfossiliferous zone-A) could possibly be the Inner Neritic Zone (Depths ranging between 0 to 30 meters); Table-9.

Zone-I (from Sample nos. R-3 to R-7 in the Column)

This zone comprises sandstone, limestone and siltyshale.

Frequency of acritarch population and their diversity in this zone are relatively poor which might be due to shallow marine area of sediment deposition.

The above observation is supported by the presence of characteristic shallow marine acritarch species like *Multiplicisphaeridium ornatum, Lophosphaeridium parvum*. In addition, the following acritarch species have also been recorded· *Polygonium gracile, Coryphidium miladum, Ordovicidium nudum* which may also be used for deciphering precise environmental regime.

A significant observation in this zone is the absence of chitinozoans and melanosclerites. However, presence of algae and bryozoans is observed in thin-sections.

Sedimentological study provides adequate information about the depositional environment of this zone. Presence of micrite in relatively greater amount than the underlying Unfossiliferous zone-A shows a trend of gradual deepening. Occurrence of pyrite in this zone, in addition to siderite, shows an increased intensity in the reducing condition of the basin in comparison to the underlying zone. Likewise, the amount of glauconite also increases in this zone which again shows a gradual deepening of the basin of deposition.

Amount percentage of clay mineral kaolinite indicates that the fluvial influx is intermittent in this zone. Boron/Gallium plot supports marine to transitional environment. The possible cause of poor recovery of acritarchs may be due to an increase in the amount of sand, a poor medium, in this zone.

Presence of acritarch species as listed above clearly indicates a shallow marine environment with possibility of intermittent fluvial influxes. The sedimentological results also support this view, as discussed above.

Hence, the area of deposition in which the sediments of this zone were accumulated might possibly be the Middle Neritic Zone (depths ranging between 30 to 100 meters); Table- 9.

Zone-II (from Sample nos. R-8 to R-24 in the Column)

This zone comprises siltyshale, limestone, siltstone and sandstone.

The acritarch population and variation accompanied with average amount percantage of Kaolinite (26.49%) in this zone indicates slightly more deepening of the basin as compared to underlying zone I. This is also supported by the occurrence of melanosclerites in this zone which indicates relatively open ocean environment.

The characteristic shallow marine acritarch species of this zone are *Multiplicisphaeridium cladum, M. thusui, Micrhystridium equispinosum, M. shientonense, M. parinconspicuum, M. diornamentum, M. robustum, M. exiguum, Dorsennidium europaeum, D. rhomboidium, Lophosphaeridium* sp.

During the present study, the following species are also recorded: *Domasia trispinosa, D. algerensis, Acanthodiacrodium simplex, Deunffia brevispinosa, D. monospinosa, Triangulina* sp. and *Leiofusa bernesgae.*

The sedimentological data and results of this zone are more or less similar to those described against underlying zone I. The presence of micrite, siderite, pyrite, glauconite and clay mineral like Kaolinite in subordinate amount, whereas, illite in considerable amount suggests that the sediments of zone II were deposited mainly under marine condition with very little fluvial influx. Boron/Gallium plot supports largely marine to less transitional environment of deposition.

The possible cause of high yield of acritarch in this zone is due to greenish black siltyshale, a suitable medium of preservation.

The presence of acritarch species, as listed above, indicates marine to transitional environment with decreased fluvial influx as compared to the underlying zone I.

The sedimentological results point towards the same inference as discussed above.

The area of deposition, therefore, could be Middle Neritic Zone (depths ranging between 30-100 meters). Presence of melanosclerites in this zone and absence of melanosclerites in the underlying zone I indicates that the basin of deposition (Middle Neritic Zone) was relatively deeper during deposition of sediments in zone II as compared to zone I; Table-9.

Zone-III (from Sample nos. R-25 to R-47 in the Column)

This zone comprises sandstone, dolostone, limestone, siltyshale and siltstone.

Acritarchs again show decrease in population as well as in variety in this zone. However, there is a marked increase in the melanosclerite contents in the sediments. Increase in population of melanosclerites, as well as, abundance of chitinozoa indicate dominantly marine environment i.e. still deeper basin of sedimentation as compared to those in zones II and I.

The characteristic open ocean indicator species of acritarchs recorded in this zone are: *Dorsennidium* sp., *Domasia limaciforme*. In addition to the above, the following species were also recorded during the present study: *Deunffia monospinosa, Tetradinium* sp., *Dactylofusa oblancae* and *Polygonium* sp. which may also be used as environmental indicators. As in other zones, bryozoans and algae continue to be present in this zone also.

Presence of siderite points to the reducing condition in the basin, while presence of dolomite in this zone, indicates open ocean environment. Amount of illite in this zone is 100% indicating dominantly marine environment. Boron/Gallium plot also supports dominantly marine conditions of deposition.

Dominance of sand and higher silt percentage in siltyshale samples, in this zone, in particular, could be the cause of decreased acritarch population and increased chitinozoan and melanosclerite populations.

The presence of characteristic open ocean acritarch species as listed above, presence of dolomite, Boron/Gallium plot indicate that the site of deposition could possibly be in the Outer Neritic Zone (depths ranging between 100 to 130 meters); Table 9.

Zone-IV (from Samples nos. R-48 to R-51 in the Column)

This zone comprises exclusively limestone lithology. The characteristic and typical open ocean acritarch species recorded in this zone are: *Domasia* sp., *Veryhachium* sp. cf. *V. lairdii, Dorsennidium* sp. *Veryhachium* sp. cf. *V. wenlockium, Polygonium* sp., *oppilatala* ? *indianae*, aff. *Diexallophasis* sp. In addition to the above, the following species are also recorded in abundance which may be used to indicate open ocean environment. They are: *Multiplicisphaeridium osgoodence, Dasydiacrodium* sp., *Tetradinium* sp., *Leiofusa bernesgae, L. algerensis, Geron* sp., *Neoveryhachium* sp. Population of melanosclerites and chitinozoans remain almost similar to that of underlying zone III with slight increase in the population of certain specific melanosclerite and chitinozoan forms indicating still deeper conditions of the basin of sedimentation.

Presence of wackstone (bioclast: with algae and bryozoa) shows quiet marine environment with slow rate of sedimentation and less wave energy, characteristic of open shelf area.

The presence of characteristic open ocean acritarch species as listed above; abundance of melanosclerites and wackstone lithology indicate an open ocean shelf environment which could be the Outer Neritic Zone (depths ranging between 100 to 130 meters); Tabl. 9.

Unfossiliferous Sequence-B (from Sample nos. R-52 to R-66 in the Column)

This sequence comprises typically discernible choclate coloured siltyshale, mudstone, wackstone and subordinate siltstone & sandstone.

Palynoforms of any type have been found to be totally absent in this zone during the present study. Algae and bryozoans still continued to be present in this zone and are observed in thin- sections. However, as mentioned in chapter 1, corals have been recorded in the lower part of this zone by earlier workers. Brachiopods, corals and trace-fossils have also been recorded by earlier workers from the upper part of this zone.

The sedimentary petrographic characters of this zone are largely similar to that of the rocks of the underlying zone IV. Presence of 100% illite and Boron-Gallium plot indicate exclusively marine environment.

Silt percentage in siltyshale of this zone shows a marked increase in comparison to its percentage in the underlying zones.

There are a few possibilities to explain the total absence of palynoforms in this zone. They are as follows:

(i) Flora might have existed but they got oxidised due to prevalance of oxidising environment in the basin of deposition. This feature manifests itself by the presence of typical choclate coloured siltyshale as a dominant lithology of this zone.

(ii) There is marked increase in silt percentage in siltyshale of this zone which could have hindered the process of preservation.

(iii) Whatever little quantity of palynoforms escaped oxidation, might have possibly been eaten by macro-invertebrates (Tappan, 1980).

Presence of wackstone which characterises quiet environment, slow sedimentation and less wave energy indicates open shelf environment and, therefore,an Outer Neritic Zone (depths ranging between 100 to 130 meters) might have been the site of deposition, where, the sediments of this zone were laid (Table-9).

By incorporating entire data and results obtained after investigations on acritarchs and sedimentological, chemical-sedimentological aspects, an estimated paleobathymetry from Llandeilo (?) to Downtonian (?) of the Sumna-Rimkhim section is presented (Table-9).

Temperature, Salinity and Current Conditions

Occurrence of *Deunffia, Domasia* and *Neoveryhachium* assemblages in the sediments; presence of calcareous algae and bryozoa throughout the stratigraphic column; presence of corals and dolomite indicate warm waters.

Occurrence of *Domasia, Micrhystridium* and *Veryhachium* assemblages in the sediments; presence of calcareous algae and bryozoa throughout the stratigraphic column as recorded in the present study and reports of occurrence of brachiopods, gastropods and corals by earlier workers indicate normal-marine salinity condition (35‰). Hence, it can be inferred that acritarchs, and certain co-existing chitinozoans and melanosclerites can tolerate the normal marine salinity condition fairly well.

It is observed, at times, that some shallow water acritarch speices are found to occur in deep water sediments. Likewise, some deep water species are found to occur in shallow water sediments. Both of these features are possible due to current circulation patterns operating in the marine ecosystem.

CHAPTER 6

CONCLUSIONS

Field and laboratory investigations carried out on the rock samples of the Sumna-Rimkhim section of the Tethyan Garhwal Himalaya were completed. Studies done on acritarchs and results obtained after sedimentological and chemical-sedimentological investigations led to the following conclusions :-

1. The lithostratigraphic units erected and designated by earlier workers (Shah & Sinha, 1974) as Garbyang, Shiala, Yong Limestone and Variegated formations ranging in age from Cambrian to Silurian have been adopted during the present study.

However, **the present study reveals that the boundary between Ordovician and Silurian lies within the Shiala Formation and not within the Yong Limestone Formation** as was proposed by earlier workers (Shah & Sinha, 1974).

2. **Twenty genera** and **sixty seven species of acritarchs** have been **identified** and **recorded for the first time from the Ordovician-Silurian (Caradocian to Ludlovian) marine sequence of the Sumna-Rimkhim section in the Tethyan Garhwal Himalaya, India.**

A detailed taxonomic description of all palynoforms recorded has been given.

In addition, **three chitinozoan genera** have also been identified and recorded. **Melanosclerites** have been well differentiated and their occurrence reported.

3. Four acritarch biostratigraphic assemblage zones (assemblage palynozones, I, II, III and IV in stratigraphic order) have been erected based on first occurrence and last occurrence levels (i.e., F.A.D. and L.A.D.) of stratigraphically significant forms. These assemblage palynozones in descending stratigraphic order are :-

Zone IV: *Leiofusa algerensis - Multiplicisphaeridium osgoodence* Assemblage Zone,

Zone III: *Domasia limaciforme - Dactylofusa oblancae* Assemblage Zone,

Zone II: *Domasia trispinosa - Deunffia monospinosa* Assemblage Zone,

Zone I: *Baltisphaeridium longispinosum* var. *longispinosum - Multiplicisphaeridium ornatum* Assemblage Zone.

4. Based on occurrence and similarity of assemblages, an attempt has been made to correlate each palynozone with other localities in the world. These localities are situated in United Kingdom, United States of America, South Ameria, Canada, Sweden, Belgium, Spain, Russia, Germany, Saudi Arabia, Portugal, Jordan, Bohemia, Northern and Western parts of Africa.

5. Precise age assignment of the strata in the stratigraphic column has been attempted based on the marker species which have helped to delineate the base and top of the biostratigraphic unit. Thus, Ordovician to Silurian (Caradocian to Ludlovian) age has been assigned to the strata of the Sumna-Rimkhim section of the study area.

6. The excercise of acritarch zonation reveals that the Ordovician/Silurian boundary lies within the Shiala Formation which was earlier considered to lie within the lower part of the Yong Limestone Formation.

7. Absence, presence, population frequency and variation of acritarchs; occurrence of typical depth indicator species of acritarchs; absence, presence and population frequency of chitinozoans & melanosclerites; petrographic characters including presence of glauconite throughout; percentage amounts of clay minerals; Boron-Gallium plots; percentage of silt content in rocks and presence of algae and bryozoa throughout have helped in paleoenvironmental deductions of the sediments studied.

Thus, it is inferred that the site of sedimentation possibly was Neritic Zone (Shelf region). It is interpreted that the sedimentation started in the Inner Neritic Zone initially with fluvial influx followed by sedimentation in the Middle Neritic Zone with varying fluvial influxes and finally, sediments were laid in the Outer Neritic Zone.

Occurrence of acritarch assemblages comprising *Deunffia, Domasia, Veryhachium, Micrhystridium* and *Neoveryhachium* in the sediments studied characterise **warm waters with normal marine salinity conditions.**

In addition to the characteristic acritarch assemblages, earlier workers have reported the occurrence of brachiopods, gastropods and corals in these sediments. Presence of calcareous algae and bryozoa have been recorded throughout the stratigraphic column during the present study. These additional evidences also support the inferences drawn based on acritarch assemblages.

Hence, it is inferred that **warm waters with normal marine salinity conditions** possibly prevailed throughout in the basin of sediment deposition.

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Plate-1

(All the magnification x 2000 approx. unless otherwise mentioned)

Figs.

1.	*Multiplicisphaeridium osgoodense* (Cramer & Diez) Eisenack et al., 1973 Sample No. R-47(2); coord. 92x37.8; x 800
2.	*Oppilatala*? *indianae* (Cramer & Diez) Priewalder, 1987 Sample No. R-47(2); coord. 94x30.9; x 800
3.	*Solisphaeridium* sp. Staplin et al., 1965 Sample No. R-8(0); coord. 103.7x66.1
4.	*Micrhystridium shinetonense* Downie, 1958 Sample No. R-8(0); coord. 107.2x59
5.	cf. *Diexallophasis* sp. Loeblich, 1970 Sample No. R-47(1); coord. 107.3x64.3; x 800
6&15.	*Micrhystridium parinconspicuum* Deflandre, 1945
Fig. 6 :	Sample No. R-8(0); coord. 106.4x68.5
Fig.15 :	Sample No. R-8(0); coord. 104.9x63.3
7.	*Solisphaeridium nanum* (Deflandre) Turner, 1984 Sample No. R-21(5); coord. 93.4x66.2
8.	*Cheleutochroa diaphorosa* Turner, 1984 Sample No. R-15(1); coord. 106x50.8; x 800
9.	*Micrhystridium* sp. Sample No. R-8(0); coord. 99.1x63.6
10.	*Multiplicisphaeridium cladum* (Downie) Lister, 1970 Sample No. R-8(0); coord. 104.6x52.3
11.	*Buedingiisphaeridium tremadocum* Rasul, 1979 Sample No. R-8(0); coord. 105.3x50.5
12.	*Micrhystridium* sp. cf. *M. shinetonense* Downie, 1958 Sample No. R-8(0); coord. 103.2x60.4
13.	*Multiplicisphaeridium thusuii* (Thusu) Eisenack, 1976 Sample No. R-8(0); coord. 104.1x63.4
14.	*Micrhystridium* sp. Sample No. R-21(5); coord. 103.6x44.5
16.	*Filisphaeridium henryi* (Paris & Deunff) Sarjeant & Stancliffe, 1994 Sample No. R-8(0); coord. 103.3x36.2

Plate - 1

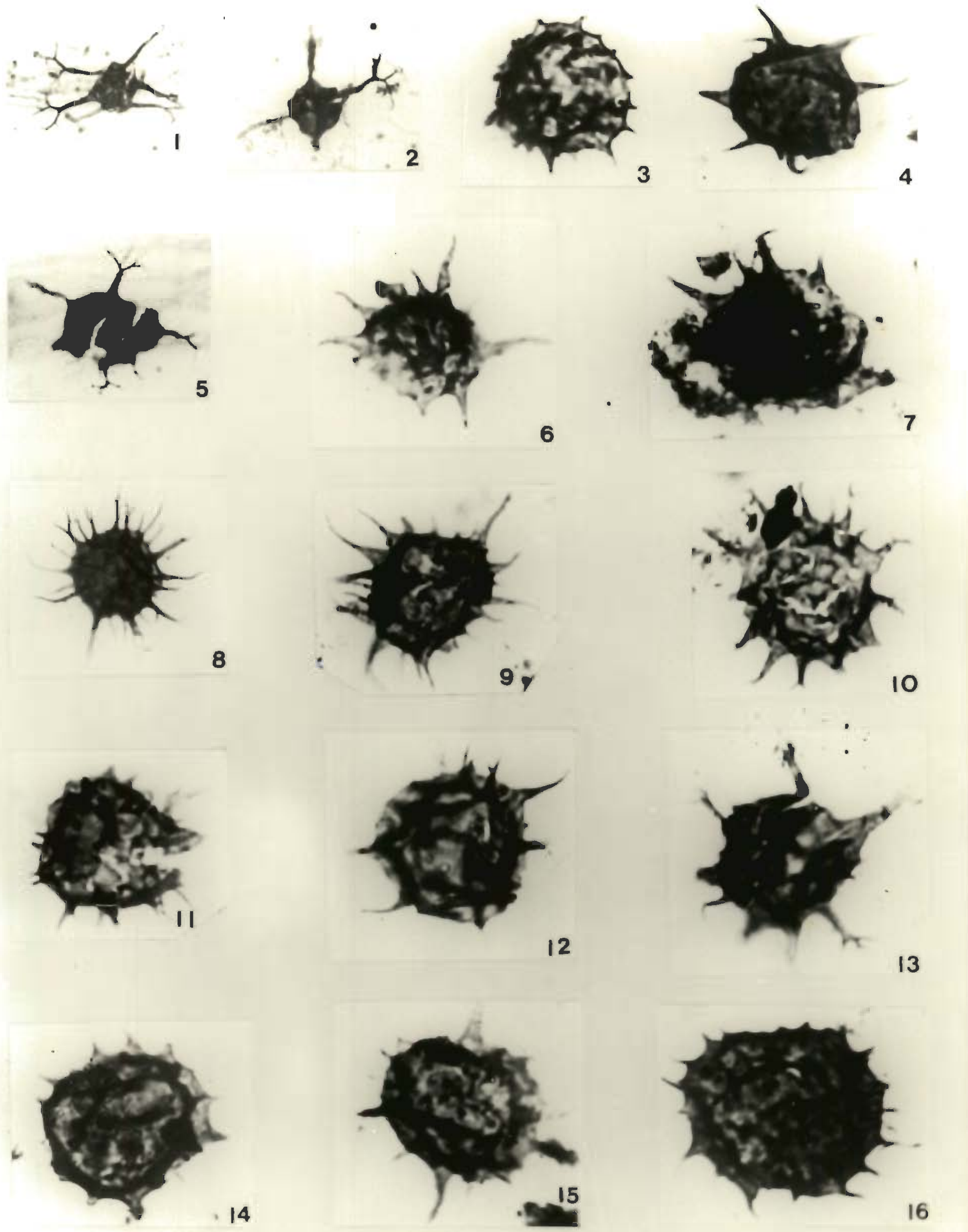


Plate-2

(All the magnification x 800 times unless otherwise mentioned)

Figs.

1. *Veryhachium* sp.
   Sample No. R-8(0); coord. 107.5x37.7; x 2000

2. aff. *Lophosphaeridium* sp.
   Sample No. R-5(1); coord. 101x51

3. *Dorsennidium rhomboidium* (Downie) Sarjeant & Stancliffe, 1994
   Sample No. R-8(0); coord. 107.7x31.2; x 2000

4. *Helosphaeridlum citrinipeltatum* (Cramer & Diez) Dorning, 1981
   Sample No. R-21(5); coord. 92.6x64; x 2000

5. *Veryhachium downiei* Stockmans & Williere, 1962
   Sample No. R-8(0); coord. 103x63.1; x 2000

6. *Baltisphaeridium accinctum* Loeblich & Tappan, 1978
   Sample No. R-8(1); coord. 100.5x27.5

7&8. *Baltisphaeridium citrinum* (Downie) Stockmans & Williere, 1974
Fig.7: Sample No. R-21(5); coord. 93.1x31.5; x 2000
Fig.8: Sample No. R-21(5); coord. 106.4x65.6; x 2000

9&14. *Ordovicidium nudum* (Eisenack) Loeblich Jr. & Tappan, 1978
Fig.9: Sample No. R-11(2); coord. 103.6x59
Fig.14: Sample No. R-17(2); coord. 95.5x41.3

10&11. *Vulcanisphaera imparilis* Rasul, 1976
Fig.10: Sample No. R-11(2); coord. 105.5x35.6
Fig.11: Sample No. R-11(3); coord. 92.5x42.5

12. *Peteinosphaeridium* sp.
    Sample No. R-8(2); coord. 92x65.5

13. *Baltisphaerosum bystrentos* (Loeblich & Tappan) Turner, 1984
    Sample No. R-8(2); coord. 95x31.3

Plate - 2

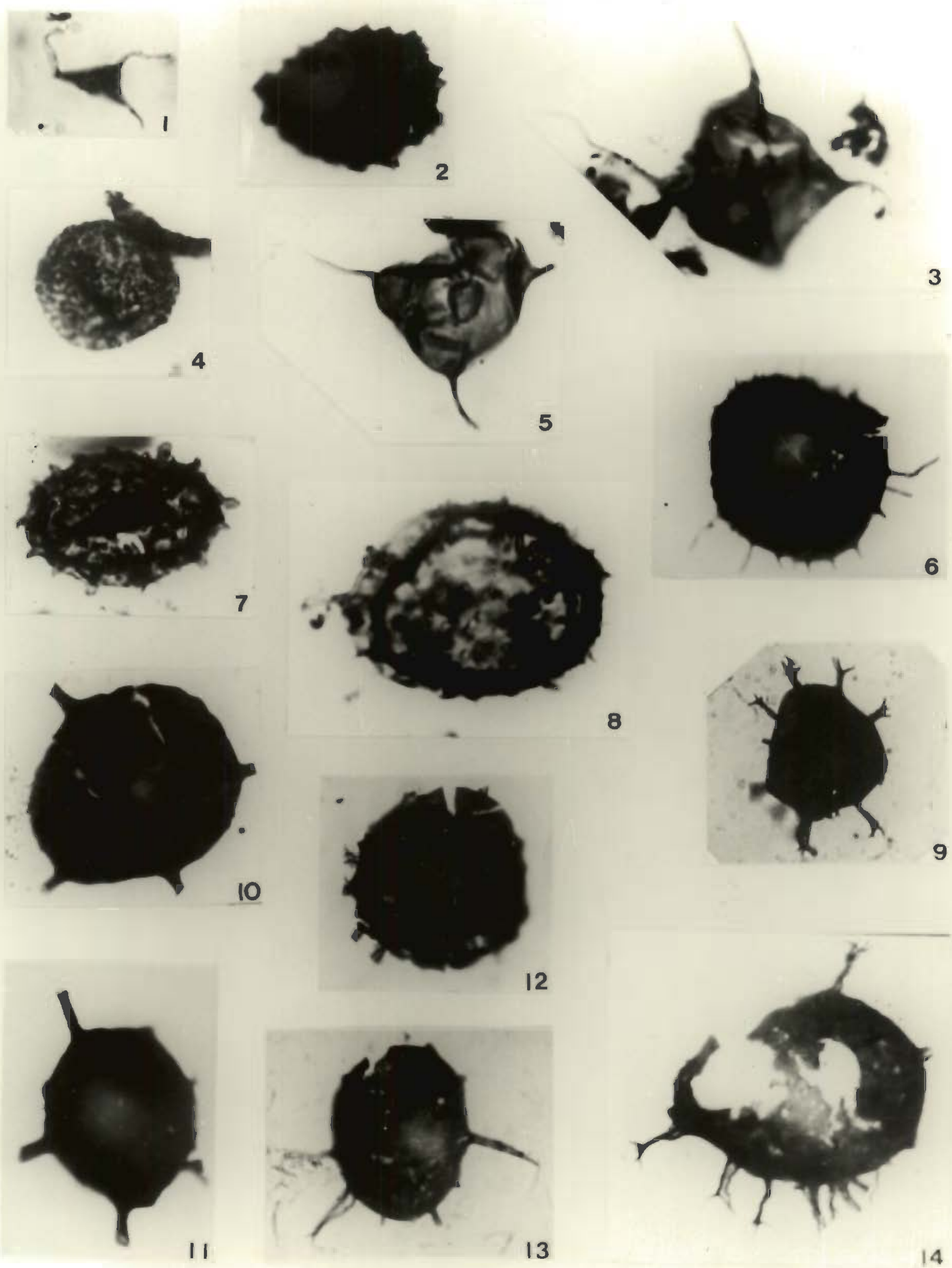


Plate-3

(All the magnification x 800 appox., unless otherwise mentioned)

Figs.

1. *Dasydiacrodium* sp. (Timofeev) Deflandre & Deflandre, Rigaud, 1962
Sample NO. R-47(0); coord. 92.8x38; x 2000

2,3&10. *Micrhystridium ? diornamentum* Rasul, 1979
Fig.2: Sample No. R-8(0); coord. 103.5x40.8; x 2000
Fig.3: Sample No. R-8(0); coord. 102.6x40; x 2000
Fig.10: Sample No. R-8(0); coord. 95.8x38.5; x 2000

4. *Lophosphaeridium* sp. (Timofeev) Lister, 1970
Sample No. R-12(1); coord. 99.8x61.6

5. *Baltisphaeridium archaicum* Cramer & Diez, 1972
Sample No. R-8(2); coord. 94.1x36

6. *Baltisphaeridium* sp.
Sample No. R-8(1); coord. 105.5x28.7

7. *Polygonium delicatum* Rasul, 1979
Sample No. R-15(1); coord. 102x58

8a&b *Multiplicisphaeridium variabile* (Lister) Dorning, 1981
Sample NO. R-47(1); coord 94.6x60; x 1000

9. *Goniosphaeridium splendens* (Eisenack) Turner, 1984
Sample No. R-21(5); coord. 93.2x50.8; x 2000

11. *Micrhystridium robustum* Downie, 1958
Sample No. R-21(5); coord. 94x54.8; x 2000

12. *Baltisphaeridium* sp.
Sample No. R-8(1); coord. 91.2x34

Plate - 3

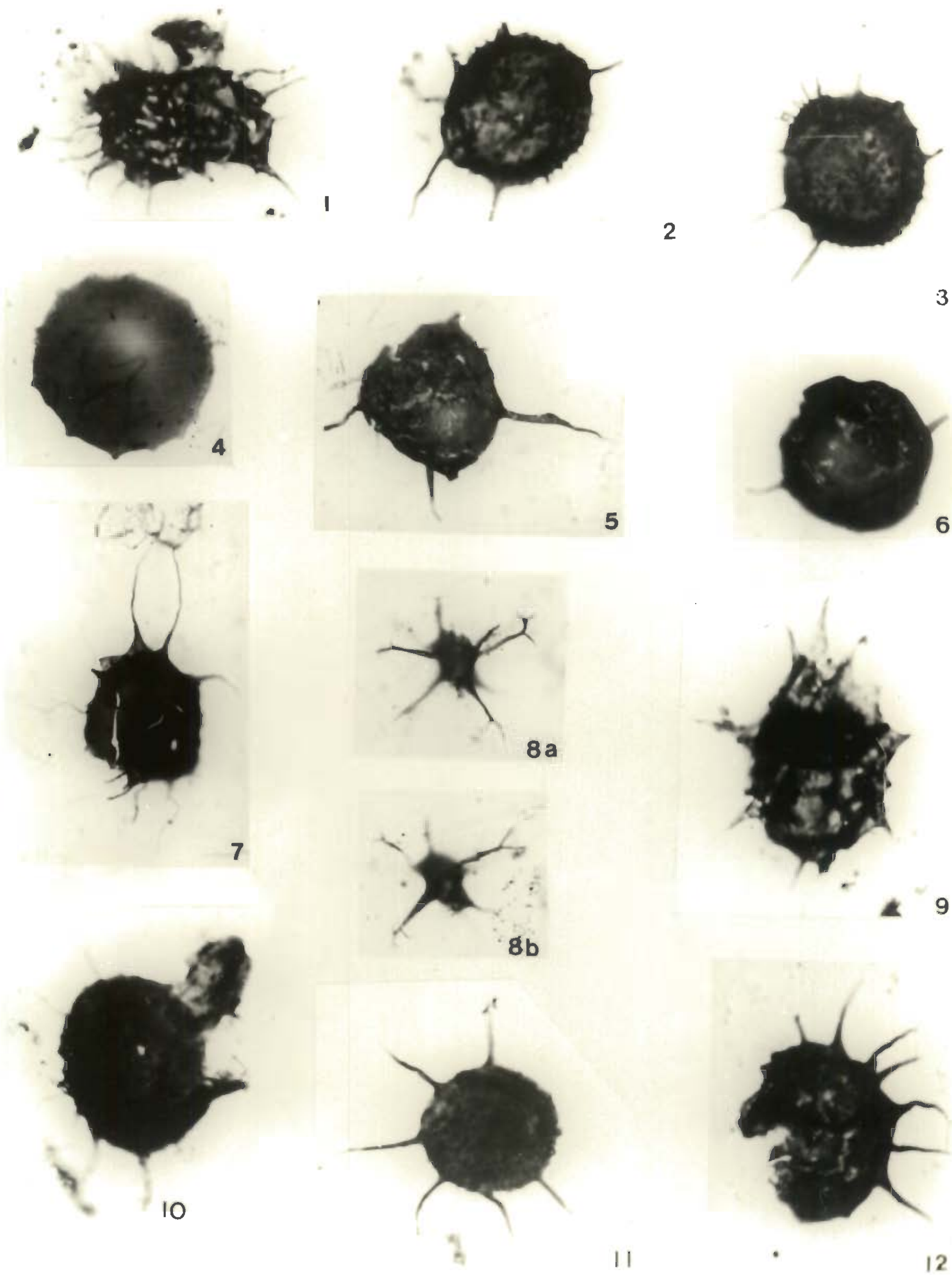


Plate-4

(All the magnification x 2000 approx., unless otherwise mentioned)

Figs.

1.	*Lophosphaeridium* sp.cf.*L. parvum* Stockmans & Williere, 1963
	Sample No. R-22(1); coord. 94x59; x 800
2.	*Micrhystridium exiguum* Rasul, 1979
	Sample No. R-8(0); coord. 95x35.2
3&4.	*Triangulina* sp. Cramer, 1964
Fig.3:	Sample No. R-8(0); coord. 103.5x68.4
Fig.4:	Sample No. R-8(0); coord. 103.3x40.1
5&6.	*Coryphidium miladum* Cramer & Diez, 1976a
Fig.5:	Sample No. R-17(2); coord. 97x50.7; x 800
Fig.6:	Sample No. R-21(1); coord. 104.8x27.9; x 800
7.	*Veryhachium reductum* (Deunff) Downie & Sarjeant, 1965
	Sample No. R-8(0); coord. 102.4x69
8.	*Veryhachium* sp.cf. *V. wenlockium* (Downie) Downie & Sarjeant, 1964
	Sample No. R-8(0); coord. 103.4x69.6
9.	*Multiplicisphaeridium ornatum* Pothe de Baldis, 1971
	Sample No. R-3(1); coord. 107.6x26.3; x 800
10,11 12&13	*Tetradinium* sp. Vavrdova, 1973
Fig.10:	R-21(0); coord. 108x52.5
Fig.11:	R-21(5); coord. 96.6x26.7
Fig.12:	R-21(5); coord. 93x31.3
Fig.13:	R-47(0); coord. 99.7x59.3
14.	*Micrhystridium equispinosum* Turner, 1984
	Sample No. R-8(0); coord. 103.5x41
15,16 17&20	*Polygonium gracile* (Vavrdova) Jacobson & Achab, 1985
Fig.15:	Sample No. R-47(1); coord. 91.5x37.2; x 800
Fig.16:	Sample No. R-8(1); coord. 92.4x42.5; x 800
Fig.17:	Sample No. R-12(1); coord. 96x46.5; x 800
Fig.20:	Sample No. R-8(0); coord. 102.5x51.4
18.	*Dasydiacrodium* sp. cf. *D. longicornutum* Gorka, 1967
	Sample No. R-8(0); coord. 105.1x38
19.	*Acanthodiacrodium rotundatum* Gorka, 1967
	Sample No. R-21(5); coord 93x48.3
21.	*Cymatiosphaera* sp. cf. *C. celtica* Deunff, 1958
	Sample No. R-8(0); coord. 104.4x59.4
22.	*Leiofusa bernesgae* Cramer, 1964a
	Sample No. R-8(0); coord. 104.3x70.6
23.	*Polygonium* sp. (Vavrdova) Sarjeant & Stancliffe, 1994
	Sample No. R-43(2); coord. 101.7x32.1; x 800
24.	*Stelliferidium redonense* (Paris & Deunff) Deunff *et al.*, 1974
	Sample No. R-10(1); coord. 105x39.4; x 800

Plate - 4

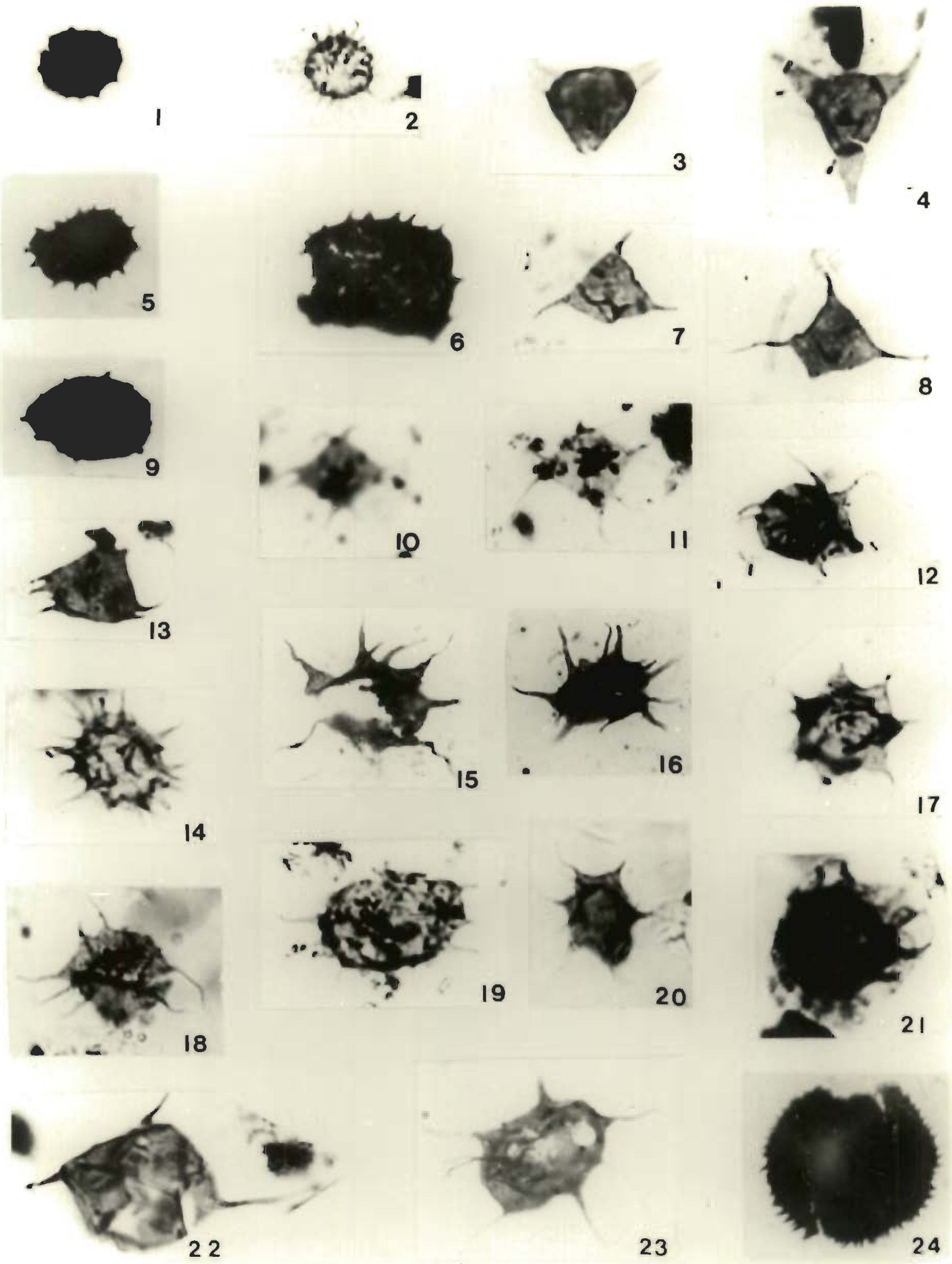


Plate-5

(All the magnification x 2000 approx., unless otherwise mentioned)

Figs.

1,2,6, 9&10.	*Dorsennidium minutum* (Downie) Sarjeant & Stancliffe, 1994
Fig.1:	Sample No. R-8(0); coord. 102.9x62.3
Fig.2:	Sample No. R-8(0); coord. 103.7x65
Fig.6:	Sample No. R-8(0); coord. 105.2x28.7
Fig.9:	Sample No. R-8(0); coord. 104.3x69.7
Fig.10:	Sample No. R-8(0); Coord. 104.8x50.4
3.	*Veryhachium oklahomense* Loeblich, 1970 Sample No. R-8(0); coord. 106x30.5
4,5&7.	*Neoveryhachium* sp. (Cramer) Sarjeant & Stancliffe, 1994
Fig.4:	Sample No. R-47(0); coord. 93.8x52.8
Fig.5:	Sample No. R-8(0); coord. 98.7x37.6
Fig.7:	Sample No. R-8(0); coord. 98.7x37.6
8.	*Dorsennidium europaeum* (Stockmans & Williere) Sarjeant & Stancliffe, 1994 Sample No. R-8(0); coord. 103.8x66.8
11.	*Dorsennidium* sp. (Wicander) Sarjeant & Stancliffe, 1994 Sample No. R-8(0); coord. 106.1x29.2
12.	*Veryhachium* sp. (Deunff) Sarjeant & Stancliffe, 1994 Sample No. R-8(0); coord. 109.8x62.2
13.	*Stellechinatum celestum* (Martin) Turner, 1984 Sample No. R-21(5); coord. 111x33.7
14.	*Veryhachium valiente* Cramer, 1964 Sample No. R-8(0); coord. 105.2x28.7
15.	*Veryhachium longispinosum* Jardine et al., 1974 Sample No. R-8(0); coord. 105.1x37.2
16.	*Veryhachium calandrae* Cramer, 1970 Sample No. R-50(1): coord. 111.6x63.3
17.	*Veryhachium lairdii* (Deflandre) Deunff ex. Downie, 1959 Sample No. R-21(5); coord. 98.3x29

Plate-5

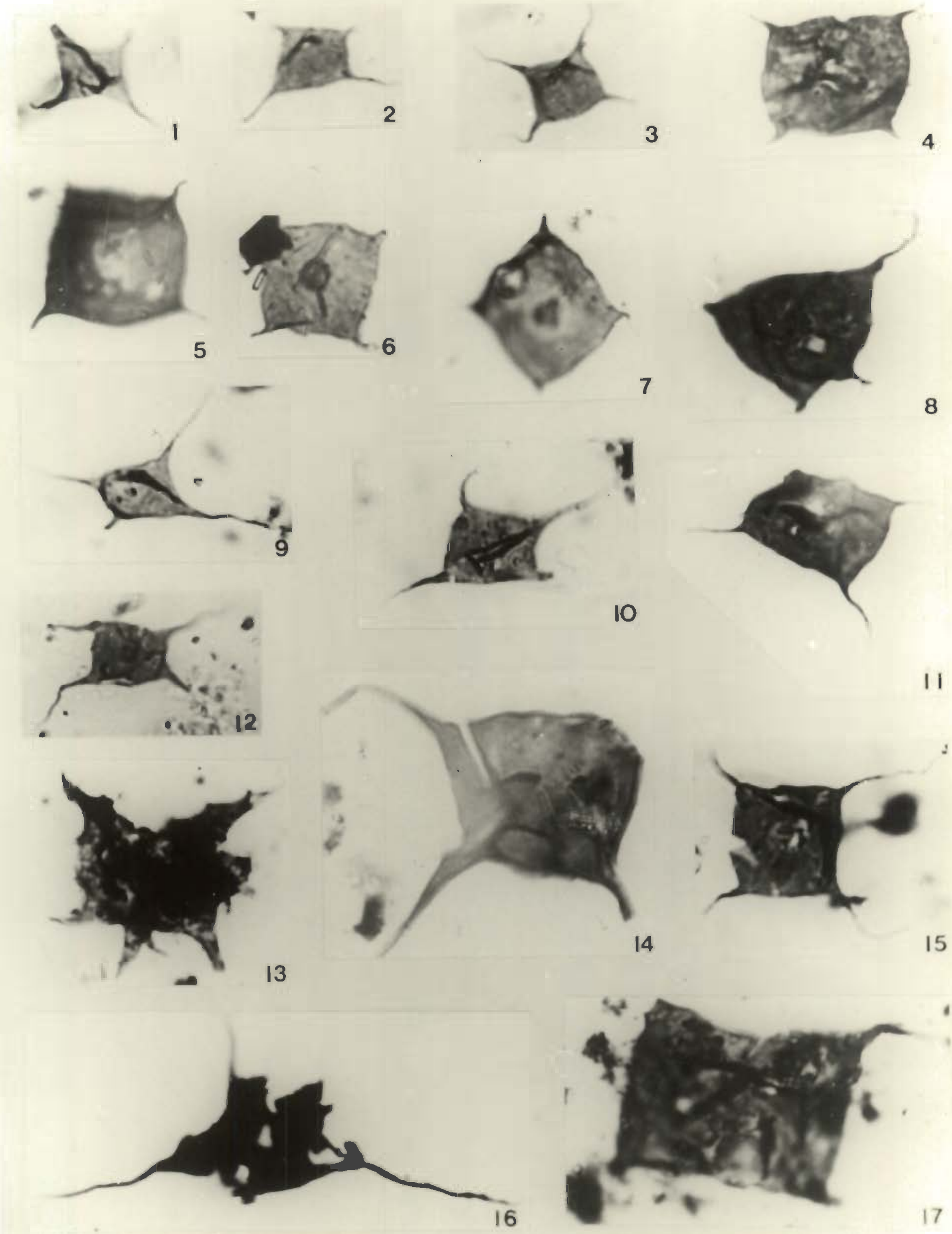


Plate-6

(All the magnification x 2000 unless otherwise mentioned)

Figs.

1-5.	*Deunffia monospinosa* Downie, 1960
Fig. 1:	Sample No. R-8(0); coord. 99.9x63.9
Fig. 2:	Sample No. R-8(0); coord. 99.4x63.1
Fig. 3:	Sample No. R-8(0); coord. 102.6x69.4
Fig. 4:	Sample No. R-8(0); coord. 94.7x47.9
Fig. 5:	Sample No. R-8(0); coord. 106.4x48.7
6&10	*Geron* sp. cf. *G. amabilis* Cramer, 1969
Fig. 6:	Sample No. R-8(0); coord. 106x67.7
Fig.10:	Sample No. R-8(0); coord. 97x40
7.	*Deunffia brevispinosa* Downie, 1960
	Sample No. R-8(1); coord. 100.5x59.9; x 800
8.	*Dactylofusa oblancae* (Cramer & Diez) Cramer, 1970
	Sample NO. R-47(0); coord. 93.6x51.2
9&17	*Leiofusa parvitatis* Loeblich, 1970
Fig. 9:	Sample No. R-8(0); coord. 106.7x32.6
Fig.17:	Sample No. R-47(0); coord. 94.8x47.8
11&12	*Geron* sp. Cramer, 1967
Fig.11:	Sample No. R-8(0); coord. 100.1x34.5
Fig.12:	Sample No. R-8(0); coord. 107.4x49.6
13.	*Leiofusa* sp.
	Sample No. R-8(0); coord. 105x50.2
14.	*Domasia limaciforme* (Stockmans & Williere) Cramer, 1970
	Sample No. R-39(0); coord. 107.2x69.9
15.	*Eupoikilofusa* sp. Cramer, 1970
	Sample No. R-8(0); coord. 104.8x36.1
16.	*Leiofusa algerensis* Cramer, 1970
	Sample No. R-8(0); coord. 105.5x37.6
18.	*Acanthodiacrodium simplex* combaz, 1967
	Sample No. R-8(0); coord. 102.4x39.6
19.	*Deunffia monacantha* Deunff, 1951
	Sample No. R-8(2); coord. 92.2x64.3; x 800
20&21	*Domasia trispinosa* Downie, 1960
Fig. 20:	Sample No. R-8(0); coord. 97x27.6
Fig. 21:	Sample No. R-8(0); coord. 97x27.6; x 2800
22.	*Domasia algerensis* (Cramer) Hill, 1974
	Sample No. R-8(0); coord. 100.6x34.3
23.	*Domasia* sp.
	Sample No. R-47(0); coord. 94.7x40.4
24&25	*Leiofusa bernesgae* Cramer, 1964a
Fig. 24:	Sample No. R-8(0); coord. 94.1x55.5
Fig. 25:	Sample No. R-8(0); coord. 104.7x65.5

Plate - 6

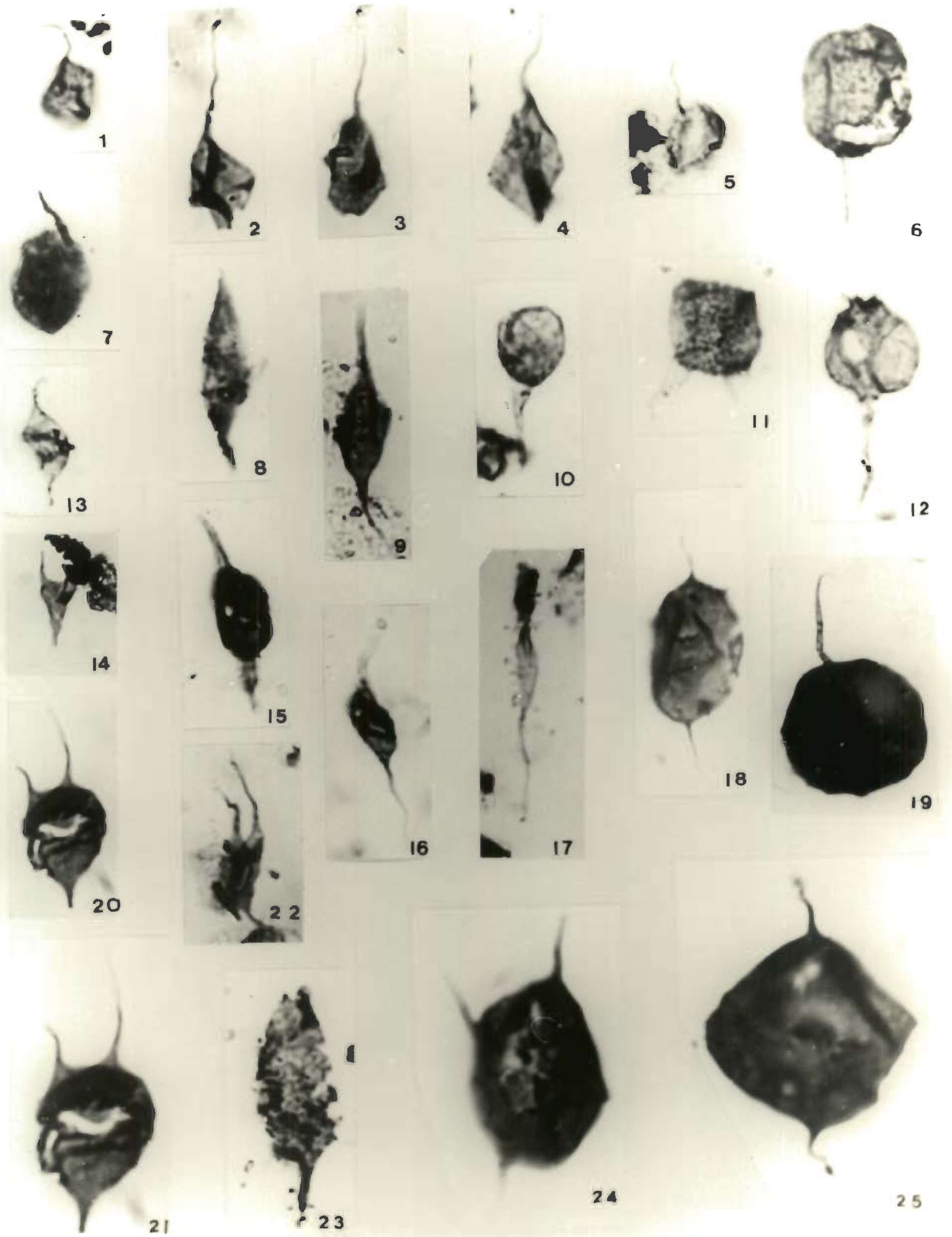


Plate-7

(All the magnification x 2000 unless otherwise mentioned)

Figs.

1 & 5.	*Baltisphaeridium longispinosum* var. *longispinosum* Eisenack, 1959
Fig.1:	Sample No. R-5(2); coord. 103x33.5
Fig.5:	Sample No. R-5(1); coord. 99.7x27.8
2.	*Leiofusa elenae* Cramer, 1964a Sample No. R-15(1); coord. 100.7x49.8
3.	aff. *Orthosphaeridium* sp. (Eisenack) Kjellstrom, 1971 Sample No. R-50(1); coord. 111x57.3
4.	*Stellechinatum* sp. Sample No. R-47(3); coord. 108x49.4; x 800
6.	*Baltisphaeridium longispinosum* subsp. *delicatum* Turner, 1984 Sample No. R-5(2); coord. 100.5x33.5

Plate-7

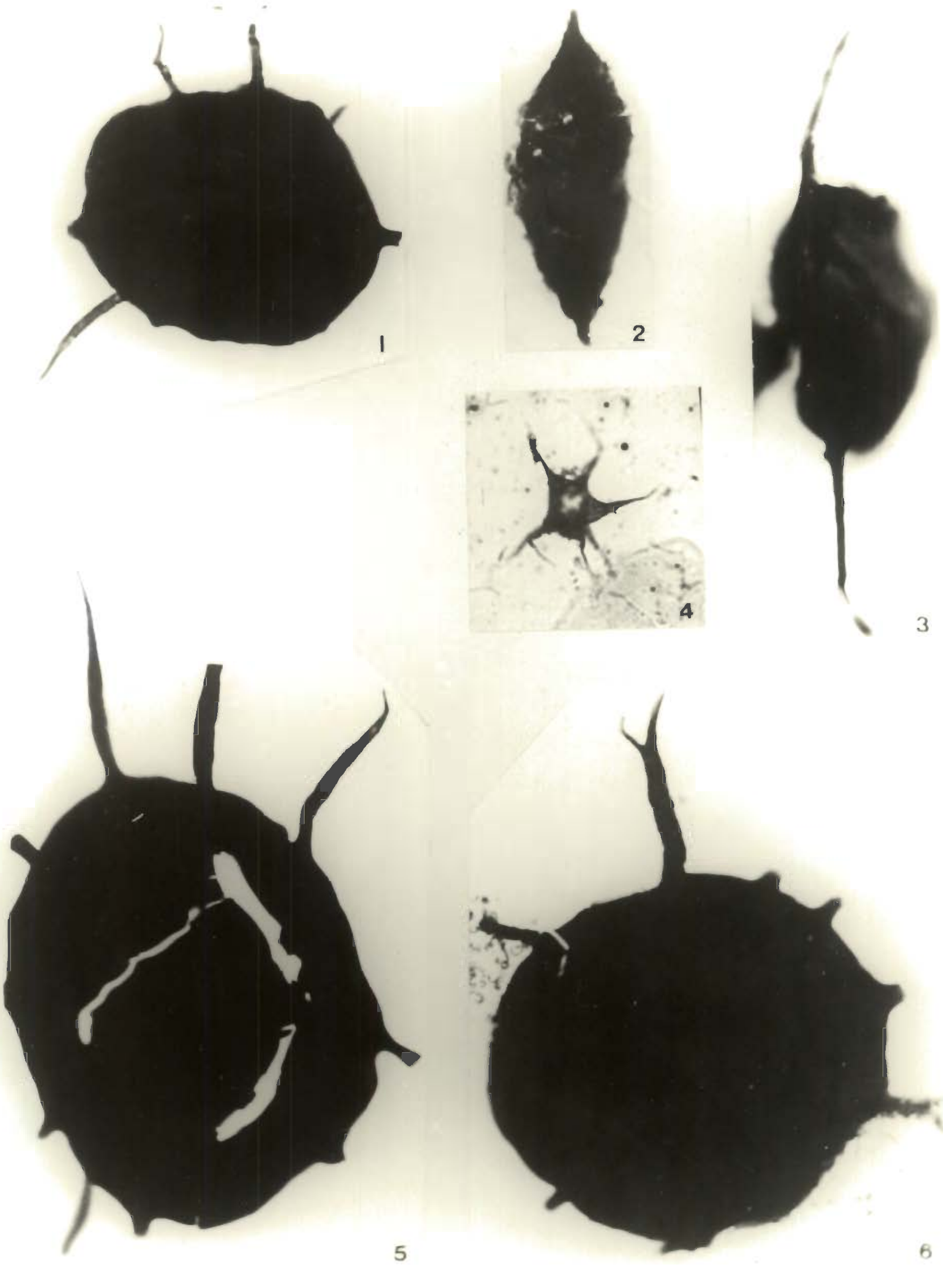


Plate-8

(All the magnification x 2000 unless otherwise mentioned)

Figs.

1 & 2.	*Impluviculus* sp. cf. *I. stellum* Rasul, 1979
Fig. 1:	Sample No. R-8(0); coord. 104.4x66.2
Fig. 2:	Sample No. R-8(0); coord. 104x59.3
3.	*Villosacapsula* sp. cf. *V. setosapelliculum* Loeblich, 1970
	Sample No. R-8(0); coord. 103.3x69.3
4.	*Villosacapsula* sp. cf. *V. entrichos* Loeblich, 1970
	Sample No. R-8(0); coord. 103.3x30
5.	*Cymatiosphaera* sp.
	Sample No. R-8(1); coord. 94.2x44.4
6.	*Leiosphaeridia viswanathiae* (Maithy & Shukla) Viswanathiah *et al.*, 1980
	Sample No. R-8(2); 104.7x46.5
7 & 11.	*Ancyrochitina* sp.
Fig. 7:	Sample No. R-20(1); coord. 93.9x51; x 800
Fig.11:	Sample No. R-20(1); coord. 93.9x51; x 1000
8.	*Desmochitina* sp.
	Sample No. R-40(1); coord. 95.1x35.8
9.	*Aremoricanium* sp. cf. *A. simplex* Loeblich & MacAdam, 1971
	Sample No. R-8(1); coord. 94.7x23.8
10.	*Multiplicisphaeridium* sp.
	Sample No. R-8(1); coord. 99.6x42
12.	*Conochitina* sp.
	Sample No. R-21(5); coord. 94.7x27.7; x 800
13.	*Lophosphaeridium* sp.
	Sample No. R-12(1); coord. 92.1x65
14.	*Helosphaeridium* sp. cf. *H. clavispinulosum* Lister, 1970
	Sample No. R-21(5); coord. 94.1x73
15.	*Bavlinella* sp.
	Sample No. R-8(2); coord. 106.8x29.5
16.	*Cymatiogalea* sp.
	Sample No. R-21(5); coord. 95.2x36.5
17.	*Lophosphaeridium parvum* stockmans & Williere, 1963
	Sample No. R-21(1); coord. 108.5x41.7

Plate - 8

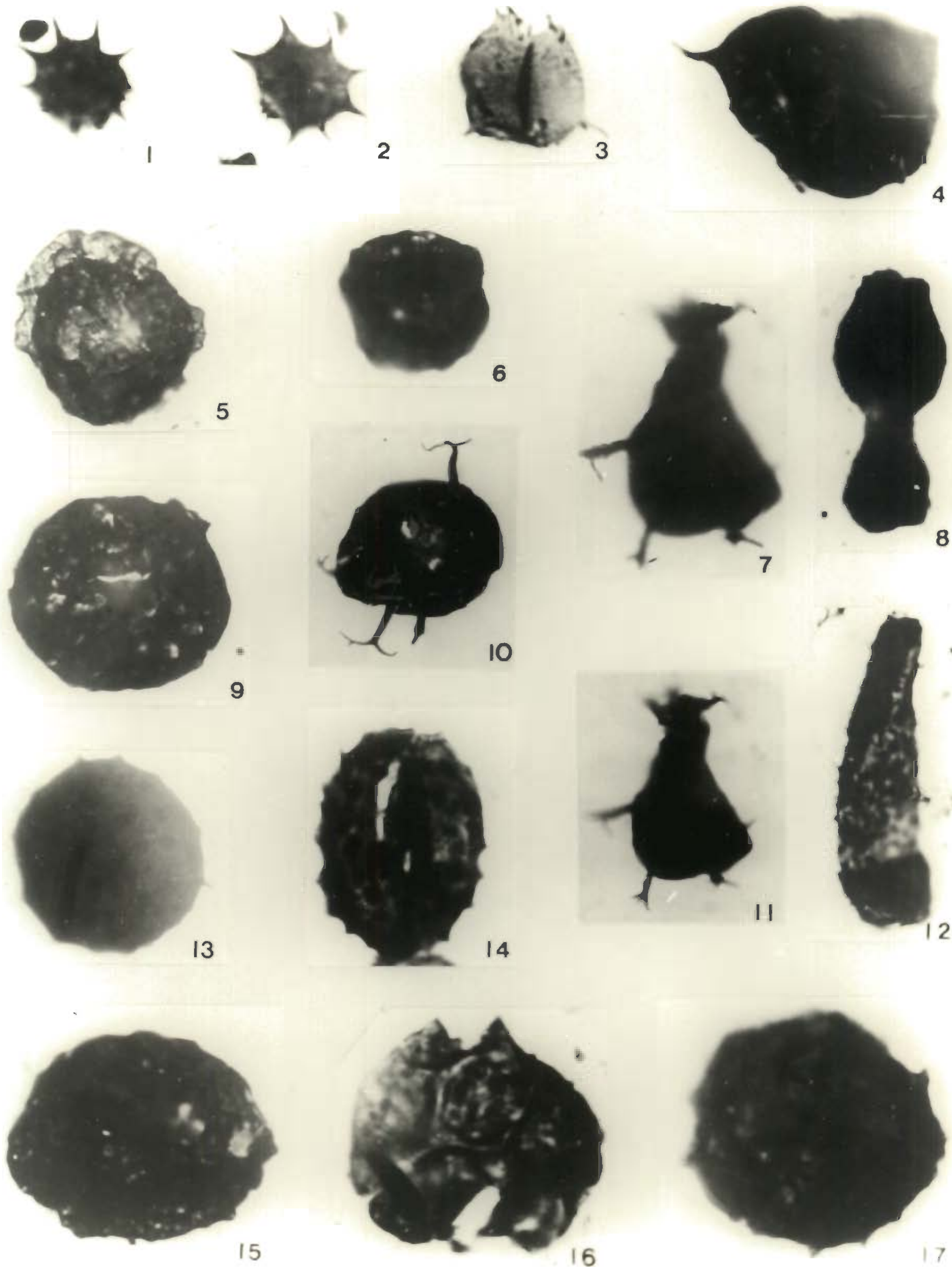


Plate-9

(SEM - Photographs)

Figs.

1 & 2.	Melanosclerite
Fig. 1:	Sample No. R-43; x 750
Fig. 2:	Sample No. R-41; x 750
	(Not hollow)
3.	aff. *Conochitina* sp. (broken)
	Sample No. R-43; x 500
4 & 4a.	Melanosclerite
Fig. 4:	Sample No. R-43; x 750
Fig. 4a:	Showing thickness of the wall of fig.4 x 1500
5 & 5a.	Looks like a *Bursachitina* sp. but is likely a melanosclerite
Fig. 5:	Sample No. R-41; x 750
Fig. 5a:	tilted view; x 750
6.	Fragment of melanosclerite
	Sample No. R-42; x 750
7 & 7a.	Melanosclerite
Fig. 7:	thick wall; x 1500
Fig. 7a:	Sample No. R-41; x 500

Plate-9

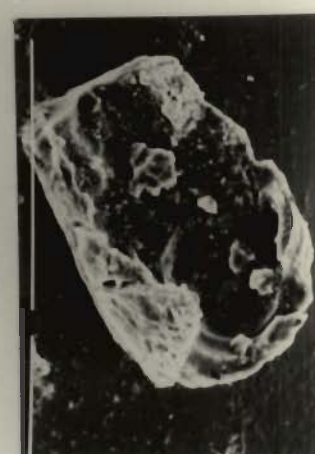

1


2

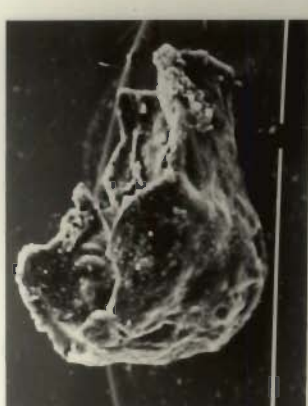

3

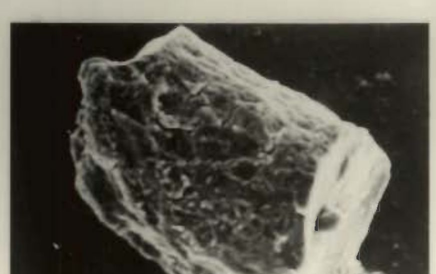

4


4a


5


7


5a


6


7a

Plate-10

Photomicrograph-1 :	Calcareous quartz arenite showing line to sutured contact fabric. Fragment of mollusca is coated with siderite and the concentration is mostly along the grain boundary. (Sample No. R-11; x 35, CN)
Phoromicrograph-2 :	Very fine to fine grained calcareous quartz arenite. Sparitised algae is associated with the sandstone. (Sample No. R-12; x 17, CN)
Photomicrograph-3 :	Very fine to fine grained calcareous quartz arenite, containing sparitised bryozoa fragments. (Sample No. R-12; x 35, CN)
Photomicrograph-4 :	Ferruginised and micritised molluscan shell fragments in siltstone. (Sample No. R-10; x 35, CN)

Plate-10

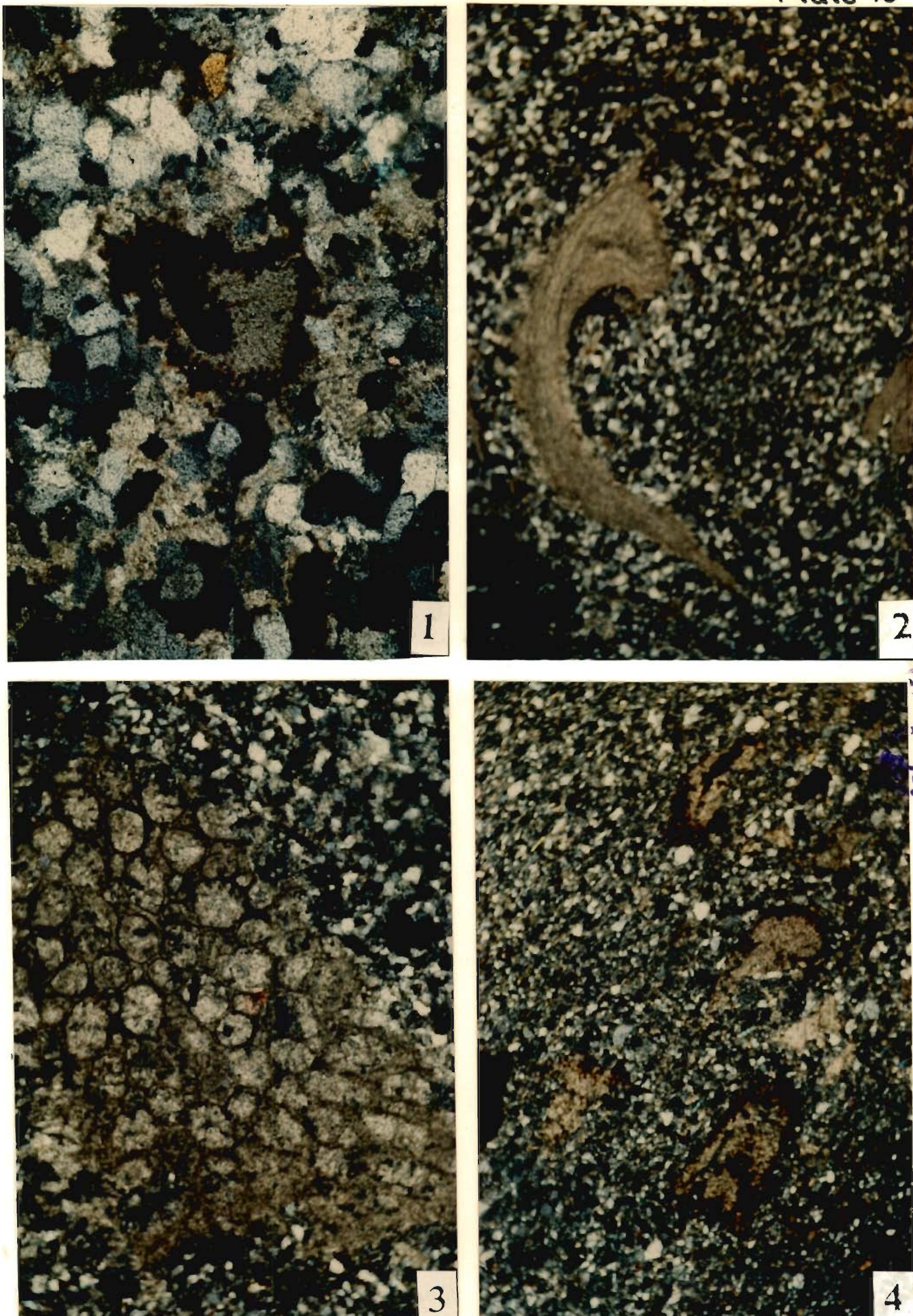


Plate-11

Photomicrograph-1 :	Solution seam along micritised algae and clay/sand clasts in alterantion of siltstone and siltyshale. (Sample No. R-17; x 35, CN)
Photomicrograph-2 :	Packstone with glauconite. The individual grains are showing coatings of iron oxide and glauconite. (Sample No. R-9; x 35, CN)
Photomicrograph-3 :	Ribbon shaped feature indicating the filling of algal filament by pyrite in packstone and leaching of iron around and within the grain indicate post depositional phenomenon. (Sample No. R-9; x 35, PP)
Photomicrograph-4 :	Packstone showing corrosion of grains by calcareous matter. Cubical and disseminated pyrites are also associated with packstone. (Sample No. R-19; x 35. CN)

Plate-11

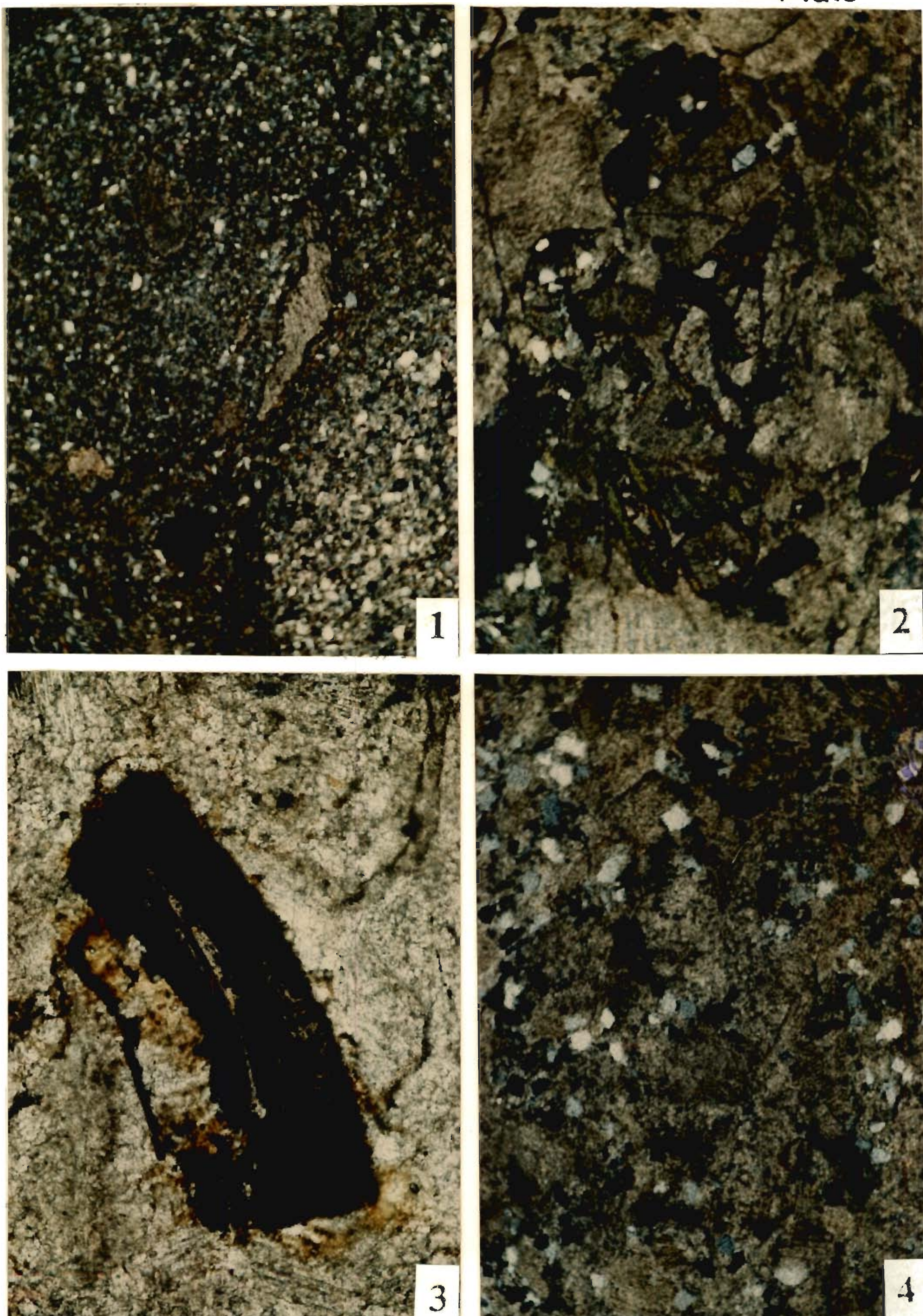


Plate-12

Photomicrograph-1 :	Boundstone (algal) showing cellular type of algae. Boundstone is arenaceous in nature. (Sample No. R-2; x 35, CN)
Photomicrograph-2 :	Micritised/sparitised bryozoa and algae are associated with siltyshale. (Sample No. R-21; x 14, CN)
Photomicrograph-3 :	Micritised bioclasts subsequently sparitised (rims). The wackstone (bioclast) seems to be fractured which are filled with the residual solution (iron oxide) indicating post depositional feature. (Sample No. R-42; x 14, CN)
Photomicrograph-4 :	Showing conodonts and solution seams in wackstone (bioclast). (Sample No. R-41; x 35, CN)

Plate -12

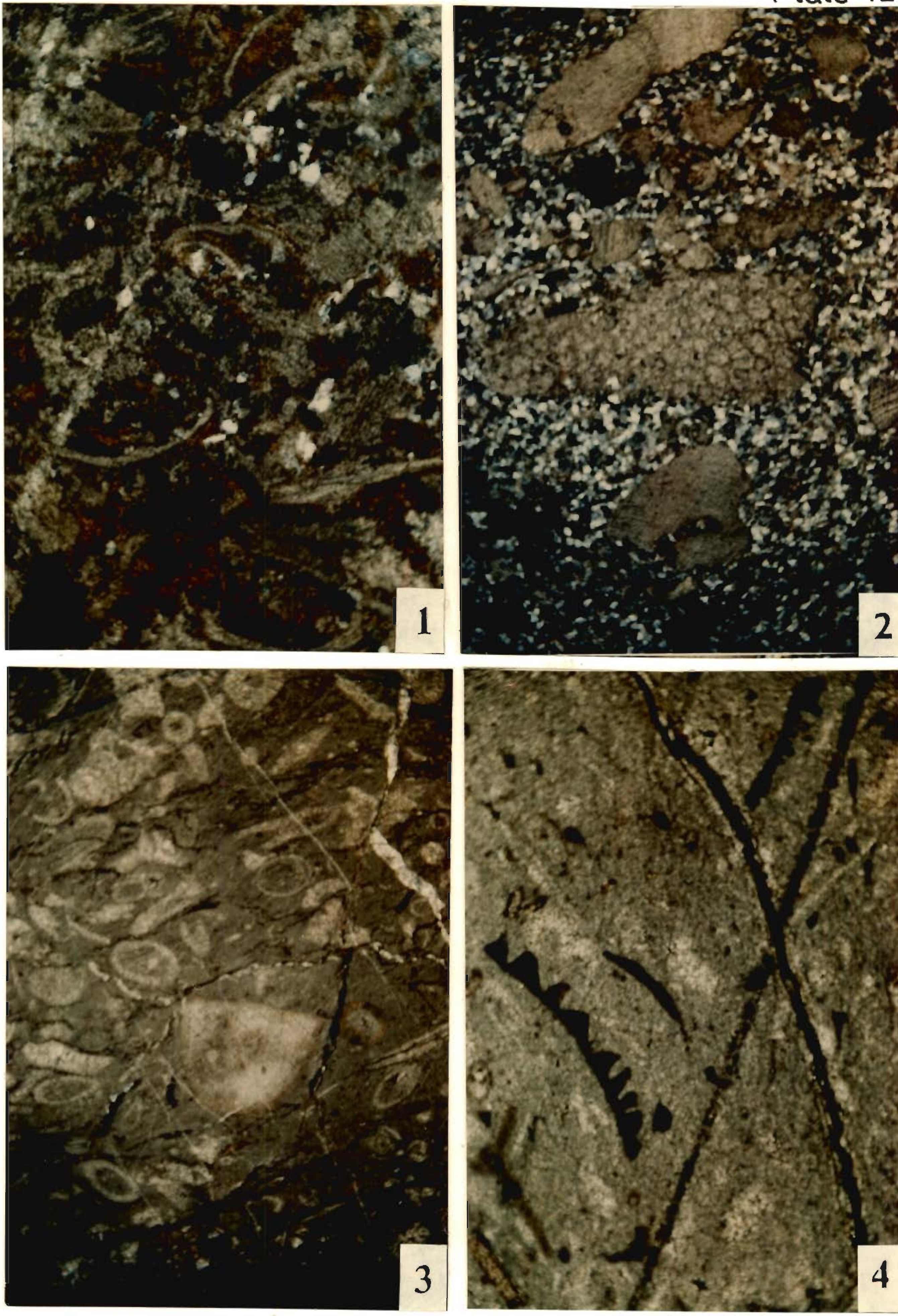


Plate-13

Photomicrograph-1 :	Showing micritised chitinozoa (?) in wackstone (bioclast), along with solution seams and pyrite grains. (Sample No. R-52; x 35, PP)
Photomicrograph-2 :	Showing dendritic pattern of stylolites in wackstone (bioclast). The bioclasts are initially micritised and subsequently sparitised. (Sample No. R-50; x 35, CN)
Photomicrograph-3 :	Showing microfault being filled by solution seam of dendritic nature in wackstone (bioclast). (Sample No. R-49; x 14, CN)
Photomicrograph-4 :	Solution seams in wackstone (bioclast). The algal peloid is showing rim-cementation of different shape. (Sample No. R-54; x 35, CN)

Plate-13

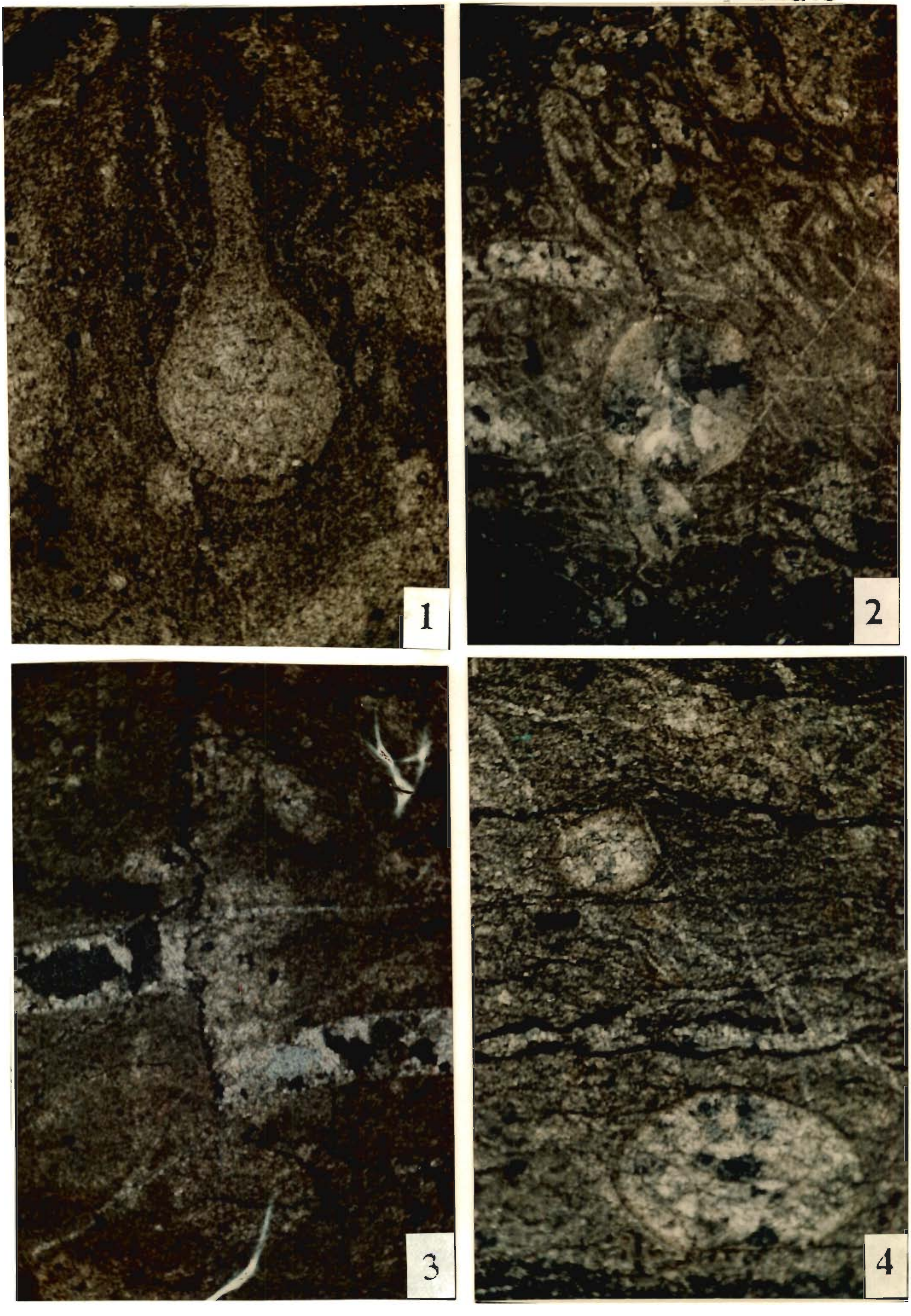


Plate-14

Photomicrograph-1 : Peloides showing rim cementation by

(i) Chert (cortical),
(ii) ferruginised micrite,
(iii) micrite with sparite in argillaceous nature of wackstone (bioclast).

(Sample No. R-49; x 70, CN)

Photomicrograph-2 : Solution seam along equant dolomite grain boundaries.
(Sample No. R-28; x 35, CN)

Photomicrograph-3 : Algal peloids; algae (sparitised) in highly fractured wackstone. The fractures are filled with iron-oxides.
(Sample No. R-55; x 35, CN)

Photomicrograph-4 : Showing micritised criss-cross vein in mudstone (argillaceous) i.e., fractures refilled.
(Sample No. R-57; x 14, CN)

Plate-14

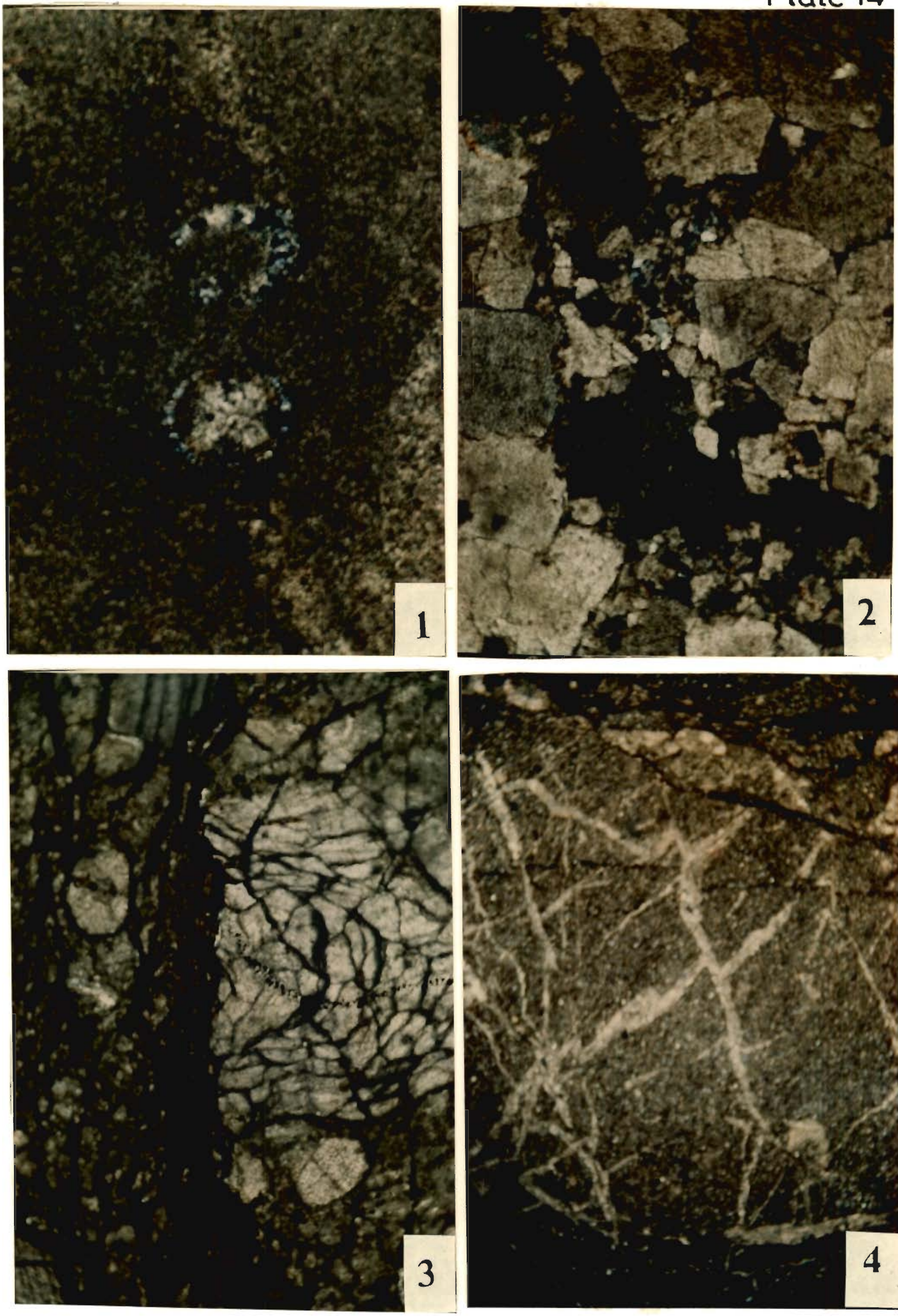
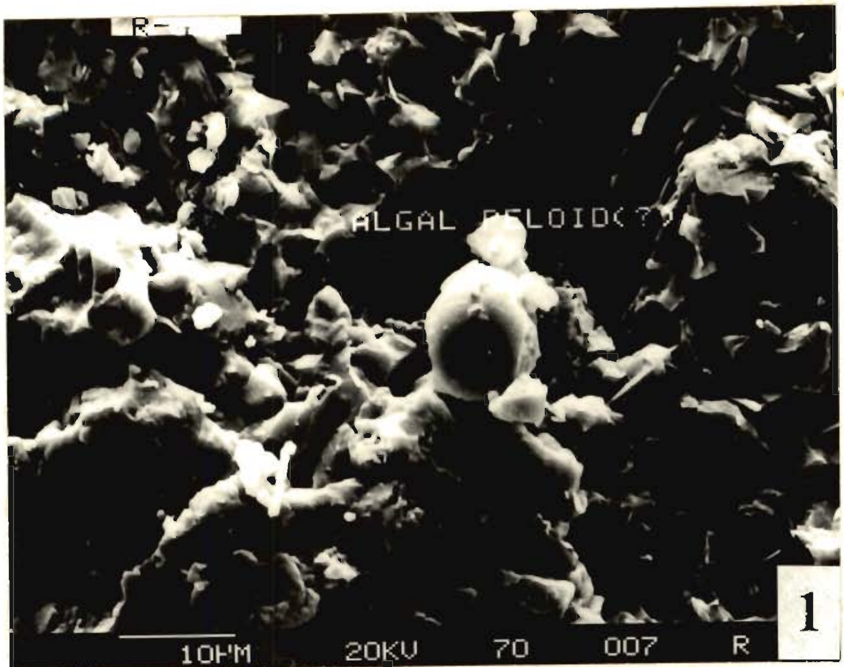
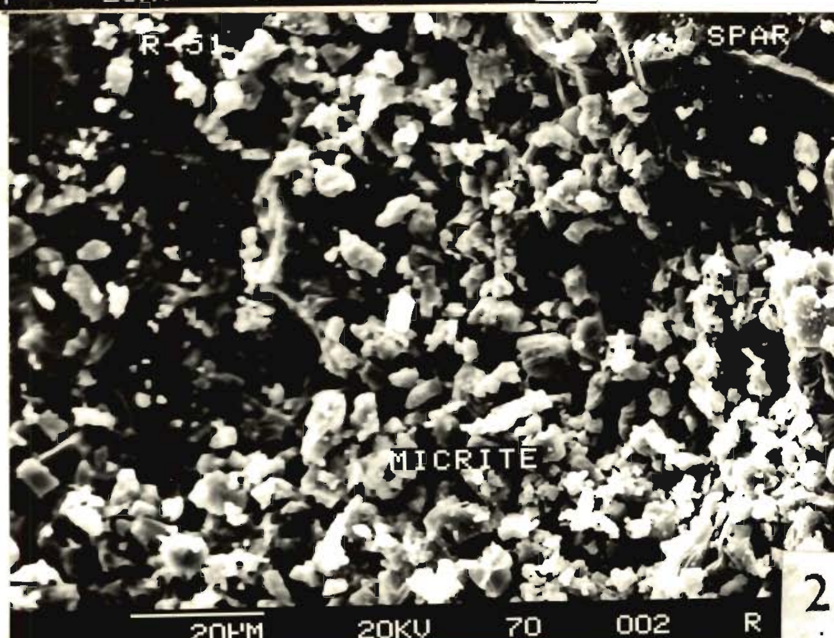


Plate-15


ALGAL
10µM 20KV 70 007 R
1


SPAR
MICRITE
20µM 20KV 70 002 R
2

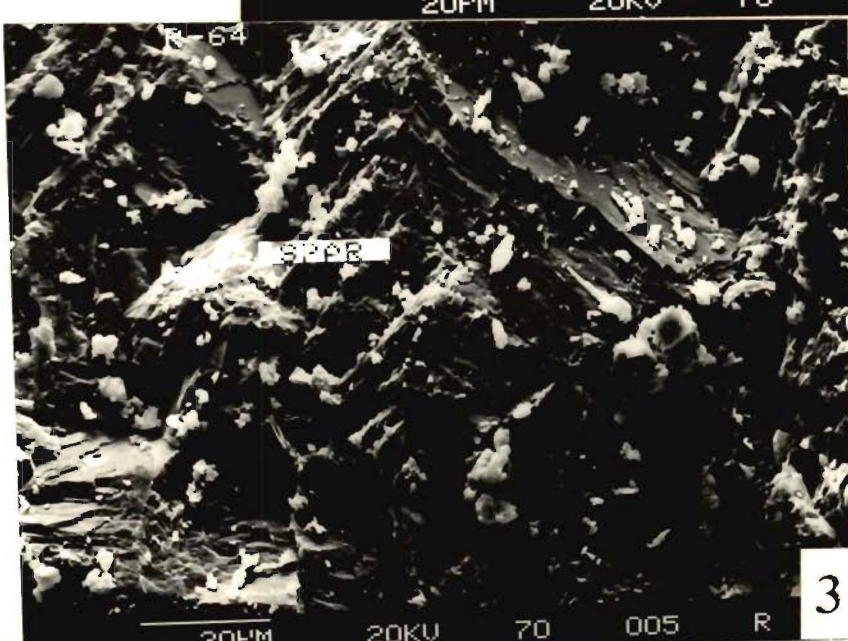
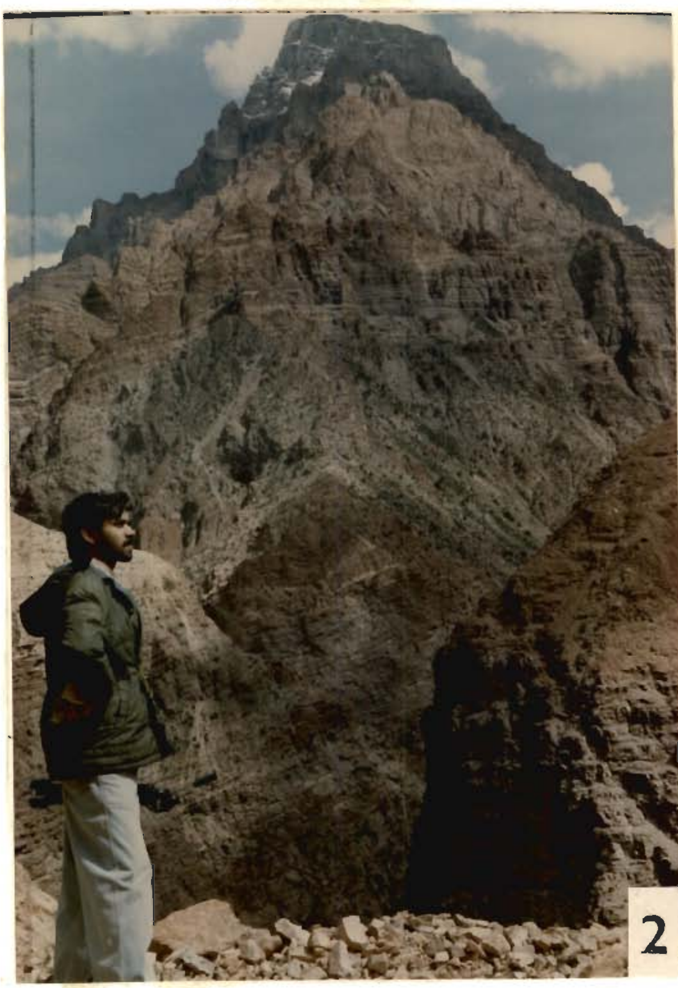

R-64
20µM 20KV 70 005 R
3

Plate-16

Fieldphotograph-1:	Looking N 160°. Sandstone and subordinate limestone of the Garbyang Formation. Location : Malari-Sumna mule track, 25.475 Km. pt.
Fieldphotograph-2:	A panoromic view of study area. Rocks of the Garbyang, Variegated and Muth formations are demarcated by change in colour. Location : Malari- Sumna mule track, 19 Km. pt.
Fieldphotograph-3:	Mule track on the Garbyang Formation and the Girthiganga river. Location : Malari- Sumna mule track, 21 Km. pt.

Plate-16

1



2

3

Plate-17

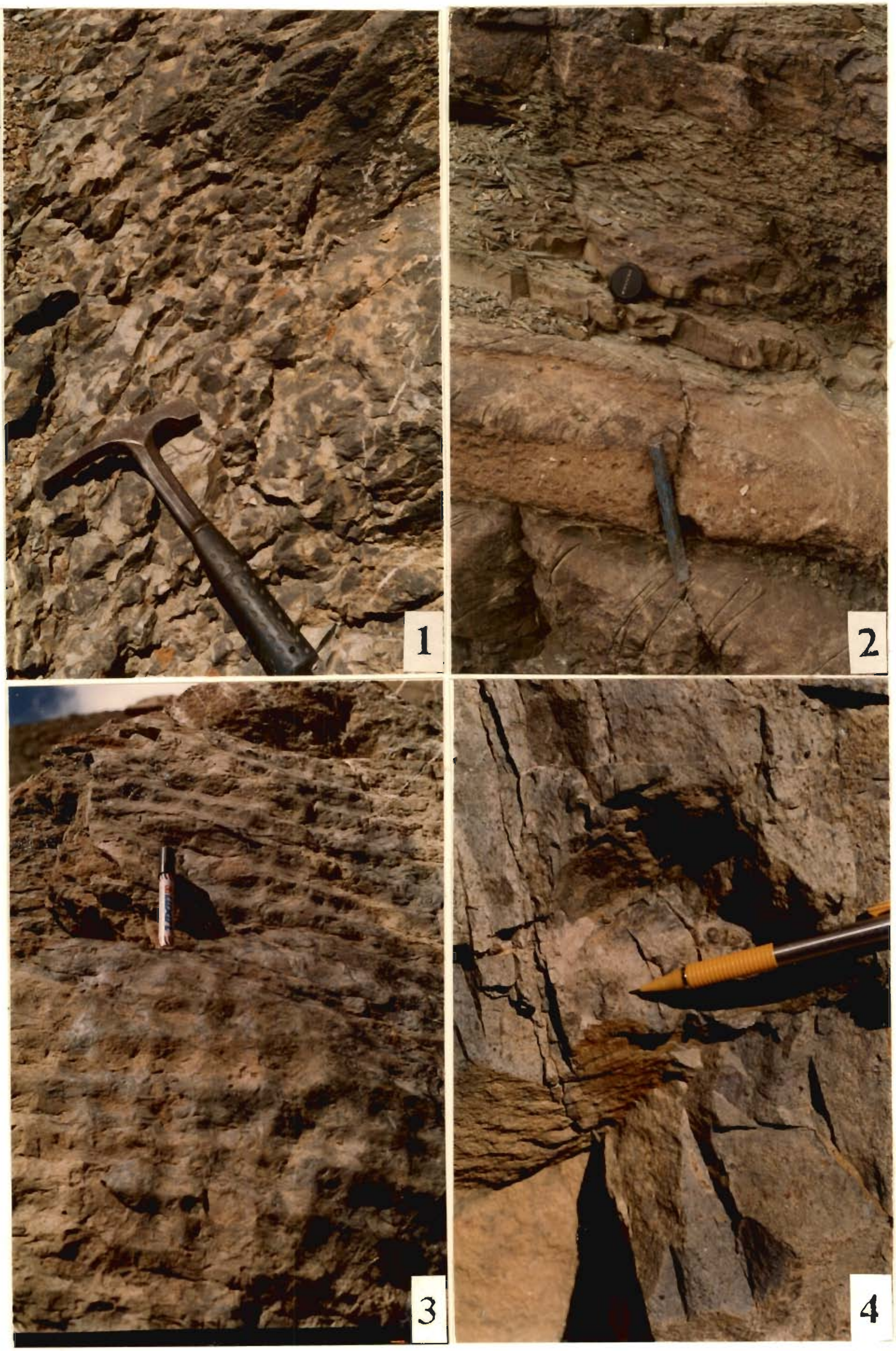


Plate-18

Fieldphotograph-1:	Looking N 158°. Rhythemic alternation of sandstone and shale in the Shiala Formation. Location: Sumna-Rimkhim mule track, 2.310 Km. pt.
Fieldphotograph-2:	Looking N 320°. Black and weathered limestone of the Yong Limestone Formation. Location: Sumna-Rimkhim mule track, 3.700 Km. pt.
Fieldphotograph-3:	Looking N 335°. Hot spring on the bank of the Yong Gad (river). Location: Sumna-Rimkhim mule track, 4.155 Km. pt.

Plate-18


1


2


3

AUTHOR'S CLARIFICATIONS AND MODIFICATIONS AS SOUGHT BY THE OVERSEAS EXAMINER ON THE PH.D. THESIS ENTITLED " ACRITARCH BIOSTRATIGRAPHY OF THE ORDOVICIAN-SILURIAN SEQUENCE ALONG SUMNA-RIMKHIM SECTION, TETHYAN GARHWAL HIMALAYA, CHAMOLI DISTRICT, UTTAR PRADESH

By

H.N. SINHA

Title - The word "Tethyan" for the sequence treated has been used after consulting all the available literature dealing with the nomencultural terms pertaining to the Himalaya. The term "Tethyan Zone" was proposed by Auden (1937) as mentioned on page 5.

Figs. 1&2 : Figure 1 is after Gansser, 1964 and Figure 2 is after A.K. Sinha, 1985. These figures have been included as such, without incorporating chronostratigraphic information on the rock units in the legends, so as to refer the work of these two pioneers on the geology of the area, in original.

Page 7 : Emended as suggested. Please see the Errata attached.

Page 21 : Top para : The para should read as "Shah and Sinha (1974) delineated the lower boundary of this formation on the basis of the first appearance of *Calostylis* occurring in green nodular biohermal limestone. The *Rafinesquina* bearing calcareous sandstone of the Shiala underlies the biohermal limestone".

Page 33 : Laboratory methodology adopted for sample preparation

Following steps were followed :

1. About 50 g sample was taken, and washed with distilled water to make it free from atmospheric contamination.

2. **Removal of carbonates** : Samples were broken in pestle and mortar upto a size of 2-3 mm granules and transferred to a 500 ml. propylene beaker (propylene beaker can withstand a temperature upto 160^{o}C and also treatment with HF acid). 10% HCl acid was added drop by drop to check the presence of carbonates. Treatment was continued till effervescence ceases.

3. **Removal of silicates** : After complete removal of carbonates, the residue was treated with 40% HF acid for removal of silicates. Treatment was done inside the fume chamber.

4. **Oxidation of unwanted organic debris** : This was done by using Nitric acid.

5. **Washing** : The macerated and decomposed material was centrifuged by adding distilled water at 2000 rpm for 30 minutes. This was repeated 3-4 times. Finally, the tube was inverted over blotting paper for maximum removal of liquid from the residue.

6. **Heavy liquid separation** : Heavy liquid was made by using KI, CdI_2 and ZnI. This heavy liquid was added to the residue and allowed for homogenization for better separation. Centrifuge between 800-900 rpm was done for 30 minutes. The supernatant liquid was decanted in a glass beaker and diluted with little glacial acetic acid.

7. **Seiving** : Recovered material after heavy liquid separation was filtered through 10 micron nylon monofilament. The fossil rich residue was washed from the screen with water into the 15 ml glass centrifuge tube.

8. **Preparation of permanent slides** : In the residue, 2 or 3 drops of polyvinyl alcohol was added and mixed thoroughly and smeared over coverslip, dried at 60°C over hot plate, mounted with Canada Balsam and kept for 20 minutes over hot plate at 80°C.

Page 34 : The text-figures were prepared for important and dark forms in the laboratory for morphological details. However, all of them got damaged due to carelessness of one of the laboratory staff. Time constraint did not allow to prepare the same, once again, as it is a time consuming process.

Page 43 : As mentioned on page 10 of the thesis, the lithostratigraphy proposed by Shah and Sinha, 1974, has been retained as it is in the present work because no need to emend the same was felt necessary after detailed field-work. Though it is true that the Yong Formation is a rock unit. However, the acritarch occurrence, especially indicative of age, is the basis of revision of the Ordovician-Silurian boundary.

Page 57 : Accepted the suggestion given by the examiner.

Page 58 : Corrections made. Please see the Errata attached.

Page 58-61 : Accepted the suggestion given by the examiner.

Page 64 : I have examined the specimen of *Bavlinella* and found the presence of pyrite crystals on the cyst wall, which hinders the identification upto specific level. However, the generic characters of the vesicle seem to be of genus *Bavlinella*.

The examiner has rightly enquired whether the sculpturing on the vesicle wall is of foveolate type. This was examined under the microscope but foveolate appears rather obscure.

Page 65 and in many other places :

The original description of the genus/ species was emended and extended by subsequent author(s); the emended concept was carefully studied, compared, examined and then the morphology of the Tethyan specimens was written in the text while working on the Systematics of the acritarch.

Page 83 : The ages given have been taken as such from the following (as given under References):

(1) Eisenack, A. Cramer, F.H. and Diez.C.R. (1979); Band V, page 487-488.

(2) Downie, C. (1958) : page 331-350.

Page 109 : Reference : Turner, R.E. (1984) : page 141-142.

Explanation : *V. lairdii* was proposed by Deunff 1959 but the genus *Veryhachium* was itself technically invalid until a type species was subsequently designatged (Downie, 1959, page 62).

Page 110 : As indicated by Fensome et al. (1990, p 517), the name *lairdii* was not validly published until 1970. Since, Deunff's publication of the combination V. *lairdii* did not include indication of holotype and was thus not valid. Therefore, *V. lairdii* must be treated as the taxonomically junior synonym of the *V. valiente* Cramer, 1964, p. 311 (Sarjeant & Stancliffe, 1994).

Page 115 : It is true that the specimen is very small (size 14 μm at maximum length) but the morphological characters are same as that of *V. setosapelliculum* Loeblich 1970. This type species recombined as *Villosacapsula setospellicula* (Loeblich) Loeblich and Tappan, 1976. The present specimen should be treated as a distinct, but as it is solitary form in the present assemblage, therefore, a new species cannot be erected, and, therefore, it may be treated as *Villosacapsula* sp.

Page 117 : Taken from Catalogue :

Eisenack, A., Cramer, F.H. and Diez, C.R. (1973): Band III, pp. 257.

Page 122 : Since the Tethyan specimen is relatively smaller (20 μm in length) than the Cramer's 1970 one. However, the other morphological characters are same. Therefore, the Tethyan form of *Dactylofusa* can be closely comparable with *Dactylofusa* sp.cf. *D. oblancae* (Cramer & Diez) Cramer in place of *Dactylofusa oblancae* (Cramer & Diez) Cramer, 1970

Page 127 : The photograph of the specimen got overexposed during photomicrography. The fine sculptural elements are doubtfully present in the same specimen but are clearly visible in the other specimens of the same slide (Slide No. R-8(o):104.2x36.2). The sculptural elements are arranged in a striate pattern parallel to the longitudinal axis. The mistake of not mentioning the sculpture in the text is admitted.

Page 130 : The diagnostic characters of the *Leiofusa algerensis* of the present assemblage are similar to Cramer's species except the size of the vesicle. According to author's observation, the size may be extremely variable depending on the direction of folding during burial and preservational history (Loeblich, 1969).

Reference : Loeblich, A.R. Jr. (1969) : Morphology, ultrastructure and distribution of Paleozoic acritarchs; Proc. North American Paleontological Convention, Part G:705-788.

Page 136 : The mistake of not mentioning the description in the Systematics section of the text is admitted. The following, therefore, is added :

Baltisphaeridium sp.cf. *B. scitulum*

Description: Cyst spherical, dark, matured, measuring 45 μm in diam.; cyst wall laevigate; processes sparsely arranged, 2-3μm long, sharp pointed, broad base; pylome indiscernible.

Comparision: The Tethyan specimen referable to *Baltisphaeridium* closely compares with *B. scitulum* Saluja, Rehman and Arora 1971 (p. 24-33, pp. 2:26,27) described from the Vindhyans of Son valley of Cambrian ? age. However, the Tethyan forms differ from holotype by relatively bigger size range.

Occurrence in study area : Calcareous quartz arenite of the Shiala Formation : Tethyan Garhwal Himalaya, India. R-5(1):102x73; R-5(1):97.5x53.4.

Distribution elsewhere : Upper Vindhyas (Cambrian ?), U.P India (Saluja, Rehman & Arora, 1971).

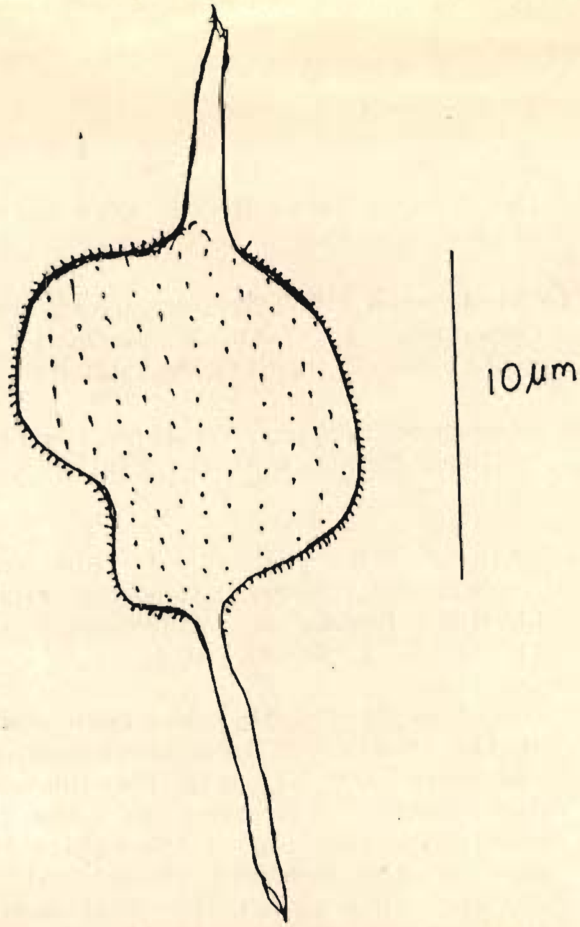
Reference : Saluja, S.K., Rehman, K. and Rawat, M.S. 1971 : Fossil palynomorphs from the Vindhyans of Rajsthan (India). Review of palaeobotany and palynology, V. 11, no. 1, p. 65-83, pl.1.

Page 154 : The concept of Tethys has been dealt on pages 2 to 5 of the thesis. It is not acceptable that the Tethyan sediments are of only Permian and Triassic ages, particularly in view of the occurrence of a continuous sequence of the entire Paleozoic and major part of the Mesozoic in Garhwal, Kumaon and Spiti regions. This is not true that sediments ranging over this period of time in the Tethyan Garhwal region were laid down in a succession of basins, formed under varying tectonic circumstances. Here, the following work may be referred :
Heim and Gansser (1939), Shah and Sinha (1974), Mehrotra and Sinha (1978, 1981), Sinha (1989), Srivastava and Kumar (1992) and others in this connection.

References : 1. Mehrotra, N.C. and Sinha, A.K. (1978) : Discovery of microplanktons and the evidences of the younger age of Sangcha Malla Formation (upper Flysch) of Malla Johar area in the Tethyan zone of the Kumaon Himalaya, Himalayan Geology, 8(2), 1001-1004.

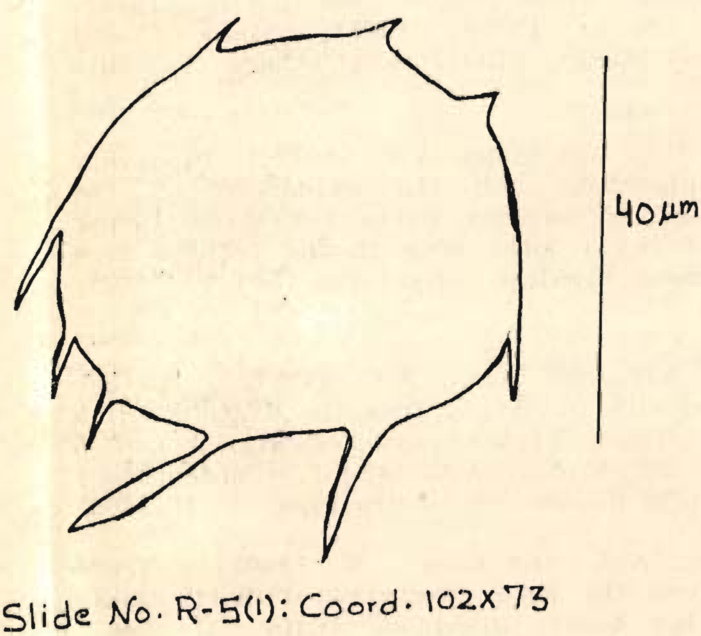
2. Mehrotra, N.C. and Sinha, A.K. (1981) : Further studies on microplanktons from the Sangcha Malla Formation (Upper Flysch) zone of Higher Kumaon Himalaya, in Sinha, A.K. (Ed.), Contemporary Geoscientific Researches in Himalaya, 1, 151-160.

3. Srivastava, A.K. and Kumar, S. (1992) : Trace fossils from the Muth Quartzite of Malla Johar Area, Tethys Kumaon Himalaya, India. Jl. Geol. Soc. Ind., Vol. 40 p. 43-47.

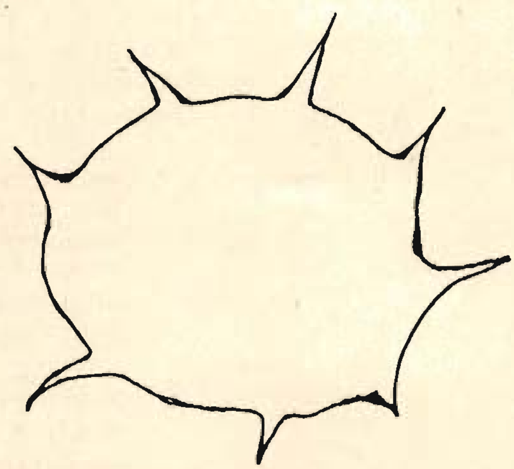


Eupoikilofusa sp., Slide No. R-8(0): Coord. 104.2 x 36.2

(page 127)



Slide No. R-5(1): Coord. 102 x 73



Slide No. R-5(1): 97.5 x 53.4

Baltisphaeridium sp. cf. *B. scitulum*

(page 136)

Errata (Chapter 3 on Systematics) from pp. 64 to 133)

Page No.	Original Author and year of Genus/type species
65.	Genus : Timofeev ex Downie, 1963 Type species: Timofeev ex Downie, 1963
67.	Genus : Eisenack, 1958
69	Genus : Eisenack, 1958 Type species : (Eisenack)Eisenack, 1958
74.	Genus : Schaarschmidt, 1963
75.	Genus : Loeblich & Tappan, 1978
77.	Genus : Staplin, Jansonius & Pocock, 1965
79.	Genus : Deflandre, 1937
86.	Genus : Staplin, 1961
93.	Genus : Staplin *et al.*, 1965 Type species : (Deflandre) Staplin *et al.*, 1963
94.	Genus : Deunff, 1961
96.	Genus : Wicander, 1974
99.	Genus : Eisenack, 1969
100.	Type species : (Deunff) Loeblich & Tappan, 1969
101.	Genus : Cramer, 1964
102.	Genus : Eisenack, 1968 Type species : (Eisenack) Eisenack, 1963
103.	Genus : Vavrdova, 1966 Type species : Vavrdova, 1966
108.	Genus : Deunff, 1958 ex Downie, 1959
115.	Type species : Loeblich & Tappan, 1976
117.	Genus : Wetzel, 1933 Type species : O. Wetzel, 1933

118. Genus : Deunff, 1933
Type species : Deunff, 1933

120. Genus : Timofeev, 1959

122. Genus : Brito & Santos, 1965

122. Genus : *Deunffia* Downie, 1960

130. Genus : Eisenack, 1938
Type species : (Eisenack) Eisenack, 1938

ERRATA

Page,	Line(S)	In place of	Read
5	12	dhura	Dhura
5	13	Southwest	southwest
7	1	Northeastern	northeastern
7	4	Geologists	geologists
7	7	Palynological, Sedimentological Chemical	palynological, sedimentological chemical
7	12	Northern	northern
7	13	Kms., North	km, north
8	4	Kms., North	km, north
8	6	kms.	km
8	7	Kms.	km
8	16	Occassional	occasional
8	20	O' Clock in the morning	a.m.
9,	3	Birch	birch
9,	14	*deodar*	*deodara*
10	5	Occassionally	occasionally
11	5	Leptaena rhomboidalis	*Leptaena rhomboidalis*
11	6	Calostylis dravidina?	*Calostylis dravidina?*
11	7	Streptelasma	*Streptelasma*
11	13	Laptaena	*Leptaena*
12	15	stuided	studied
13	2	appears	appear
13	10	liguilid	lingulid
13	11	grastropod	gastropod
14	4	Cambrain	Cambrian
16	19	*Skalolithous*	*Skalolithus*
17	9	Conodont	conodont
20	3	*Streptelesma*	*Streptelasma*
21	3	point	horizon
21	4	merge	merges
21	15	clacareous	calcareous
22 TABLE-4 (second line)		dravidiana	*dravidiana*
23	5	Overlying	overlying
23	13	fromation	formation
23	14	*Streplesma*	*Streptelasma*
26	16	Palynozonation	palynozonation
29	11	Kms., metres	Km , m
29	12	metres	m
29	17&18	metres	m
30	2	form of the	to be deleted
30	19	Seventyone	Seventy one

Page, Line(S)		In place of	Read
32,3,7,8,9,13,14		meters	m
33	7	diagonostic	diagnostic
33	18	palynoforms	palynomorphs
35	8	most	to be deleted
36	1	fine grained	fine-grained
37	13	well sorted	well-sorted
38	4	post depositional	post-depositional
38	17	exhibit	exhibits
41	14	rim cemented	rim-cemented
41	18	remanant	remnants
41	23	rhomb shaped	rhomb-shaped
44	4	kilometer	km
44	6	Cross bedded	Cross-bedded
44	18	meters	m
45	2	meters	m
50	6,8	Kaolinite	kaolinite
54	5	sedidments,Boron	sediments, boron
54	7	Boron	boron
56	6	sedidments	sediments
56	9	Palynozonation	palynozonation
57	1	pollens	pollen
57	6	Palynomorphs	palynomorphs
57	8	Palynology,started	palynology, published
57	9	Pollenalysis	pollen analysis
57	10	cross	Cross
57	13	Palynologists	palynologists
57	14	Science	science
58	1	Palynotogical, Oil	palynological, oil
58	2	Exploration,, Oil	exploration, oil
58	11	Kerogen	kerogen
58	12	mirphological	morphological
58	15	acritarchs	Acritarcha
58,14,16,21		hystrichosphaeres	hystrichospheres
58	19	Hystrichosphaere, Hystrichosphaera	hystrichosphere, *Hystrichosphera*
59	2	Hystrichosphaeridium	*Hystrichospheridium*
59	6	Hystrichosphaera Hystrichosphaeridium	*Hystrichosphera* *Hystrichospheridium*
59	10	hystrichosphaeres	*hystrichospheres*
60	2	hystrichosphaeres	*hystrichospheres*
60	12	Tasmanites, Leiosphaerida	*Tasmanites,* *Leiosphaeridia*
60,14,15		Cymatiogalea, Cymatiosphaera, Polyedryxium, Polyplanifer	*Cymatiogalea,* *Cymatiosphaera,* *Polyedryxium,* *Polyplanifer*

Page,	Line(S)	In place of	Read
60	17	Acanthomarphitae	Acanthomorphitae
61	14	Chitinozoans	chitinozoans
61	21	gm.	g
62	6	informations	information
62	7	1990	1990 unpublished
63	5	plates 8&9	plate 9
64, Title		TAXONOMY	SYSTEMATICS
64	5	upto	to
66	16	comparble	comparable
68	5	the suket	the Precambrian Suket
71	11	hetromorphic	heteromorphic
71	14	speicmens	specimens
73	1	occassional	occasional
76	8	later	latter
76, 13, 14		1970	1969
77	4	Comparble	comparable
		differes	differs
77	13	Sajeant	Sarjeant
77	20	the Calymene	the Lower Ordovician Calymene
80	8	has	have
80	20	Pylome	pylome
81	10	spherical	circular
81	18	He	They
82	16	Limestone	limestone
84	19	shropshire	Shropshire
85	5	measruing	measuring
86	14	1970	1970,
86	18	have	has
87	18	Eisenack et al	Eisenack, Cramer & Diez, 1973
88	10	yong	Yong
88	13	*thusuii*	*thusui*
90	7	trifuracating	trifurcating
93	6	processess	processes
93	11	compares	compare
93	18	Arening	Arenig
95	15	calymene shales	Calymene Shales
96	6	subsqure	subquadrate
96	19	drak	dark
100	4	gradualy	gradually
101	20	speices	species
102	17	as	as aff.

Page,	Line(S)	In place of	Read
103	18	(Vavrdova) Jacobson& Achab, 1985	Vavrdova, 1966
104	7	Fig.3)Jacobson	Fig.3)as emended by Jacobson
104	15	(Vavrdova) Sarjeant & Stancliffe, 1994	to be deleted
105	18	by	from
106		*stellechinatum*	*Stellechinatum*
108	11	ruptered	ruptured
109	1	ohio	Ohio
109	3	Stockmnans & Willire	Stockmans & Williere
109	6	occassional	occasional
109	11	d'alienes	d'Alienes
109	12	Frasnian	Frasnian age
111	13	occassionally	occasionally
112	1	Oklahaoma	Oklahoma
112	2	Downie and Sarjeant, 1965	de Jekhowsky, 1961
112	10	Downie and Sarjeant, 1965	to be deleted
113	4	La vid	La Vid
114	5	*Veryhchium sp.*	*Veryhachium sp.*A
114	7	occassionally	occasionally
114	17	*Veryhachium sp.*	*Veryhachium sp.*B
115	17	entrichos	*entrichoe*
116,5,12		setosapelliculum Loeblich, 1970	*setosapellicula* (Loeblich) Loeblich &Tappan, 1976
116	13	forms	form
117	11	presquile de crozon	Presquile de Crozon
118	13	bronw	brown
118	18	*Cymatoigalea*	*Cymatiogalea*
120	2	occassionally	occasionally
120	9	Acadian	Arcadian
120	16	equitorial	equatorial
121	3	equitorial	equatorial
123	12	Deunff, 1951	(Deunff) Downie, 1960
123	15	assymetrical	asymetrical
123	18	Deunff	(Deunff)
125	11	Hill	(Cramer) Hill
126	20	eaxmined	examined

Page, Line(S)		In place of	Read
127	18	*typica* Cramer & Diez, 1972	(Cramer) Cramer, 1970
128	15	occassional	occasional
132	3	spain	Spain
132	17	New york	New York
134	13	*osgoodence*	*osgoodense*
137	22	globlly	globally
138	16	*coryphidium*	*Coryphidium*
138	17	stelliferidium	*stelliferidium*
139	8	Domasia algerensis	*Domasia algerensis*
140	19	Southern	southern
140	24	Northwest	northwest
144	5	are found to be absent	were not seen
144	13	siegenian	Siegenian
146	6	enviornment	environment
146	9	informations	information
153	7	micrite	to be deleted
154	3	Kaolinite	kaolinite
(i)	4	little	few
(ii)	19	evidences	evidence
(ii)	22	speices	species
(iii),3		*var*	*var.*
(iii),13		Geron	*Geron*
(iii),14		*Var. longispinsoum*	*var. longispinosum*
(iv),7		reveals	reveal
(vi),7		Palynological	palynological

REFERENCES

S.N.	In place of	Read
2.	Travereses	Traverses
4.	mannual on Carbonate	manual on carbonate
9.	microfosseis	microfossis
14.	d	d'
15.	Leiosfusidae	Leiofusidae
26.	Ross	ross
30.	society, mineralogists	Society, Mineralogists
31.	Carbonate	carbonate
37.	micropaleontologie	Micropaleontologie
38.	Micropaleontologic	Micropaleontologie
40.	scances	seances
41.	Frnace	France

44.	speances, Frances	seances, France
45.	Paleoplancton, devonienns Bulletion	paleoplancton, devoniens, Bulletin
46.	Palezoique	Paleozoique
48.	Shrosphire	Shropshire
52,53,54,55	Hystrichosphaeres	Hystrichospheres
57.	Carbonate, Carbonae	carbonate, carbonate
61.	melanosklerltolden, zeitschriuft	Melanosklerltoiden, zeitschrift
67	Hystrichaspharen Geologic	Hystrichspharen Geologie
73	hystrichosphaeres	hystrichospheres
75	Microflora	microflora
79	micropaleontologie	Micropaleontologie
87	Palynology of Acritarchs	palynology of acritarcha
91	Acritarches	acritarches
99	Myriastiches gigas	*Myriastiches gigas*
100	1974, palynol.	& Downie,C.1974, Palynol.
103	Mac Adam	MacAdam
109	courtrai	Courtrai
113	Limestone	limestone
121	Karniosche	Karnische
125	etsratigraphiques	et statigraphiques
129	zechstein	Zechstein
137,138,139	hystrichosphaera Hystrichosphaeres	hystrichosphera Hystrichospheres
140	Hystrichosphaeres, Belge	Hystrichospheres, belge
141	Momoires	Memoires
150	sedimentology, scientific	Sedimentology, Scientific
155	Arening	Arenig