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CARBONATE BUILD-UPS IN THE HIMALAYA : THEIR AGE, MICROFACIES AND PALAEOENVIRONMENT

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ABSTRACT

In the Himalaya, the carbonate build-ups are known from Middle - Late Riphean (Shali, Larji, Calczones, Baxa Group, stromatolitic knolls reefs on platform), Vendian (Basantpur Kunihar Formation of the Simla Group, foreslope- flank facies, Krol E, palaeoestuary, low energy carbonate tidal flats), Early Cambrian (Koti Dhaman Formation, Tal Group, stromatolitic build-ups of sub-littoral lagoon), Middle Cambrian (Kunzam Las, Formation, Haimanta Group, algal build-ups, restricted platform to shallow lagoon), Ordovician - Middle Silurian (Takche Formation, Sanugba Group, coral - stromatoporoid, fringing reef)?, Tournaisian (Lipak Formation, Kanawar Group, coral- algal build-ups, restricted platform to? foreslope), Visean (non-carbonate flattened *Fenestella* build-ups in the Po Formation, Kanawar Group, mid-shelf), Middle Norian (Hangrang Formation, Lilang Group, knolls on platform),? Rhaetic-Lias (Kioto Formation, Lilang Group, knolls on platform).

All the build-ups are succeeded by clastic sequences along unconformity, save the Hangrang Formation which is conformably followed by the clastic Alaror Formation.

INTRODUCTION

Carbonate build-ups in the Himalaya are known from sequenes ranging in age from Riphean to Lias. Some of the carbonate build-ups described in this paper have been earlier referred to as the reefs (Bhargava and Bassi, 1985, 1986). Reefs have received special attention due to rich assemblages of fossil fauna and their significance in petroleum geology and palaeoenvironmental interpretation. The term reef was originally used by navigators for narrow rocky structures or sand close to water surface, where a vessel might strike or ground upon them (Cummings, 1932). Since then, the term reef has undergone several changes and has been defined by different workers variously, some of which are narrow and interpretative. To avoid genetic connotation the term build-ups as defined by Heckel (1974) is used here. Heckel (1974) defined Carbonate build-up as a deposit which (i) differs in nature to some degree from equivalent deposits and surrounding and overlying rocks, (ii) is typically thicker than equivalent carbonate

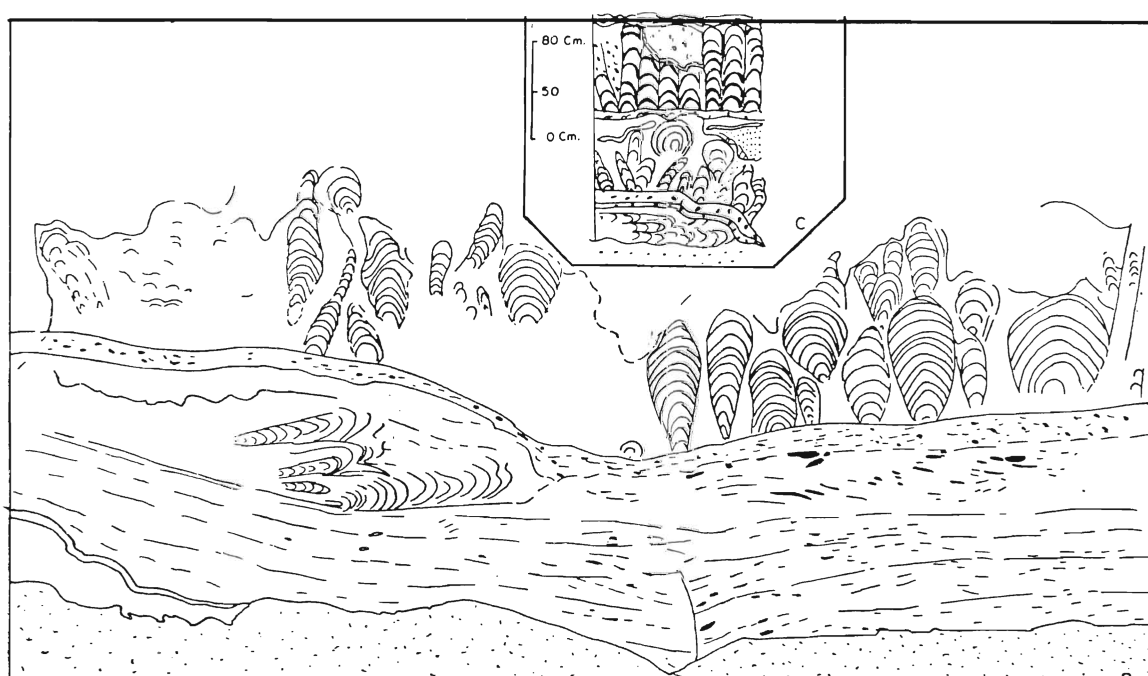

Fig. 1. Sequence in stromatolitic build-up, bottom most layer shows flattened stromatolites, middle has stromatolites with increasing width, & top layer (inset) stromatolites of constant diameter. Sketched from photograph. Dislodged boulder near Hurla (Sainj Valley).

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Table 1: Stratigraphic distribution of the Carbonate Build-ups in the Himalaya.

A. Tethyan Part.

Group	Formation	Broad age	Broad Lithology	Carbonate Build-ups
1	2	3	4	5
	Kioto	Rhaetic-Lias	Carb.	—
	Nunuluka	Norian	Sst., Carb.	
	Alaror	Norian	Sh., Carb.,	
Lilang	Hangrang	Norian	Carb.	—
	Sanglung	Mid Carnic	Sh., Sst., Carb.	
	Chomule	Early Norian		
	Kaga	Ladinic-Early Carnic	Carb.	
	Mikin	Ladinic	Sh., Carb.	
	—Unconformity—			
	Gungri	Late Permian	Sh., Sst.	
Kuling	—Unconformity?—			
	Gechang	Early Permian	Sst., Congl.	
	—Unconformity—			
Kanawar	Ganmachidam	Late Carboniferous (?)	Congl., Sst., Sist.	
	Po	Visean	Sst, Sh.	*
	Lipak	Tournasian	Sh., Sst., Carb., Gypsum	—
	Muth	Mid- Late Devonian	Sst.	
	—Unconformity—			
	Takche	Late Ordovician Mid Silurian	Carb., Sh., Sst., —	
Sanugba	Thango	Ordovocian	Sst.. Cong.	
	—Unconformity,			
Haimanta	Kunzam La	Early-Mid Cambrian	Sst. Sist, Carb.,	
	Batal	Vendian	Sst. Sh.	—

*Non-Carbonate build-ups.

B. Lesser Himalayan Part

Tal	Koti Dhaman	Early Cambrian	Sh, Ss, Carb	—
	Sankholi		Sh, Sst, Sist, Carb,	
	Shaliyan		Sh, Ch, Carb.	
	B		Carb,-	
	D	Vendian	Sst, Sh, Carb.	
	C		Carb.	
Krol	B		Sh, Carb	—
	A		Carb.	
	Infra-Krol	Vendian	Sh, Sist, Sst,	
	Blaini		Congil., Sh, Sst, Sist, Carb.	
	—Unconformity—			
	Sanjauli		Sst, Sist, Cong,	
Simla	Chaossa	Vendian	Sst, Sist, Sh.	
	Basantpur-Kunihar		Sh, Sist, Carb.	—
	—Unconformity—			
	Bandla		Carb., Sst,	
	Parnali		Carb.	
	Makri		Sst., Sh., Carb.	
Shali	Tattapani	Riphean	Carb.	
(Larji, Sorgharwari			Carb.	
Deoban, Khatpul			Carb.	
Calczones	Khaira Ropri		Sst., Carb	

Expl. Carb-Carbonate, Ch- Chert Congil- Conglomerate Sh-Shale Sist-Siltstone Sst-Sandstone.

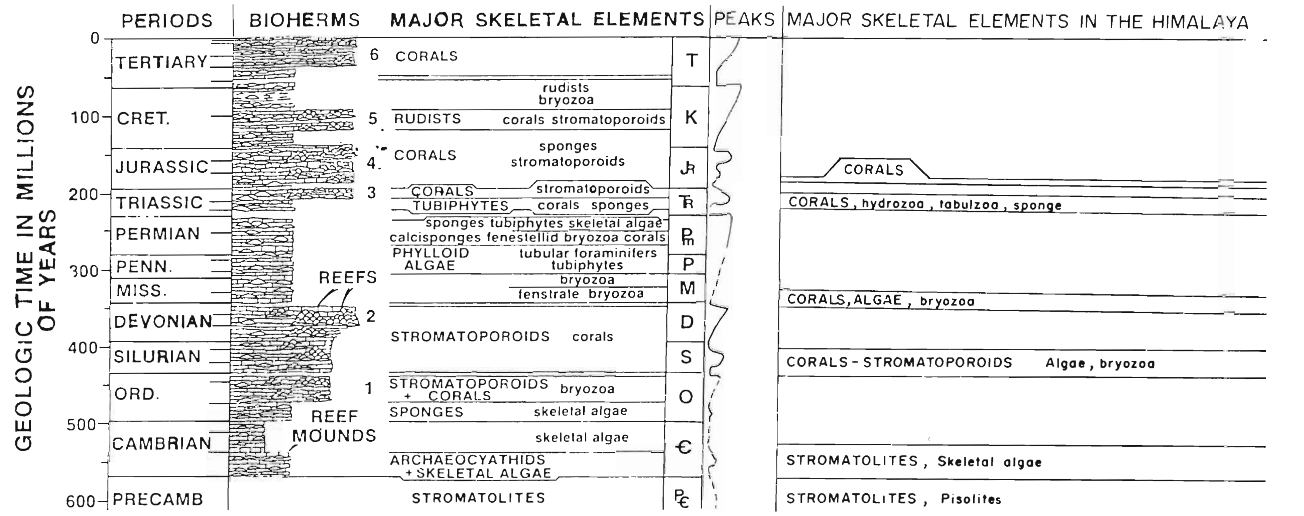

Fig. 2. General depiction of skeletal elements in build-ups through ages (modified after James, 1983), various reef building peaks (adopted from Talent, 1988). The skeletal elements in the build-ups are those of the Himalaya.

rocks and (iii) probably stood topographially higher than the surrounding sediments during sometime in its depositional history.

The distribution of the carbonate buildups in the stratigraphic column of the Himalaya is furnished in table 1. Main constraint in the study of carbonate build-ups, especially of the Tethyan part is the rugged topography in high altitude terrain, severe compaction and deformation which make reconstruction of the buildups in three dimension difficult. The studies of carbonate build-ups were mainly carried out in the Himachal Pradesh, the data from other parts have been collated from various publications and reinterpreted.

CARBONATE BUILD-UPS

1. Proterozoic Build-ups

During this period, stromatolitic build-ups were more predominant in Riphean than Vendian.

A. *Middle-Late Riphean Build-ups* : Stromatolitic and oolitic buildups have been recorded in Larji, Shali and Deoban Groups. Only preliminary information is available about the extent of development of the carbonate build-ups from selected sections (Bhargava and Bassi, *in press* b). In the Larji group, these are known from Sainj Valley, near Aut. In the Shali Group, the stromatolitic build-ups are reorded from Parnali and Tattapani areas. In the Deoban Group, the build-ups have been observed in the Meenas gad section. The build-ups are made of several cycles of stromatolitic columns of various shape and size (fig. 1). In some build-ups (e.g., Deoban mat in the Meenas gad section), the height of columns exceeds one metre. These can be traced for about a kilometer along strike. The buildups show variable relationships with the overlying and adjoining carbonate sediments, viz. (i) they are more or less sharply bounded by overlying bedded carbonates and (ii) with reduction in size and frequency of stromatolities they grade laterally and vertically into bedded carbonates. The stromatolitic build-ups are associated with oolitic and peloidal facies, showing evidences of wave resistant characters and can be classified as reefs (Bhargava and Bassi, *in press* b).

The carbonate microfacies recorded in these build-ups are (i) boundstone facies (including framestone built by robust stromatolitic columns, and also bindstone formed by lameller algal mat (ii) ooidal/ peloidal packstone (iii) ooidal grainstone, (iv) rare grapestone (v) rudstone and (vi) mudstone. All the facies show submarine and phreatic cements and fenestral fabric.

Though some study on microbiota of stromatolitic sequences have been carried out (e.g., Kumar and Srivastava, 1992), information regarding the characters of builders, binders and encrustors is lacking.

The stromatolitic sequences of large dimensions are known from the Sirban Group (Jammu), Calc-zones of Tejam-Pithoragarh (Kumaon-Garhwal), Nawakot (Nepal) and to much lesser extent in the Baxa Group of Darjeeling-Bhutan of Eastern Sector of the Himalaya (Srikantia and Bhargava, 1982).

The build-ups are largely comparable with knoll-type reefs which flourished on platform. Definite outer-reef facies in stromatolitic build-ups have so far not been recorded.

The stromatolitic sequences in the Lesser Himalaya have been assigned mostly the Middle - Late Riphean age, covering a span of 500 Ma. However, in general, save Shali and Deoban Groups in H.P., no attempt has been made to classify these sequences in smaller units and assign the stromalites to these units. There is a possibility that many surfaces of omission exist within these sequences.

The stromatolitic build-ups have world-wide distribution (Cloud and Semikhatov, 1969) which have been studied for macro- and micro-structures, eucaryotes and multicellular colonies of algae. An excellent study of stromatolitic reef of an early Precambrian is provided by Cecile and Cambell (1978).

B. *Vendian Build-ups* : Besides appearance of metazoans as grazers of stromatolites, more or equally important was the world-wide Vendian glaciation which led to marked decline in algal stromatolitic communities (Copper, 1974). In the Lesser Himalaya, the pre-Blaini carbonate sequences show large-sized stromatolitic build-ups, as compard to post-Blaini sequences.

Basantpur-Kunihar Formation forming basal part of the Simla Group, shows stromatolitic build-ups at Kakarhatti, Arki and Naldera. These carbonates are about 5 to 10 m is thick at Kakarhatti, 10-30 m thick at Arki and Naldera. At Kakarhatti and Arki, small-sized, somewhat globular, haphazardly arranged stromatolites occur. These are interbedded with shale sequence.

The microfacies in these build-ups are: (a) stromatolitic rudstone/grainstone. These buildups possibly represent the foreslope/flank facies. The main buil—ups from which these have been derived probably have been eroded.

The Krol E shows fairly large-sized stormatolitic buildups in Nainital (Singh and Rai, 1977). From these Gansser (1974) reported *Epiphyton* and *Renalcis*. The slides containing these forms were loaned by Prof. Gansser to A.D. Ahluwalia and could be examined by the present author who found both these forms of doubtful affinity.

In the Mussoorie area, small stromatolitic build-ups and the build-up (5-10m) of forms resembling Archaeocyatha(?) containing *Ephiphyton* and *Renalcis* have been reported by Singh and Rai (1983).

The palaeoenvironment of these build-ups is interpreted as essentially a carbonate tidal flat' with extremely low energy (Singh and Rai, 1983).

No details of microfacies of these build-ups are known.

Besides stromatolitic build-ups, algal pisolitic builups (PlI, fig.1), about 0.5m to one metre thick and two to three metres long, have been recorded in the Krol E Formation at Dohana and Tattyana in the Nigali Dhar Syncline. They show crinkle-margined, several layered, and well-sorted pisolites in micritic to partly sparitic matrix.

The pisolitic build-ups are interpreted to have been formed by algal activity near palaeoestuaries (Bhargava, 1969).

2. Palaeozoic Build-ups

Explosion of life at Precambrian-Cambrian boundary saw varieties of animals emerging as builders, binders and encrustors in various buildups. In the Himalaya, during the Cambrian algae continued to be the main builder.

A. *Early Cambrian Build-ups:* The Koti Dhaman Formation of the Tal Group enclosing *Redlichia noetlingi* and *Lingulella*, is assigned an early Cambrian age (Kumar *et al*, 1987). This formation is divisible as follows in the Nigali Dhar and Korgai Synclines (Bhargava 1984) and, though not mapped, in the Mussoorie Syncline also.

Upper Quartzite Member
Algal Limestone Member
Arkosic Sandstone Member
Shale Member
Lower Quartzite Member

The Algal Limestone Member shows spectacular large-sized club or columnar stromatolites referred to Cryptozoon (Rai and Kar, 1995) at Deona (Nigali Dhar Syncline) and Bitharku (Korgai Syncline). The 0.5 to 1.5m thick stromatolitic beds are inter- bedded with coarser clastic sequene (Rai and Kar, 1995).

The microfacies include (i) boundstone, (ii) *Epiphyton* bindstone (iii) peloidal grainstone, and (iv) layered mudstone. It shows evidence of early submarine cementation.

Rai and Kar (1995) interpret its deposition in a sublittoral lagoon with high salinity, akin to Hamelin Pool of the Shark Bay, Australia.

B. *Middle Cambrian* : A carbonate horizon forming upper most part of the Kunzam La Formation encloses build-ups in Lahaul-Zanskar region (Pl I. fig. 2). It was also referred to as the Karsha Limestone and assigned a Silurian age (Nanda and Singh, 1977). Conformably below this limestone occur ptychoparids and oryctocephalids of Middle Cam brian age. It is unconformably overlain by the Thango Formation of Ordovician age (Bhargava and Bassi, *in press*, a). In the Spiti section, this limestone has limited thickness of a few metres and it shows algal mat. At Baralacha section, it shows stromatolitic columns of limited thickness which in thin section shows fragments of skeletal algae *Epiphyton*. North of Baralacha, towards Zanskar (Ladakh) it acquires appreciable thickness.

The microfacies in the build-ups of the Kunzam La Formation are mudstone dominated with (i) fenestral fabric (filled with sparite) (ii) collapse breccia, (iii) brecciated micrite having Fe-rimmed peloids and colonies of *Epiphyton*, (iv) bioclastic wackestone having clasts of bryozoa (?) and gastropod. Bioturbation in the carbonate rocks is common. The build-up was formed in restricted platform to low energy shallow lagoon.

The build-ups are mainly made of fine muddy sediment which was possibly bound and baffled by blue-green and skeletal algae. Gastropods lived as grazer in the ecosystem.

During Cambrian time, Archaeocyatha formed prominent build-ups in Canada and Siberia.

C. *Ordovician-Silurian:* The Takche Formation is known to include coral-algal-stromatoporoid-sponge-bryozoal build-ups (Bharvaga and Bassi, 1986). The Takche Formation with conformably underlying arenaceous Thango Formation forms part of the Sanugba Group (Bhargava and Bassi, *in press*, a). The Takche Formation is sharply overlain by the quartzite of the Muth Formation, possibly along an unconformity. A part of this formation has been referred to as the Pin Limestone (Goel and Nair, 1977) and Pin Dolomite (Khanna *et al.*, 1983) without proper definition of these terms or proving their mappability. Unfortunately this terminology has been indiscriminately perpetuated by some subsequent workers also.

The age of the Takche Formation is far from settled. Srikantia (1981), who proposed the name Takche, assigned it a 'Silurian to lower Devonian' age. Bhargava and Bassi (1986) suggested an Early to Middle Silurian age for its reefal part. Kato *et al.* (1987), based on algal remains, alluded to Cardadocian age. Copper and Brunton (1991) suggested a possible Landovery to Wenlock age to the Takche Formation.

The presently defined Takche Formation was referred to as 'Ordovician' and 'Silurian' sequences by Pascoe (1969). Fossils of these sequences (table 2 a-c) include Ordovician fossils, co-existing with Silurian taxa. There could be some mix-up in fossils of different layers, but the upper age limit of the Takche Formation seems to be at least Middle Silurian, as indicated by presence of *Radiastraea* in its upper part (Bhargava and Bassi, 1986).

The Takche Formation ubiquitously contains crinoidal debris with packstone/grainstone particularly in its basal part. The crinoidal debris seems to have provided a stable substrate for the organic build-up. Though the sequence shows colonisation and diversification stages (of James, 1984), the domination stage is lacking.

Numerous microfacies are encountered in the Takche Formation (Bhargava and Bassi, 1986). These are (i) fossil wackestone/packstone with clasts of *Favosites, Halysites*, bryozoa, crinoid ossicles, echinoid plates, trilobite, gastropod, stromatoporoid, sponge-spicule, ostracode, tentaculites (?), (ii) mudstone/wackestone containing whole as well as fragmented fossils, (iii) layered bioclastic packstone/ grainstone, (iv) floatstone/rudstone containing angular clasts of *Favosites* and *Vermiporella* debris, halysitid - bryozoa (in floatstone), bryozoa (*Hallopora*), coral (*Halysites*) floatstone, (v) *Plasmoporella* boundstone, rare sponge stromatoporoid boundstone, (vi) bindstone showing encrusting *Ecclimdicityon* (Pl.I, fig. 3), (vii) mud-filled *Favosites* colonies (Pl.I, fig.4) (viii) *Halysites* bindstone, (ix) stromatoporoid-rugose coral framestone, (x) bryozoa bindstone, (xi) *Vermiporella* bindstone/ grainstone (Pl. I, fig. 5) (xii) *Girvanella* bindstone (Pl. I, fig. 6). (xiii) *Halysites-Vermiporella* boundstone (Pl. I, fig. 7).

Specialised microfacies are constituted of (i) *Halysites* chains which provided protected environment for *Vermiporella* to thrive (Pl. I, fig. 7), (ii) cavities in *Plasmoporella* colonies forming shelters for algae and (iii) intergrowth of *Favosites* with some smaller coral/ stromatoporoid (?) (Pl. I, fig. 8).

The cements in the Takche build-ups are siliceous (chalcedonic), ferruginous, micritic, sparitic and rarely ferruginous - subsequent calcite. Clear siliceous is the first generation cement in corallites of *Favosites* and *Halysites* colonies; replacement by micritic and sparitic cements is common. Open spaces, veins, fractures and fossil chambers show clear sparite. Sparry calcite is of primary origin, as well as due to recrystallisation of micrite, the latter shows hazy boundaries.

The syringoporids, favositids, halysitids and spheroidal stromatoporoids form low mound/ colonies land their current-dominated parts contain population of encrusting stromatoporoids, tabulate and rugose corals and bryozoa (dominantly *Hallopora*). In the upper part of the Takche Formation in the Kinnaur area, occur nodular colonies of *Radiastrea* and *Halysites*. *Vermiporella* and *Girvanella* are locally abundant. Besides these occur flask-shaped problematica (Bhargava and Bassi, 1986), rare ostracode, foraminifera. Cavities, in all probality formed due to borers (carnivores), exist in the Takche build-ups. In *Plasmoporella* colonies, cavities were inhabited by *Vermiporella*, while in the solitory corals these have been filled by clear sparitic cement (Pl. I, fig. 9).

Stromatoporoids occurred as encrusters, algae as binders and gastropods (*Euomphalus, Pleurotomaria*) as grazes. The trilobite in these fossil metropolis performed as scavengers and nautloids as main carnivores.

Table 2a : The fauna of units e and f of Haydon (1904) of Ordovician Sequence', near Shian, Pin Valley (in Pascoe, 1968) and their age ranges after Moore (1956-64).

UNIT	FOSSILS	ORDOVICIAN E M L	SILURIAN E M L	DEVONIAN E M L	CARBONIFERROUS
f	*Eurychilina monticuloides* Reed				
	Krausella shianensis Reed				
	Primitia everesti Reed				
	P. gerardi Reed				
	Leperditella himalaica Reed				
	Leperditia sp.				
	Beyrichia sp.				
	Illaenus punctulosus Salter				
	I. spitiensis Reed				
	I. brachyoniscus Salter				
	Bronteous lunatus Billings				
	Asaphus emodimilamensis Reed				
	Lichas tibetanus Salter				
	Calymene nivalis Salter				
	Cheirurus mitis Salter				
	Cornulites sp.				
	Lophospira serrulata Reed				
	Pterinaea thanamensis Reed				
	Hindella sp.				
	Zygospira sp.				
	Rafinesquina muthensis Reed				
	Strophomena chamaerops Salter				
	S. bisecta Salter				
	Sowerbyella himalayensis var. *repanda* Salter				
	S umbrella Salter				
	Leptaena trachealis Salter				
	Triplecia uncata Salter				
	Orthis (Plectorthis) stracheyi Reed				
	O. (Hebertella) cf sinuata Hall				
	O. (Dalmanella) testudinaria Dalman var. *himalaica* Reed				
	O. (Dinorthis) thakil Reed var. *subdivisa* Salter				
	O. (D.) thakil Reed var. *striatocosta* Salter				
	O. (D.) porcata Mc Coy var. *peregrina*				
	Ptilodictya ferrea Salter				
	Dianulites yak Salter				
e	*Orthis (Dinorthis) thakil* Salter				
	Rafinesquina cratera Salter				
	Lichas sp.				
	Pasceolus mellifluous Salter.				

Table 2b : Fauna of units g and i of Hayden (1904) of 'Ordovician Sequence' near Shian, Pin Valley, (in Pascoe, 1968) and their age ranges after Moore (1956-64).

UNIT	FOSSILS	ORDOVICIAN	SILURIAN	DEVONIAN	CARBONIFERROUS
		E M L	E M L	E M L	
i	*Streptelasma corniculum* Hall				
	Favosites sp.				
	Phylloporina sp.				
	Rhindictya sp				
	Ptilopra sp.				
	Stictopora elangulata Hall				
	Aloctoporella sp.				
	Orthis (Dalmanella) testudinaria Dalman				
	O. (Dinorthis) porcata var. *peregrina* Reed				
	Leptaena rhomboidalis Wilckens				
	Strophomena wisconsinensis Whitfield				
	Sowerbyella sericea Sowerby				
	Hindella shianensis Reed				
	Lophospira bicincta Hall				
	Hormotoma cf. trentanensis Ulrich and Schofield				
	Bellerophon sp.				
	Gonioceras anceps Hall				
	Illaenus sp.				
h					
g	*Lyopora* sp.				
	Orthis (Plectorthis) stracheyi Reed				
	O. (Dalmanella) testudinaria Dalman				
	Parastrophia indica Reed				
	Mesotrypa sp.				
	Conradella obliqua Ulrich and Schofield				
	Pseudolus shianensis Reed				
	Apidium indicum Reed				

Table 2c : Fauna of stages 1,2 and 3 of Silurian Sequence of Hayden (1904), exposed near Shian Pin Valley (in Pascoe, 1968) and their stratigraphic ranges after Moore (1956-64).

UNIT	FOSSILS	ORDOVICIAN	SILURIAN	DEVONIAN	CARBONIFERROUS
		E M L	E M L	E M L	
3	*Lindstroemia* sp.				
	Favosites forbesi Edw. and Haime				
	F. niagarensis Hall				
	Orthis aff. *rustica* Sowerby				
	Orthothetes aff. *pecten* Linne				
	Pentamerus oblongus Sowerby				
	Palaeoneilo victoriae Chapman				
	Bellerophon sp.				
	Euomphalus triquatrus Lind.				
	Orthoceras annulatum Sowerby				
2	*Orthis (Dalmanella) basalis* Dalman var. *muthensis* Reed				
	O. (D.) edgelliana Reed				
	O. (Plectorthis) spitiensis Reed				
	Stropheodonta compressa Sowerby				
	Coleostylis dravidiana Reed				
	Leptaena rhomboidalis Wilckens				
	Strophonella euglypha Hisinger				
	Orthothetes aff. *pecten* Linne				
	Camarotoechia sp				
	Calymene sp.				
1	*Propora himalaica* Reed				
	Streptelasma (Zaphrentis) sp.				
	Stylaraea kanaurensis Reed				
	Favosites spitiensis Reed				
	Halysites catenularia kanaurensis Reed				
	H. wallichi Reed				

Table 3 : Paleoenvironment of the reefal build-ups in the Takche/ Manchap Formation in the Spiti-Kinaur area, Himachal Himalaya, India (after Bhargava and Bassi, 1986).

Area	Bedding	Main microfacies	Main builders	Palaeoenvironment
Takche	Cross bedded	Arenaceous dolomite to dolomitic sand-stones	Sparsely distributed *Favosites, Halysites* and rugose corals in sandy dolomites	Shallow water, near shore.
Gehang	Cross, thick to massive bedding	Biolastic arenaceous wacke/packstones. *Thamnopora* framestones; Interfingered and interlayered.	Rugose corals, *Thamnopora, Favosites, Halysites*	Lagoon, occasionally ravaged by storms to form packstones, quartz indicates nearshore environment.
Muth-Shian	Cross, nodular, syndepo-sitional slumping	Bioclastic pack/ wackestones, framestones	Rugose corals, *Syringopora, Favosites, Halysites, Parachaetetes,* rare stromatoporoids	Low energy protected environment, possibly a lagoon.
Leo	Thick to massive	Mud/wackestones bioclastic pack/ grainstones & bioclastic floatstones; interfingered	Rugose corals (common), *Halysites* (abundant) *Favosites, Protaraea, Hallopora,* encrusting laminar to low domal stromatoporoids common in the upper part	Reef flat partially protected in proximity of a back-reef especially in the basal and middle parts of the sections. Locally ?foreslope conditions.
Manchap	Massive	Bioclastic wackestones, pack/grain stones float/rudstones, frame/bind/bafflestones	Rugose corals- including ? *Radiastraea ,Favosites* (dominant in the basal and upper parts), *Plasmoporella, Halysites,* rare stromatoporoids all through, spheri-cal and encrusting *Girvanella, Parachaetetes,? Solenopora, Ver-miporella, Hallopora,* sponge spicules.	Partially to largely sheltered organic reef and foreslope areas, locally protected niches for the growth of *Vermiporella* provided by *Halysites* and *Plasmoporella.* Photic intertidal zone near wave base in a tropical sea. Fluctuations in sea level.

Table 4 : Microfacies, builders and environment of Mid-Norian Reefs, Spiti-Kinnaur, Tethys Himalaya (after Bhargava and Bassi, 1985).

Area	Main Microfacies	Main Builders	Palaeoenvironment.
Rangring	Bioclastic/lithoclastic wackes-tone/floatstone Boundstone; coral-hydrozoan framestone, algal bindstone; calcisponge bafflstone, Grainstone	Calcisponge, corals, tabulozoans, hydrozoans, calcareous algae and microproblematica	Fluctuating energy conditions within a predominantly low energy environment.
Pin-Spiti	Boundstone, wackestone/pack stone, cortoidal packstone/ grainstone,oncoidal bioclastic floatstone	Calcisponge, corals, tabulozoans, hydrozoans, calcareous algae	Reef edge to winnowed platform edge position with high energy condition.
Latarse	Bioclastic algal grainstone, Reef rudstone	Corals	Fore-reef to a reef flank.
Hangrang	Boundstone (framestone), Oncoidal Packstone/ Wackestone	Corals, sponges, hydrozoans	High energy reef patch in central reef area with limited protected environment where sponges thrived.
Tapuk	Boundstone, Algal encrusted grainstone	Corals, chaetitids/ tabulozoans, calcareous algae	Central reef area with high energy conditions, temporary subaerial exposure. Chaetitids may indicate localised low energy area in the framework of corals.

Profuse growth of *Vermiporella* within the chains of *Halysites* and in the cavities of *Plasmoporella* may have been some kind of symbiotic arrangement.

Individual build-ups in the Takche Formation are small and are interlayered with siliciclastic sediments, thus representing discontinuous fringing reefs. The Takche Formation extending from Spiti to Kinnaur shows a variety of microfacies. Its palaeoenvironment in different sections are variable (table 3).

The basal part of the Sanugba Group, represented by conglomerate-arenaceous Thango sequence, witnessed a relative deepening of the basin (?transgression) to cut off clastic supply to herald limestone deposition and formation of carbonate build-up. There were several prograding cycles during which individual carbonate build-ups were formed. Final regression obliterated the basin, causing a sedimentological break between the Takche and Muth Formations (Bhargava and Bassi, *in press* a).

Carbonate build-ups of the Silurian age (Rishkobal B, of Srikantia and Bhargava, 1983) were also noticed in the Aishmuqam section of the Lidder Valley (Kashmir).

In the Kumaon section, the equivalent of the Takche Formation has been described as the Yong Limestone which encloses massive stromatoporoids (Khanna *et al.*, 1985). The Yong Limestone forms the easternmost limit of Silurian build-ups in the Himalaya. The faunistic and microfacies details of the Rishkobal B and Yong Limestone have yet to be worked out.

A global review of the Silurian reefs has been provided by Copper and Burton (1991). Reefs of this age, except for Australia, are absent in the southern hemisphere. Well-developed Silurian build-ups are known from Greenland, U.S.A. Canada, and U.K.

D. *Early Carboniferous :*

a. ***Tournaisian.*** Conformably overlying the Muth Formation, the Lipak Formation comprises limestone, sandstone, shale and in upper part local gypsum pockets.

The limestone part in the Takche section shows small build-ups, which presently seem to be of tabular type. These build-ups in thickness range from 15cm to about 7.5m.

Lithostrotion and thamnoporids of Carboniferous age and hexagonarids of Devonian age (identified from the photographs by Prof. J.A. Talent) occurring about 80m above the Muth contact, show that the basal part of the Liapk Formation is certainly of Devonian age and that the Devonian - Carboniferous boundary lies with in this part. Based on conodont remains, the Lipak Formation has been assigned a Tournaisian age (Vannay, 1993).

The carbonate microfacies in the build-up part are (i) mudstone, made of clean to clotted micrite, some of which show doubtful shrinkage cracks. Burrows in the mudstone are filled with peloid (ii) varieties of packstone containing moderately sorted clasts of echinoid spine recrystallised crinoid, algal, cortoid of tentaculites, brachiopod tests (showing umbrella effect), trilobites (?) gastropod, bryozoa and corals. Packstone also shows bioturbation with concentric arrangement of grains in bioturbated parts (iii) grainstone varieties show (a) ooidal grainstone containing simple to compound (2-4 layered) oolites, some showing impinging relationship, (b) bioclastic grainstone having clasts of coral, tentaculites, ooids, peloid, crinoid and oyster, (c) peloidal grainstone. Cement in these varieties is small in volume, largely sparitic and rarely micritic.

Boundstone facies is of limited type. It includes (i) algal bindstone showing algal (Pl. II, fig. 1) and cryptalgal bedding and bird's eye structure. The cement in the bird's eye is micritic at the margin and sparitic in the central part, (ii) coral framestone (Pl. II, fig. 2) showing mud-filled coral. The coral colonies are burrowed. The interspace is filled by carbonaceous micrite and comminuted bioclasts. Cement in hardground is micritic and sparitic in burrows.

The Lipak Carbonates are rich in crinoidal remains. The crinoidal remains, shell-hash and several levels of hardground perhaps provided stable substrate to organic build-ups. Corals and algae alone seem to be the builders. Gastropod, lamellibranchs, tentaculites, crinoids, and brachiopods formed the dwellers. Gastropod was the principal grazer, trilobite the scavenger and algae possibly was the main borer. The Lipak build-up at Takche forms part of a prograding cycle. Six levels of hardground were recorded in this build-up. The Lipak build-up represents restricted platform with possible foreslope palaeoenvironment.

The Lipak Formation extends in sizeable parts of Spiti-Zanskar, but so far no build-ups have been described, though the corals and occasional algal mats have been reported. In the Lidder valley of the Kashmir Himalaya, the equivalent of the Lipak Formation is the *Syringothyris* Limestone (= Aishmuqam Formation of

Srikantia and Bhargava, 1983). In this part also corals and algal mats are known.

In the Bhutan Himalaya, the equivalent of the Lipak Formations seems to be the Wachi La (Tangri and Pande, 1995) and Ripakha Formations. In this part, doubtful build-up made of crinoids and *Fenestella* have been reported.

b. ***Visean.*** This period in Kashmir, Spiti-Zanskar is represented by clastics. In the Shale facies of the Po Formation and *Fenestella* Shale (Ganeshpura Formation of Srikantia and Bhargava, 1983) non-Carbonate build-ups (now flattened), made by branching *Fenestella* are conspicuous in the shale sequence. The carbonate originally present in *Fenestella* colonies, have since been washed away in a mid-shelf to shore-face environment. Though these are not carbonate build-ups, a mention is made here as it represents an important event in the Himalaya stretching from Kashmir to Bhutan.

Early Carboniferous build-ups of varying ages are found in Belgium, Ireland, U.K., Algeria and Central to Western U.S.A. (Wilson, 1975; Heckel, 1974).

3. Mesozoic Build-ups

E. *Late Triassic:*

a. ***Middle Norian.*** The 'Coral Limestone' forming part of the 'Lilang System' under a detailed lithostratigraphic classification was designated as the Hangrang Formation (Bhargava, 1987). Sandwiched in between the underlying Member of the Sanglung Formation is made of grey dolomite. Almost in all sections it shows build-ups of various sizes, notable being at Rangring (new spelling Rangrik), Pin - Spiti confluence and near Hangrang Pass (Pl. II, fig. 3). It is assigned a middle Norian age (Bhargava and Bassi, 1985). The important ones are : (i) Boundstone facies including (a) calcisponge bafflestone with echinoid spine, ostroacode, lamellibranch, (b) *Seriastrea*- calcisponge framestone with hydrozoa echinoid spine, brachiopod, ooid, (c) *Colospongia* hydrozoa bafflestone with lamellibrach (Pl. II, fig. 4), (d) tabulzoan framestone with solitary coral, echinoid spine, ostracode, bivalve, gastropod, (e) *Thecosmilia* framestone with sponge, gastropod, ooid, oncoid, and locally sponge encrusting coral, (f) hyrozoan framestone with brachiopod, problematica *Pycnoporidium*? *eomesozoicum*, mud-filled coral, echinoid spine, ostrocode, bivalve gastropod, (g) Stromatomorpha framestone with shell and crinoidal debris, (h) algal bindstone with algae encrusting hydrozoan and corals, (ii) packstone - grainstone facies with (a) thin - bedded to well - packed varieties, lacking bedding, (b) bioclastic cortoidal with clasts of coral hydrozoan, brachiopod, echinoid spine, (c) algal pelletoidal, (iii) wackestone/packstone showing normally to well packed oolite/oncoid, (iv) oncoidal bioclastic floatstone.

Thecosmilia colonies are the main builders in most of the sections (Pl. II, fig. 5). In Rangring area, hydrozoa - tabulozoa are main builders. Other builders include solitary coral, calcisponge, rare algae, micritic algal crust, ooid oncoid and crinoid. Of these, hydrozoan, sponges and algal crust formed encrusters / binders.

Brachiopod, lamellibranch, gastropod (also a grazer), rare cephalopod, ostracode, foraminifera and fish (?) constitute the main dwellers.

Boring/burrowing is common in the Hangrang build-ups; these could have been made by boring algae. Several cycles are found in the Hangrang build-ups; these begin with ooolitic-cortoidal layers and end in thick *Thecosmilia* colonies.

The environment and main microfacies of the Hangrang build-ups are summarised in table 4. The Lilang Group represents a mega -prograding sequence and the Hangrang Formation forms part of a regressive phase which culminated in the Nunuluka Formation. In N.W. extension of the Hangrang Formation, boundstone and allied microfacies are known as Kanglajal (Ladakh). Beyond this locality, no record of build-up is known. In Kashmir part, from the Late Triassic carbonates, solitary coral *Stylophyllopsis* has been reported over a persistent horizon (Arora *et al.*, 1996), but whether there are any build-ups is not yet known.

b. ***Rhaetic - Liassic.*** The Kioto Formation forms the youngest part of the Lilang Group. It comprises grey dolomite/limestone and is full of large sized megalodontid shells. A Rhaetic to Liassic age has been assigned to this sequence due to presence of *Stephanoceras coronatum*.

Small build-ups referable to knoll reefs have been reported from this sequence (Bhargava, 1987, Bagati, 1990). The microfacies in and around the build-ups are (i) bioclastic wackestone/packstone with bivalve, faecal pellets, (ii) peloidal grainstone and packstone, (iii) nerinid grainstone, (iv) shell-hash packstone, (iii) nerinid grainstone, (iv) shell-hash packstone and (v) *Thecosmilia* framestone (Pl. II, fig. 6). The interspace in the frame is filled with micrite and voids have been lined with dog-tooth spar sparite and central part is filled with sparite.

Very few occurrences of build-ups in the Kioto sequences have been recorded. This dearth of build-up could be due to lack of search in the rugged terrain formed by the Kioto carbonate.

From the Tandi Group in Lahual, *Thamnaestrea* and *Montlivaltia* (Picket *et al.*, 1975) have been reported. This sequence is highly tectonised, and carbonate buildup, if any, shall be difficult to decipher.

An exhaustive review of the Triassic reefs is provided by Flügel (1981, 1982). Late Triassic build-ups are known from Northern and Southern Alps, Western Carpathians, Tatra Mountain, Apeninnines, Sicily, Dinarides (Yugoslavia), Hungary, Rumania, Bulgaria, Greece, Anatolia, Caucasus, Central Iran, Pamir, Karakorum range, Yunan, Molucas, Timor, Japan and USA (Nevada, California, Oregon, Idaho, British Columbia and Alaska).

GLOBAL DEVELOPMENT OF CARBONATE BUILD-UPS THROUGH AGES VIS-A-VIS DEVELOPMENT IN THE HIMALAYA

As the evolution of life progressed the, builders, binders, encrusters and dwellers in the build-ups varied. However, the geometry and zonation of facies in build-ups and reefs have been broadly identical through out the stratigraphic column. Facies zonation even in early Proterozoic stromatolitic reef is closely comparable with those found in the younger barrier reefs (Hoffman, 1974). Global occurrences of reefs of various ages have been reviewed and summarised by Heckel (1974) and Wilson (1975). The occurrences and characteristics of Early Palaeozoic reefs have been summed up by Copper (1974) and those of the Triassic by Flugel (1981, 1982). The development of build-ups/reefs has not been uniform throughout the stratigraphic columns. There have been periods of hyper-activity of carbonate build-ups, intervened by relatively lean periods of construction. Six or seven constructional peaks have been intrepreted by James (1984) and Sheehan (1985). Sheehan (1985) interpreted that each reef building period was terminated by an extinction event involving build-up and also level-bottom communities.

Periods intervening the peaks lacked biota capable of frame-building.

Talent (1988) who identified nine pinnacles in the history of organic carbonate build-ups, argued that despite extinctions several frame builders did survive during many intervals in between the pinnacle periods. He emphasised that the sluggish construction-activity-periods of several million years could be when 'decimated population' recovered or re-established 'symbiotitic relationship' for 'grand scale frame building'. Talent (1988), besides changing fabric of symbiotic relationship, suggested major pattern of global climate, global sedimentary tectonic events and sequence of global life crises to be the controlling factors in organic reef-building activity.

The build-ups in the Himalaya are much smaller in dimensions as compared to other parts of the world but nevertheless mark important events of organic build-ups. The Early Cambrian (Tal Group) and Middle Cambrian (Kunzam La) build-ups were obliterated due to tectonic event which is correlatable with Pan-African event. The Tal sequence is followed uncomformably by the Permian Bijni Formation, whereas unconformably over the Kunzam La Formation occurs the arenaceous sequence of the Thango Formation.

The Takche Build-up (Late Ordovician? to Early-Middle Silurian) too is overlain by an arenaceous sequence of the Muth Formation along an unconformity.

The Lipak Formation shows an uneven distribution due to pre-Early Permian erosion, and only in a few sections complete sequence is developed. In such sections the build-up is followed by the gypsum of Sabkha facies.

The Hangrang sequence, as stated earlier, forms part of a major regressive cycle and is succeeded by clastic sequence of the Alror Formation.

The Kioto Carbonate sequence including build-ups, along unconformity, is succeeded by the shale of the Jurassic Spiti Formation.

The organisms which dominated building activity during various periods besides others, have been reviewed by Heckel (1974) and Talent (1988). The diagrammatic representation of skeletal elements through ages after James (1983) is provided in fig. 2 in which the Himalayan elements, too, have been shown.

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EXPLANATION OF PLATES

Plate I

1. Algal pisolite in hand specimen (x 0.75), Krol E Formation. Loc. Dohana, (Sirmaur).

2. Stromatolitic- *Epiphyton* build-up, Kunzam La Formation. Loc. Dislodged boulder near Patseo (Lahaul Valley).

3. *Ecclimdictyon* (stromatoporoid) encrusting a coral, in left top corner is a bryozoa, (x2.5), Takche Formation. Loc. Leo (Kinnaur).

4. Mud-filled *Favosites* colony, (x 3.5), Takche Formation Loc. Leo (Kinnaur).

5. *Vermiporella* grainstone, (x 40), Takche Formation. Loc. Manchap (Tidong Valley).

6. *Girvanella*- filamentous and also beaded, (x 40), Takche Formation. Loc. Manchap Valley (Todong Valley).

7. *Halysites* framestone, with in the interspace of chains occur *Vermiporella*, Takche Formation. Loc. Manchap (Tidong valley).

8. Intergrowth of *Favosites* with some smaller corals (?), (x5), Takche Formation. Loc. Takche (Spiti Valley).

9. Sparite-filled cavity in coral and bryozoa. In bryzoa central part of the cavity is filled by micrite (x 2.5), Takche Formation. Loc. Manchap (Tidong valley).

3-9. micro-sections, except figs 5 &. 6 all are slide prints.

Plate II

1. Algal (?) bindstone, (x 5), Lipak Formation, Loc. Takche (Spiti Valley).

2. Coral framestone, (x 5), Lipak Formation. Loc. Takche (Spiti Valley).

3. A view of Hangrang reef, N.W. of Hangrang pass.

4. Calcisponge (*Colospongia)* hydrozoa bafflestone (x 2.5), Hangrang Formation. Loc. Pin-Spiti confluence.

5. *Thecosmilia* colony, Hangrang Formation. Loc. Pin- Spiti confluenc.

6. *Thecosmilia* framestone 9x 5), Kioto Formation. Loc. Sakti (Lingti valley).

Plate I

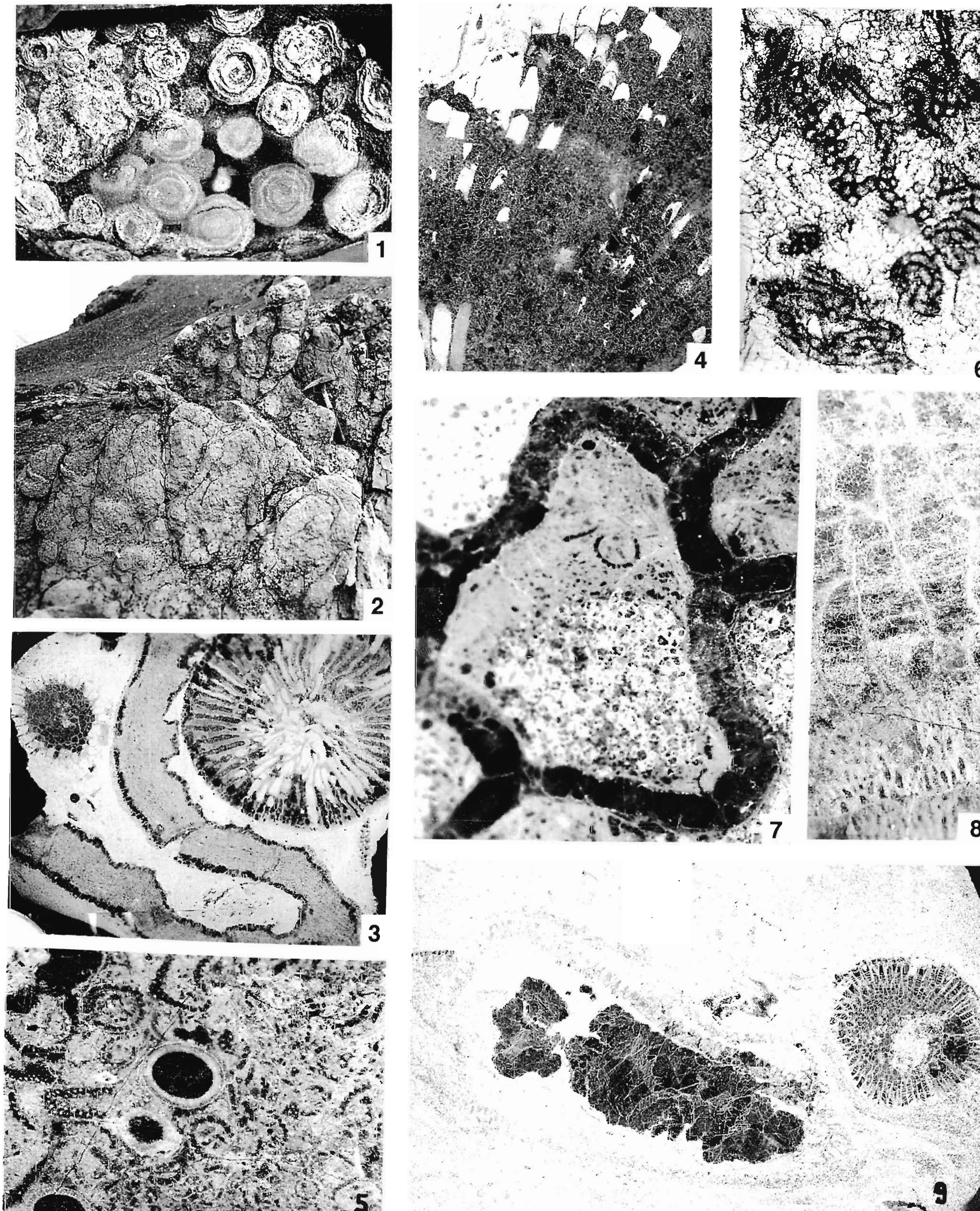

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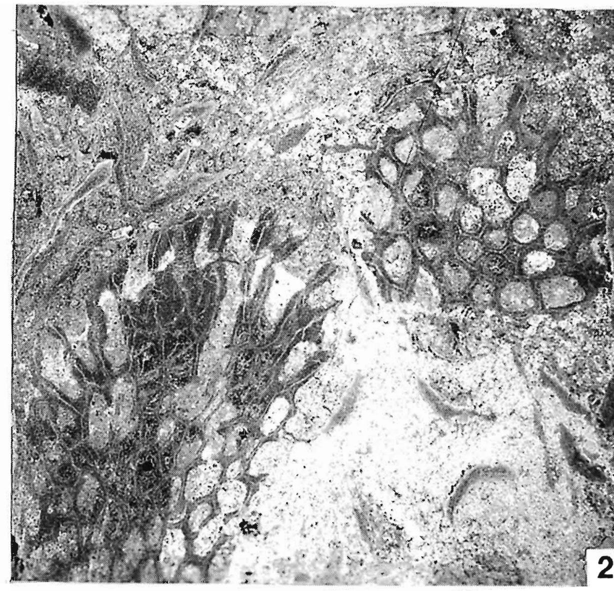
Plate II


1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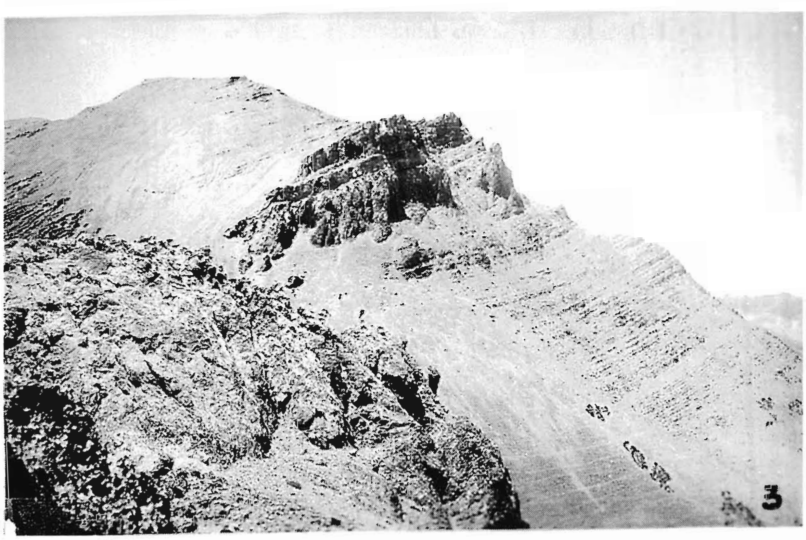
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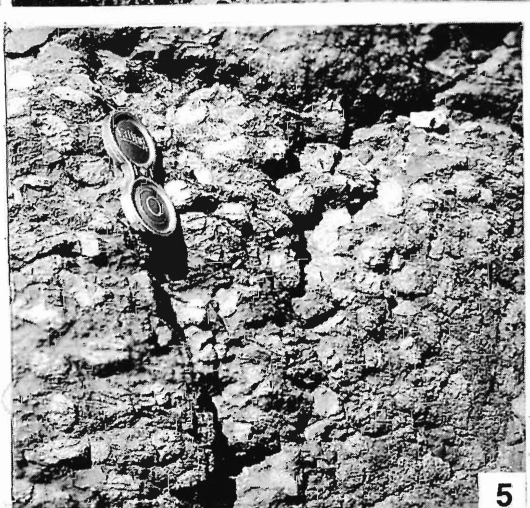
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