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LITHOSTRATIGRAPHY, STRUCTURE, DEPOSITIONAL ENVIRONMENT, PALAEOCURRENT AND TRACE FOSSILS OF THE TETHYAN SEDIMENTS OF MALLA JOHAR AREA, PITHORAGARH -CHAMOLI DISTRICTS, UTTAR PRADESH, INDIA

S. KUMAR, I. B. SINGH and S. K. SINGH

GEOLOGY DEPARTMENT, LUCKNOW UNIVERSITY, LUCKNOW — 226007.

ABSTRACT

The Tethyan sediments (Tibetan Zone) of Malla Johar area, Kumaon Himalaya, are studied from the point of view of lithostratigraphy, structure, lithology, depositional environment, palaeocurrent, trace fossils and basin evolution. Designated as Malla Johar Supergroup, these sediments are lithostratigraphically divisible into four Groups namely Malari, Sumna, Rawalibagar and Sancha Malla. These Groups are further subdivided into various formations and members, each of which shows a characteristic lithology.

Structurally, the Malla Johar area is divisible into three tectonic units; from south to north these are the Central Crystallines, the Malla Johar Supergroup and the Exotic Formation, separated from each other by thrust faults. No large scale folding is seen in the rocks of Malari Group and Sumna Group. However, very tight folding is witnessed in the rocks of the Rawalibagar Group and Sancha Malla Group. The general trend of the fold axes is NW—SE plunging in northerly direction.

The complete succession of the Malla Johar Supergroup, ranging in age from Precambrian to ?Lower Eocene represents deposits of a single sedimentation basin. Except for the topmost part, the sediments are entirely made up of shallow water deposits. This Supergroup exhibits four phases of sedimentation. Phase I (Malari Group) is marked by areno-argillaceous deposits of fluvial, tidal flat and coastal sand areas. Phase II (Sumna Group) shows areno-carbonate deposits of a coastal complex with medium to high energy. Phase III (Rawalibagar Group) is made up of argillo-carbonate sediments of carbonate coastal complex. Phase IV (Sancha Malla Group) exhibits argillo-arenaceous succession of continental margin. This phase of sedimentation is marked by the subaqueous volcanic activity interbedded with radiolarian and foraminiferal oozes (ophiolite association), along with the thrusting of the rocks of the Exotic Formation.

The palaeocurrent patterns are dominantly polymodal to bimodal and exhibit main current direction in NE. The sandy units of the succession are mostly orthoquartzitic and seem to have been derived from the quartzite rich Central Crystallines which served as source rock.

In all 36 trace fossils are described from the Malla Johar Supergroup. The shallow water facies of Sumna and Rawalibagar Groups are characterized by crawling traces and dwelling structures. The deep water Sancha Malla Group is characterised by dominantly feeding structures.

INTRODUCTION

The Trans-Himalayan Zone, north of the high mountain chain of Central Himalaya, comprises of nearly 15,000 metres thick Tethyan sediments. A highly fossiliferous and almost complete sequence from Late Precambrian to Cretaceous is well preserved in low to moderately disturbed, but more or less unmetamorphosed Tethyan sequence. This sequence is characteristically distinct from the Central and Lesser Himalayan rocks and extends from Nepal to Kashmir with remarkable similarity in lithology and fauna.

On the basis of faunal affinities between Himalaya and Alps these sediments (Tibetan Zone of Gansser, 1964) are purported to have been deposited in the early Tethys sea which extended from present day Atlantic to Pacific oceans.

As early as 1851, Strachy studied Tethyan sediments of Kumaon Himalayas. Due to hazardous terrain and unfavourable climate, the later works were in the form of sketchy notes on structure and stratigraphy. Even many expeditions from different agencies confined themselves to routine stratigraphic analysis without venturing into the domain of systematic basinal analysis.

Since 1971, Wadia Institute of Himalayan Geology, has been organising expeditions to the Tethyan belt of Kumaon Himalaya with an aim to unravel the geological history of this part of Himalaya. One of the authors (S. K.) was a member of two such expeditions of 1972-73 and made preliminary studies in Malla Johar area. An independent expedition to the same area (Fig. 1) was organised by the Department of Geology, Lucknow University, during July-September, 1974. The authors of the present paper comprised the team and they prepared a detailed litholog of the entire stratigraphic succession, systematically collected samples for paleontological and sedimentological analysis, measured azimuthal readings for paleocurrent analyses and studied layer properties for environmental reconstruction. A single profile along the Girthi Ganga, Yong and Kio valleys was chosen for detailed study.

The area of investigation constitutes northwestern part of Pithoragarh and northeastern parts of Chamoli districts U. P. It lies between long. 79°51′—80°45′ E, lat. 30°25′—30°45′ N, and is approachable by Rishikesh-Malari Road. From Malari the area is traversed along mule track. The northern limits of the area constitutes Indian border with Tibet. Field work in this area is possible only between June to September. During the rest of the year, it is covered by snow. The height ranges between 3000 m to 6000 m.

PREVIOUS WORK

Strachy's (1851) fossil collection from Malla Johar area was described by Salter and Blanford (1865). Griesbach (1891, 1893) mapped the area and established the stratigraphic subdivisions. He gave a lucid account of the geology of the Central Himalaya. von Kraft (1902) studied the Exotic Blocks in great detail. However, much insight on the geology of Malla Johar area was provided by the work of Heim and Gansser (1939) and Gansser (1964). Kumar *et al.* (1972) described the generalised stratigraphy and structure of Darma, Girthi & Niti valleys Valdiya *et al.* (1971) and Valdiya and Gupta (1972) studied paleontological and stratigraphical aspects of these sediments in Kali and Kuti valleys and reported new fossil bearing horizons. However, systematic sedimentological and palaeontological studies for the purpose of environmental analyses of these sedimens were generally neglected.

GEOLOGICAL SETTING

In the present area, the rocks are divisible into three major tectonic units (Fig. 1, 2). The southern extremity of the area is occupied by the highly metamorphosed rocks of the Central Crystallines. North of the Central Crystallines, the Tethyan sediments constitute the second tectonic unit. In the northern extremity are the rocks of the third tectonic unit, the Exotic Formation (Exotic Blocks of Griesbach, 1893). The rocks of the Exotic Formation belong to a sedimentary sequence which differs considerably from the Tethyan sediments both in lithology and faunal assemblage (von Kraft, 1902). In the present work only Tethyan sediments have been studied.

STRATIGRAPHY

The most widely accepted stratigraphical subdivisions were given by Heim and Gansser (1939). In Heim and Gansser's subdivision no distinction is made between the use of lithostratigraphic and biostratigraphic terms which need revision. Gansser (1964), Kumar et al (1972) and Valdiya and Gupta (1972) suggested some changes in the stratigraphic nomenclature of Tethyan sequence. In the present work, the scheme of stratigraphic subdivision of Heim and Gansser (1939) has been scrutinized in the light of Code of Stratigraphic Nomenclature for Indian Stratigraphy (1971). Several old names have been retained while new names have been proposed where necessary. These have been designated simply as A, B, or C etc. as non-formal units due to paucity of local names.

Heim and Gansser (1939) have lithostratigraphically subdivided the rocks of Trans-Himalayan zone into Dravidian Group and Aryan Group and have included widely contrasted lithologic units in each group. As such, the Dravidian Group includes highly metamorphosed rocks of the Central Crystallines, low grade metamorphic rocks of the Martoli Formation and unfossiliferous and fossiliferous sedimentary sequence of the Precambrian and Palaeozoic age. The thickness of the Central Crystallines is more than 1,5000m which may lithologically constitute a separate group or even a supergroup. According to the Indian Code of Stratigraphic Nomenclature (1971) a group is recognized for the purpose of expressing the natural relations of the associated formations. As such it is suggested that the high grade metamorphic rocks of the Central Crystallines which also seem to be much older than the Tethyan succession should not be grouped with the sedimentary rocks of the Tethayn Zone. For the entire Tethyan sedimentary sequence a new term Malla Johar Supergroup is suggested, the name being derived from the word Malla Johar by which the region is known and where the rocks of this Supergroup are well exposed. It has been subdivided into four lithostratigraphic units : Malari, Sumna, Rawalibagar and Sancha Malla groups.

The rocks of the Exotic Blocks of Griesbach (1893) have been redesignated as Exotic Formation. These rocks belong to distinctly different lithologic facies with respect to the underlying rocks, and constitute a separate tectonic as well as lithostratigraphic unit.

The proposed lithostratigraphic succession of Tethyan sediments of Malla Johar area and their age equivalence have been given in Table 1 (Figs. 3, 4). For the description of primary sedimentary structures and interpretation, the terminology proposed by Reineck and Wünderlich (1969), Reineck (1970) and Reineck and Singh (1973) has been followed.

DESCRIPTION OF STRATIGRAPHIC UNITS

CENTRAL CRYSTALLINES

In the area under study, the Central Crystallines are represented by augen gneisses which are mylonised and crushed near their contact with the Martoli Formation of the Malla Johar Supergroup due to Dar-Martoli Fault (Kumar *et al.*, 1972). The mesoscopic faults, sills and

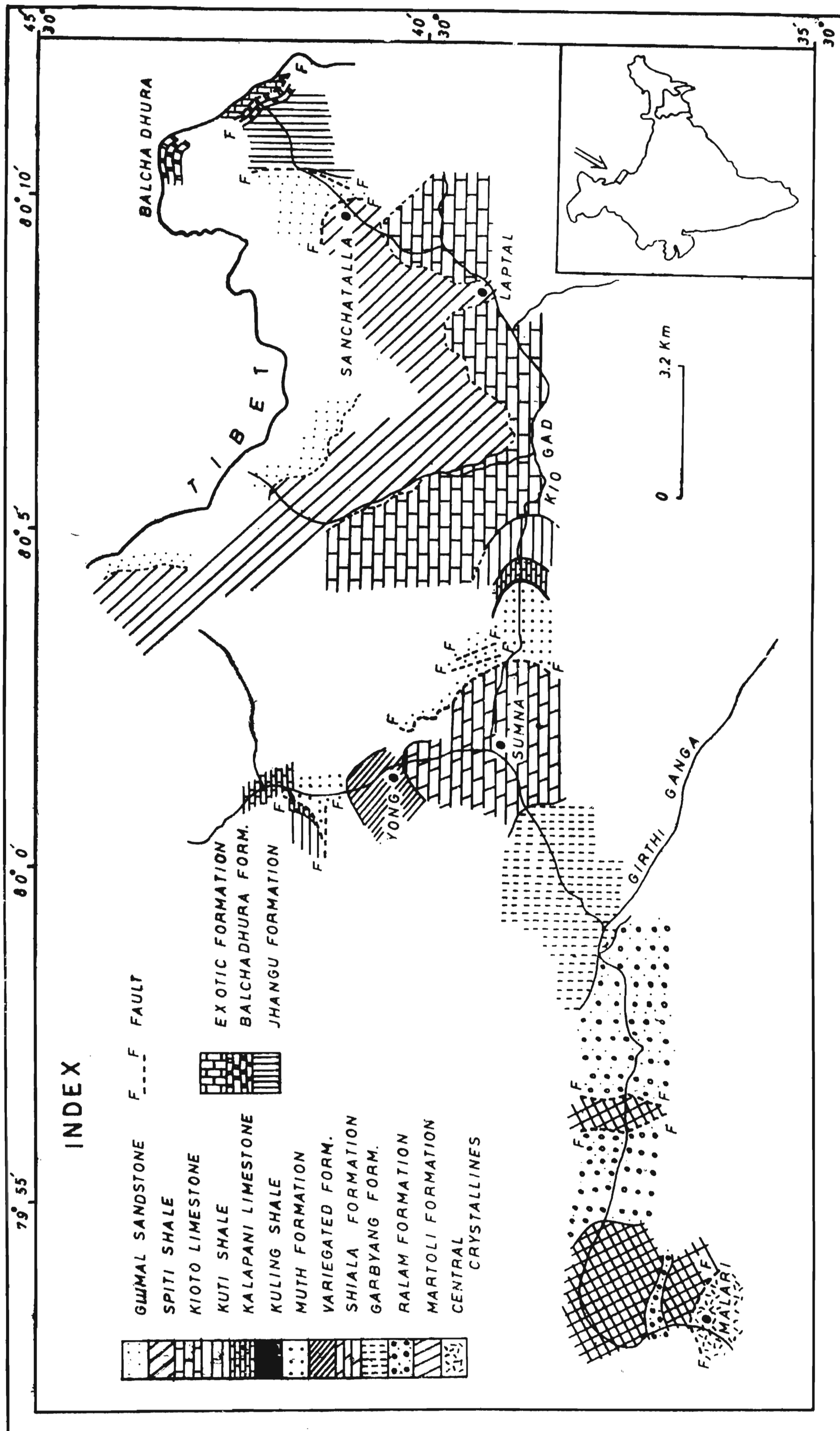


Fig. 1. Geological map of Malla Johar area, Kumaon Himalaya, Pithoragarh-Chamoli districts, U. P.

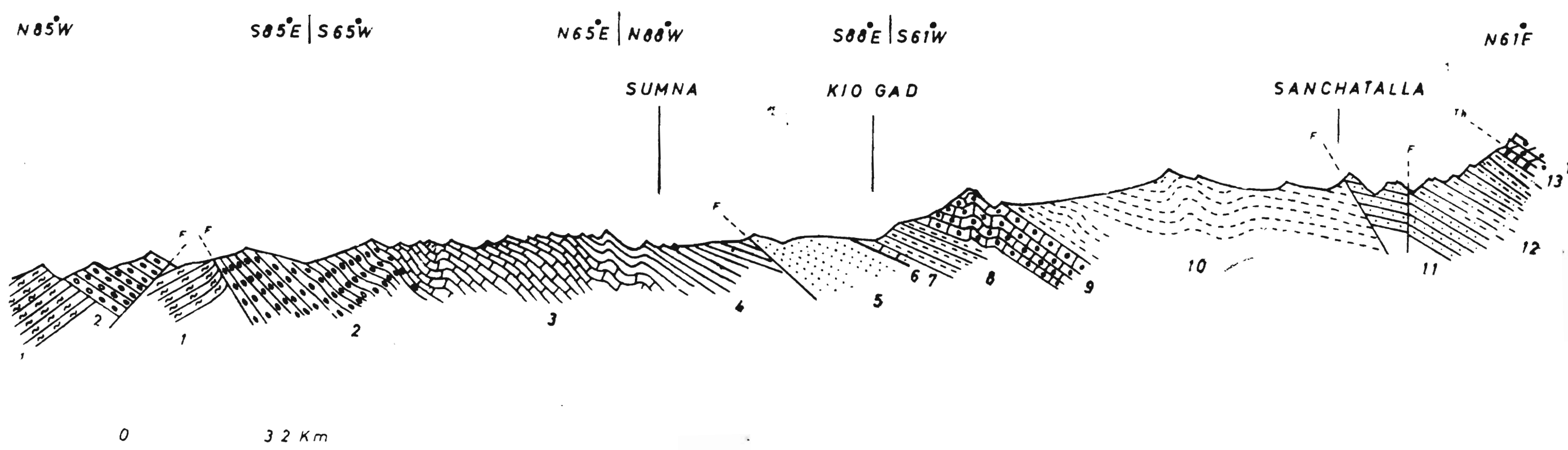


Fig. 2. Geological Section.
1. Martoli Formation, 2. Ralam Formation, 3. Garbyang Formation, 4. Shiala Formation, 5. Muth Formation, 6. Kuling Shale, 7. Kalapani Limestone, 8. Kuti Shale, 9. Kioto Limestone, 10. Spiti Shale, 11. Giumal Sandstone, 12. Jhangu Formation, 13. Balcha Dhura Formation, 14. Exotic Formation.

Table 1.

Lithostratigraphic Subdivisions, Trace Fossils and Environment of Deposition of the Tethyan Succession of Malla Johar Area, Kumaon Himalaya, U. P.

Super-group	Group	Formation	Member	Lithology	Environment of Deposition	Trace Fossils	Age
1	2	3	4	5	6	7	8
SUPERGROUP	SUMNA GROUP	GARBYANG FORMATION	Garbyang G 140 m	Silty sandstone and shale	Transition zone shelf mud area.		Cambrian
			Garbyang F 120 m	Oolitic limestone, calcareous sandstone and shale.	Tidal flat		
			Garbyang E 45 m	Shale and sandstone	Intertidal transition.	*Rouaultia* de Tromelin, 1877	
			Garbyang D 70 m	Sandstone and shale	Tidal flat	Ichnogenus *Form* B	
			Garbyang C 165 m	Limestone, calcareous sandstone and shale.	Sand bar/shoal	Ichnogenus *Form* A	
			Garbyang B 110 m	Dolomites, marls and gypsiferous shales.	Supra-intertidal.		
			Garbyang A 46 m	Limestone, dolomitic limestone and subordinate shales with veins of barytes.	Shallow tidal sea.		
MALLA JOHAR	MALARI GROUP	RALAM FORMATION	Ralam D 30 m	Sandstones and green shales	Tidal flat		Late Precambrian
			Ralam C 90 m	Orthoquartzites	Beach-shoal complex		
			Ralam B 450 m	Orthoquartzites and subordinate shales	Sand flats		
			Ralam A 30 m	Conglomerate with dark gray orthoquartzite	Coastal rivers		
				Unconformity ?			
		MARTOLI FORMATION	Martoli C 50 m	Light green and brown phyllites and quartzites	Subtidal		Early Precambrian
			Martoli B 90 m	Dark gray phyllites, quartzitic phyllites	Transition zone to shelf mud region		
			Martoli A 70 m	Black phyllites, dark gray quartzites	Subtidal		
				Thrust			
		CENTRAL CRYSTALLINES		Augen gneisses and pegmatites			Archean

Table 1—(*Contd.*)

Super-group	Group	Formation	Member	Lithology	Environment of Deposition	Trace Fossils	Age
1	2	3	4	5	6	7	8
MALLA JOHAR SUPERGROUP	RAWALIBAGAR GROUP	KULING SHALE	Kuling B 20 m	Black shales and subordinate siltstone with calcareous nodules.	Shallow shelf mud region.		Permian.
			Kuling A 7 m	Grayish black siltstone, with shell limestone.	Upper part of shelf mud-transition zone.		
	SUMNA GROUP	MUTH FORMATION	Muth C 80 m	Orthoquartzites	Sandbar/shoal		Devonian.
			Muth B 30 m	Sandy shales, siltstone and orthoquartzites.	Mixed tidal flat.		
			Muth A 60 m	Calcareous orthoquartzite, shaly sandstone and shale.	Sandy tidal flat-sandbar.		
		VARIEGATED FORMATION	Variegated C 33 m	Shale and limestone	Shallow water carbonates		Silurian.
			Variegated B 20 m	Limestone, shale and siltstone.	Shallow water carbonates.	*Volkichnium* Pfeiffer, 1965	
			Variegated A 46 m	Nodular limestone and calcareous shale	Zero energy carbonate flat.		
		SHIALA FORMATION	Shiala G 75 m	Sandy shell limestone and shale.	Medium energy coastal sand area.		Ordovician
			Shiala F 70 m	Shell limestone, shale and sandstone	Medium to high energy coastal area.	*Dimorphichnus* Seilacher, 1955 *Fucusopsis* Vassoievitch, 1932	
			Shiala E 40 m	Shell limestone and calcareous shale	Medium to high energy coastal area.	*Helminthopsis* Heer, 1877	
			Shiala D 180 m	Orthoquartzites and shale	Medium energy sandy tidal flat/shoal complex	?*Planolites* Nicholson, 1873 Ichnogenus *Form* C	
			Shiala C 165 m	Shell limestone intraformational conglomerate and shale.	Subtidal to intertidal zone.	? *Tomaculum* Groom, 1902.	
			Shiala B 40 m	Shales and limestones	Intertidal-subtidal zone		
			Shiala A 140 m	Shales and sandstones with shell limestone	Transition zone		

Table 1—(*Contd.*)

Super-group	Group	Formation	Member	Lithology	Environment of Deposition	Trace Fossils	Age
1	2	3	4	5	6	7	8
MALLA JOHAR SUPERGROUP	SANCHA MALLA GROUP	**SPITI SHALE** 200 m		Black friable shales and siltstone with abundant nodules containing ammonites.	Shelf mud region	Ichnogenus *Form F* *Zoophycus* Massalongo 1855 *Chondrites* Sternberg, 1833 *?Gyrolithes* Desaporta, 1884.	Portlandian.
	RAWALIBAGAR GROUP	**FERRUGINOUS OOLITE FORMATION** 10 m		Ferruginous oolitic limestone and shale with abundant ammonites.	High energy carbonate shoals.		Callovian.
		LAPTAL FORMATION 70 m		Shell limestone, limestone, oolitic limestone, marls and shales.	High energy shoals and channels.		Liassic.
		KIOTO LIMESTONE	Kioto D 30 m	Oolitic limestone and shell limestone.	Oolitic sand bar		Rhaetic.
			Kioto C 30 m	Limestone, shell limestone and shale.	Coastal carbonate complex.	Ichnogenus *Form E*	
			Kioto B 30 m	Nodular limestone	Coastal carbonate.		
			Kioto A 50 m	Oolitic limestone, limestone and shale.	Carbonate shoal-sandbar.		
		PASSAGE FORMATION 90 m		Shell limestone, limestone silty shale and orthoquartzites.	Tidal flat complex.	*Laevicyclus* Quenstedt, 1879. Ichnogenus *Form D*	
		KUTI SHALE	Kuti C 100 m	Silty shale and sandy limestone.	Transition zone-subtidal zone.		Noric.
			Kuti B 280 m	Grayish black, friable shale with hard calcareous shale.	Transition zone		
			Kuti A 130 m	Black friable shales and shaly limestone.	Upper part of shelf mud region.		
		KALAPANI LIMESTONE 25 m		Limestones, shell limestone, and shales with abundant megafossils (ammonites).	Shelf mud carbonate shoal/sandbar.		Anisic. to Carnic
		CHOCOLATE FORMATION 7 m		Limestone, shell limestone with black shale.	Upper part of shelf mud-transition zone.		Scythic.

Table 1—(*Contd.*)

Super-group	Group	Formation	Member	Lithology	Environment of Deposition	Trace Fossils	Age
1	2	3	4	5	6	7	8
		EXOTIC FORMATION		White oolitic limestone	Marine shallow water.		
....	....	....	....	Thrust	....	....	....
		BALCHADHURA FORMATION 90 m		Basic volcanic rocks interbedded with reddish brown and grayish green shales. Volcanic rocks show pillow structure.	Deep sea		Lower Eocene (?)
MALLA JOHAR SUPERGROUP	SANCHA MALLA GROUP	JHANGU FORMATION	Jhangu F 5 m	Red shales	Deep sea	Ichnogenus *Form L*	Upper Cretaceous.
			Jhangu E 5 m	Red and green shales and chert.	Deep sea—continental margin	*Rhizocorallium* Zenker 1836 *Zoophycus* Massalongo, 1855 *Planolites* Nicholson, 1873 aff. *Sublorenzinia* Ksiazkieniez, 1968 *Olivellites* Fenton and Fenton, 1937.	
			Jhangu D 120 m	Dark grayish green grawacke and shales.	Continental margin.	Ichnogenus *Form K*	
			Jhangu C 35 m	Orthoquartzites, Calcareous sandstones, shales and limestones with cone in cone structure.	Continental margin.	Ichnogenus *From J* *Nereites* Macleavy, 1839.	
			Jhangu B 170 m	Black shales, marls and limestone.	Continental margin.		
			Jhangu A 65 m	Red foraminiferal limestone and red shales.	Deep sea		
		GIUMAL SANDSTONE.	Giumal E 80 m	Shale and siltstone	Continental slope.	*Rhizocorallium* Zenker, 1836 *Taenidium* Heer, 1877 *Phycosiphon* Fischer Ooster, 1858.	Lower Cretaceous.
			Giumal D 30 m	Glauconitic sandstone, siltstone and shale.	Continental margin.	Ichnogenus *Form I*	
			Giumal C 160 m	Glauconitic sandstones with minor shale.	Continental slope.	*Zoophycus* Massalongo, 1855	
			Giumal B 90 m	Glauconitic sandstone and shale.	Continental shelf-continental slope.	*Neonereites* Seilacher, 1960 Ichnogenus *Form H* Ichnogenus *Form G*	
			Giumal A 40 m	Shales siltstone, limestone and radiolarian chert.	Continental shelf-continental slope.	*Stellascolites* Etheridge, 1876. *Saportia* Squinabol, 1891	

dykes occur near this contact. These gneisses dip in NE—40° and mark the southern limit of the Tethyan sediments. The study of the Central Crystallines is beyond the scope of present work and hence, will not be discussed further.

MALLA JOHAR SUPERGROUP

This Supergroup includes rocks of the Tethyan sequence between highly metamorphosed rocks of the Central Crystallines and the sedimentary rocks of the Exotic Formation (Exotic Blocks of Griesbach, 1893) (Table 1).

MALARI GROUP

The non-carbonate areno-argillaceous units occurring between the Garbyang Formation and the Central Crystallines have been designated as Malari Group after the village Malari. This Group shows a faulted contact with the underlying Central Crystallines and gradational relationship with the overlying Garbyang Formation of Sumna Group. The Garbyang Formation is more or less destitute of fossils, therefore, the boundary between the Malari Group and the Garbyang Formation is taken from where the argillo-arenaceous facies grades to calcareous facies.

The Malari Group is divisible into two formations; namely the Martoli Formation and the Ralam Formation.

MARTOLI FORMATION

The Martoli Series of Heim and Gansser (1939) is exposed in the Gori Ganga Valley, east of the present area which overlies the Central Crystallines. These low to medium grade metamorphosed rocks constitute the oldest lithologic unit of the Tethyan sequence in Kumaon Himalaya and have been assigned Algonkian age. The Martoli Series has been redesignated as Martoli Formation by Gansser (1964). The thickness of the Formation near Malari is much reduced due to Dar-Martoli Fault. Their distribution in the area is given in Fig. 1. These rocks are repeated due to a fault near Girthi Valley Bridge.

This Formation is characterized by dominance of rhythmites which occur as several different variants viz. finely inter-layered sand mud bedding, graded rhythmites and combinations.

Based on lithological changes, the Martoli Formation is subdivided into three members with gradational boundaries.

Martoli A—This basal member is about 70 m thick succession of black shale/quartzite alternations. The major part of the succession shows 5-6 cm thick sand layer alternating with black shaly rhythmites. Part of the succession is also developed as 50 cm to 1 m thick lenticular and flaser bedded sequence along with tidal bedding. Rarely, thick black quartzites occur as 1 m or thicker units exhibiting large-scale cross bedding. Mud pebble layers are comonly seen in the quartzite. Quartzites are interbedded with 50 cm—1 m thick shaly units, made up of rhythmites in which 1 cm thick ripple bedded sand layers are also present.

This succession shows characteristics of a tidal environment. Moreover, planes of discontinuity and features indicating subaerial exposure are also observable. At the same time the predominance of black colour points to deposition in a reducing milieu. Apparently this sequence has been deposited in a partially protected tidal flat environment, dominantly in subtidal zone. Energy of the depositional site fluctuated resulting in the deposition of sand rich and mud rich units.

Martoli B—It is about 90 m thick succession of dominantly graded rhythmites and sand/shale alternations. Shales are dark gray in colour showing fine lamination and thinly interlayered sand/mud bedding. Though thick sand layers are totally lacking, the thin sand layers are graded often showing development of lenticular and wavy bedding. These graded sand layers show foreset laminae of ripples.

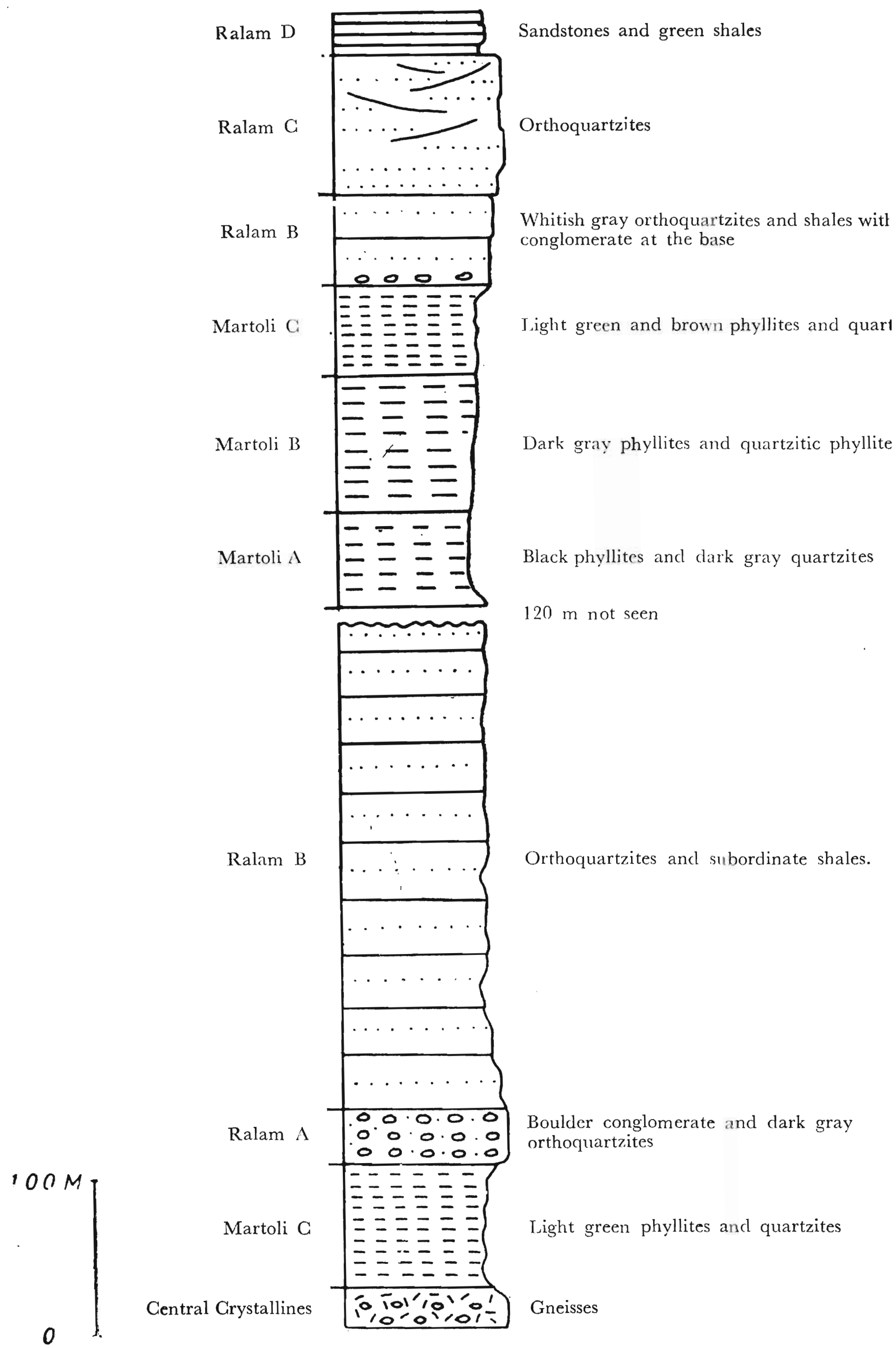
This part of the succession seems to be a deposit of a tidal sea with better circulation and aeration than Martoli A. It also lacks feature indicating subaerial exposure. It is suggested that Martoli B was deposited in more deeper subtidal zone (Transition zone to upper part of shelf mud) where sand was supplied regularly due to storms etc., and deposited as graded beds.

Martoli C—About 50 m thick light green sandy shales constitute the youngest member of the Martoli Formation. The lower part of this member is often ferruginous. On fresh surface sediments appear light greenish gray and on weathering the sand layers acquire brown colour, while the shale layers retain their greenish colour. Thick horizons of mud pebble conglomerate, and a few quartzite pebbles occur towards the base. Dominantly, the succession is made up of sandy rhythmites.

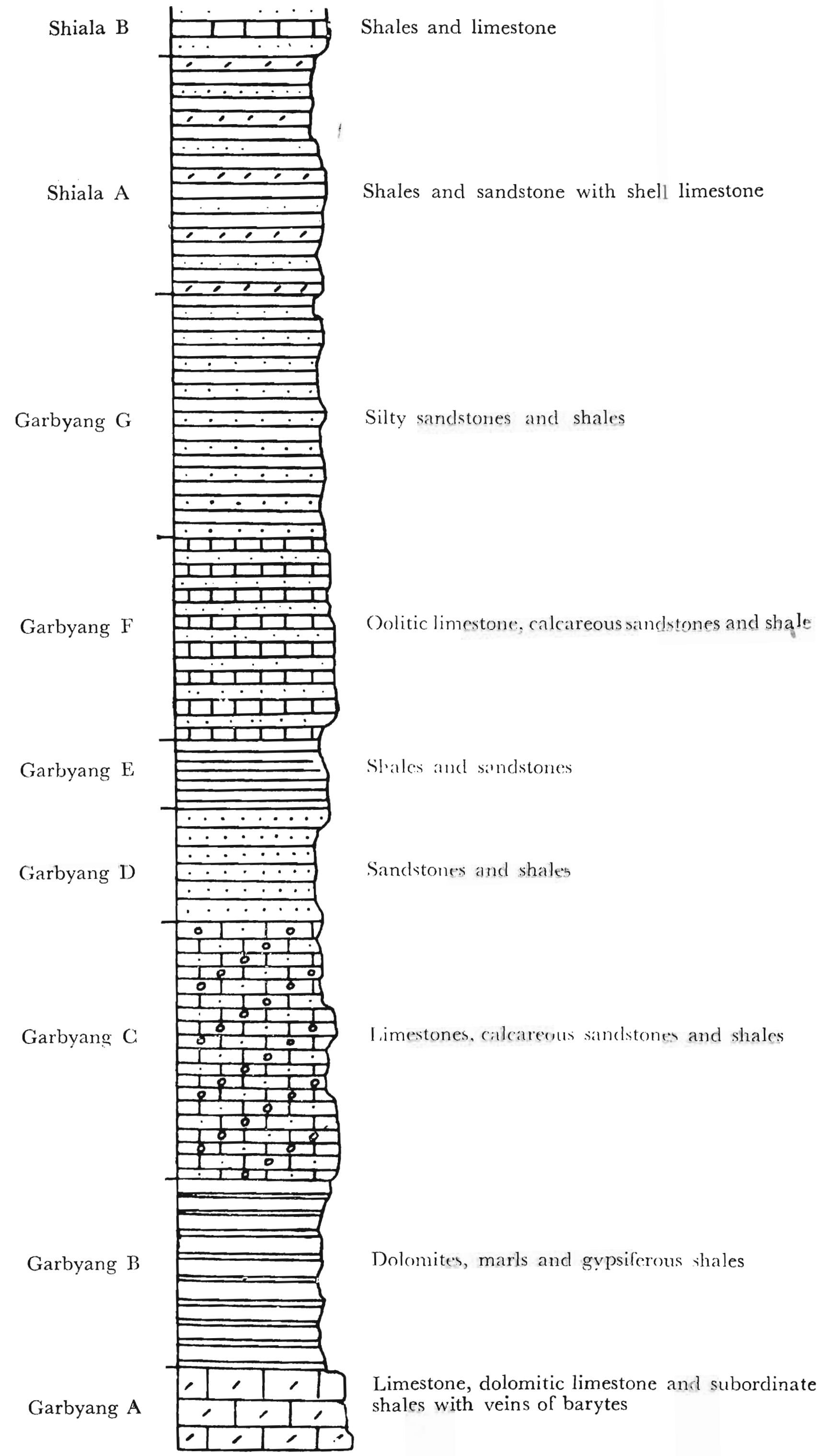
The succession shows general characteristics of a tidal environment. However, an increase in the energy of depositional site in comparison to Martoli B is inferred. The succession was laid down in the subtidal zone of an open tidal flat environment.

RALAM FORMATION

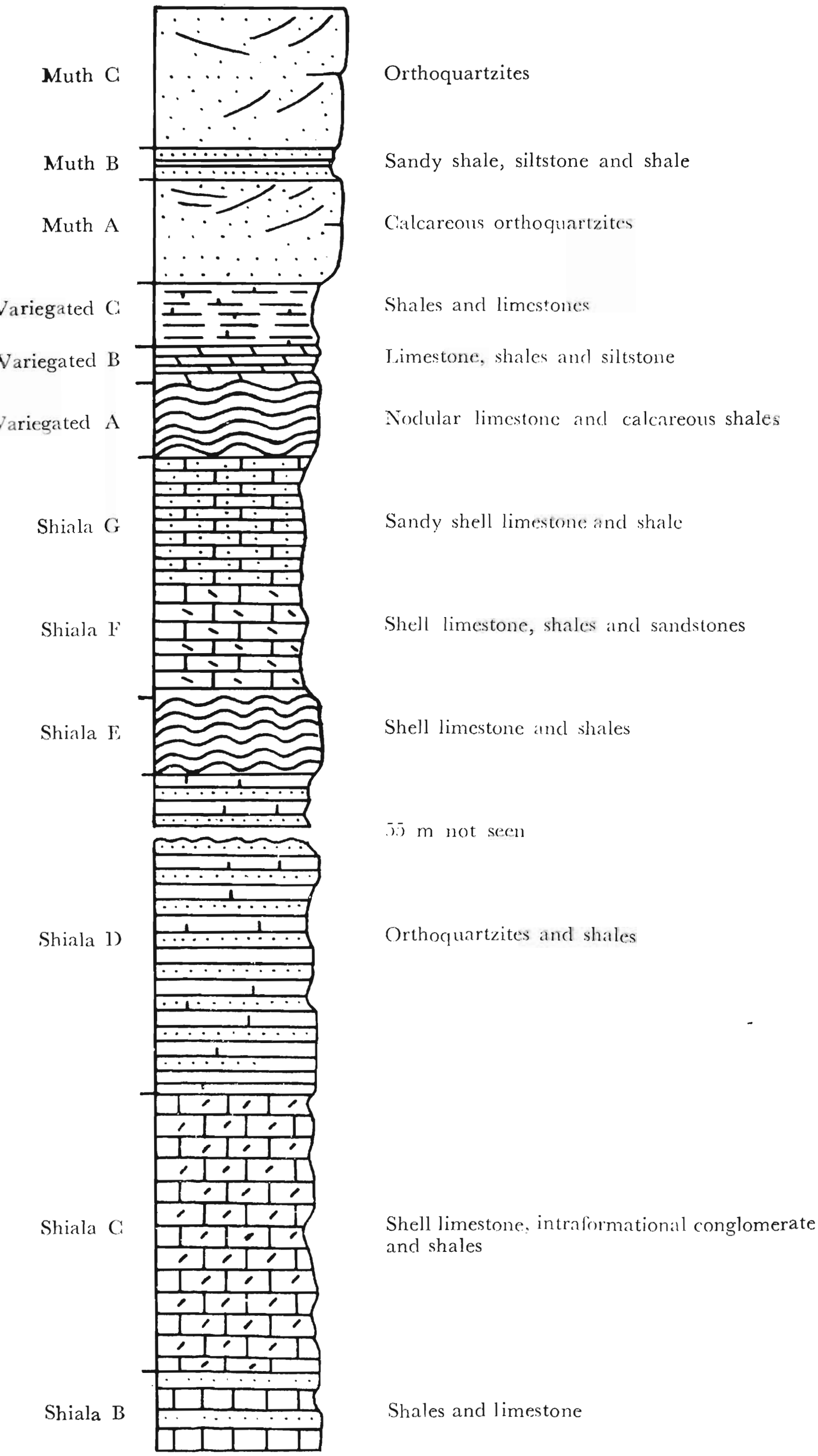
The unfossiliferous Ralam Formation (270 m) succeeds Martoli Formation possibly with an uncomformity. The unconformable contact between Martoli and Ralam formations can be studied about 2 km west of Malari on Malari-Deepak Nagar road. At other places the contact is faulted. The Ralam Series of Heim and Gansser (1939) was redesignated as Ralam Formation by Gansser (1964). The Ralam Formation is made up of conglomerate, quartzite and shale with good exposures on the motor road, east

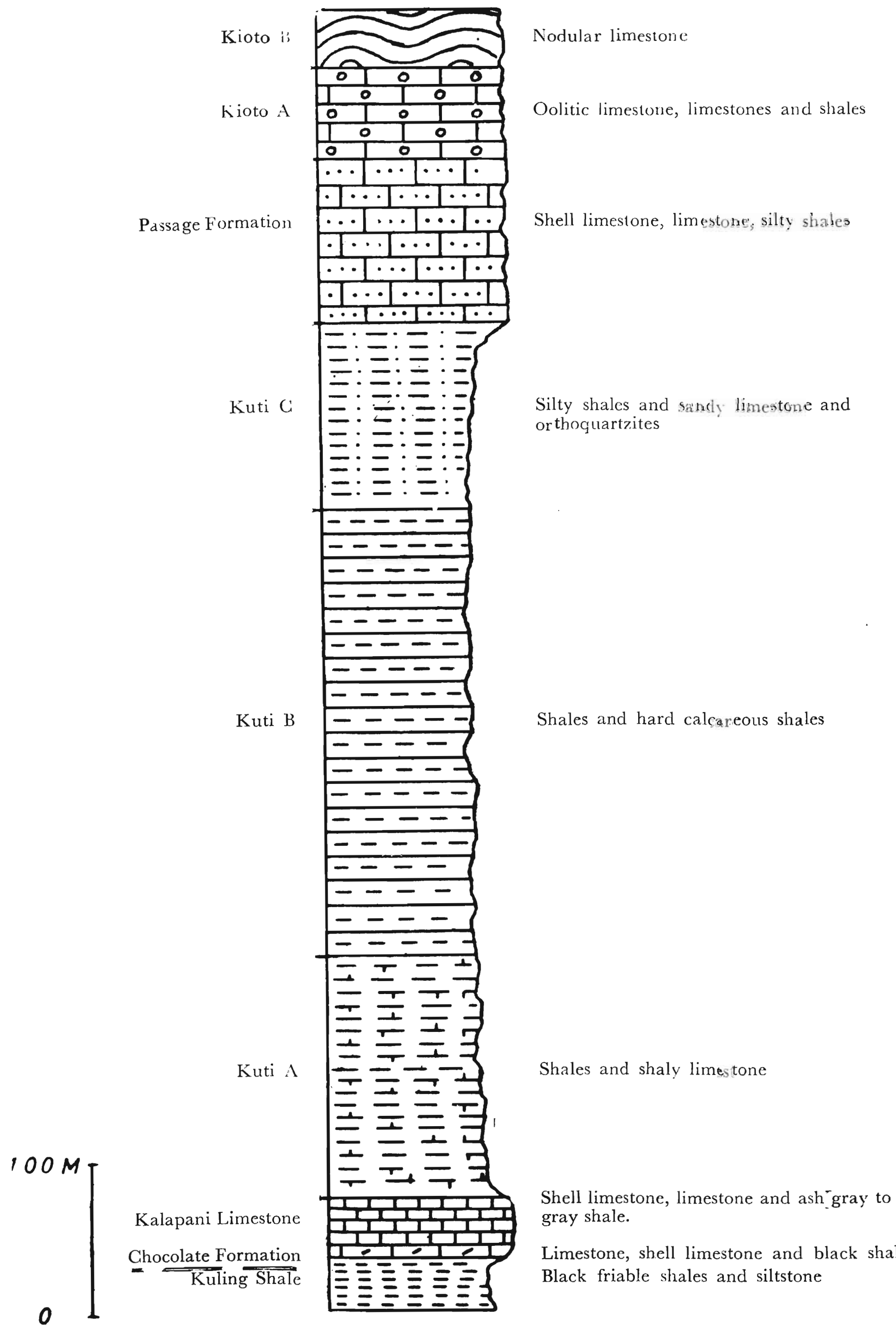


Ralam D
Sandstones and green shales
Ralam C
Orthoquartzites
Ralam B
Whitish gray orthoquartzites and shales with conglomerate at the base
Martoli C
Light green and brown phyllites and quart
Martoli B
Dark gray phyllites and quartzitic phyllite
Martoli A
Black phyllites and dark gray quartzites
120 m not seen
Ralam B
Orthoquartzites and subordinate shales.
Ralam A
Boulder conglomerate and dark gray orthoquartzites
Martoli C
Light green phyllites and quartzites
Central Crystallines
Gneisses
100 M
0



. 3. Litholog of the Tethyan Succession of Malla Johar area, Kumaon Himalaya, U. P.


Muth C
Orthoquartzites
Muth B
Sandy shale, siltstone and shale
Muth A
Calcareous orthoquartzites
Variegated C
Shales and limestones
Variegated B
Limestone, shales and siltstone
Variegated A
Nodular limestone and calcareous shales
Shiala G
Sandy shell limestone and shale
Shiala F
Shell limestone, shales and sandstones
Shiala E
Shell limestone and shales
55 m not seen
Shiala D
Orthoquartzites and shales
Shiala C
Shell limestone, intraformational conglomerate and shales
Shiala B
Shales and limestone


Kioto B
Nodular limestone
Kioto A
Oolitic limestone, limestones and shales
Passage Formation
Shell limestone, limestone, silty shales
Kuti C
Silty shales and sandy limestone and orthoquartzites
Kuti B
Shales and hard calcareous shales
Kuti A
Shales and shaly limestone
100 M
0
Kalapani Limestone
Shell limestone, limestone and ash-gray to gray shale.
Chocolate Formation
Limestone, shell limestone and black sha
Kuling Shale
Black friable shales and siltstone

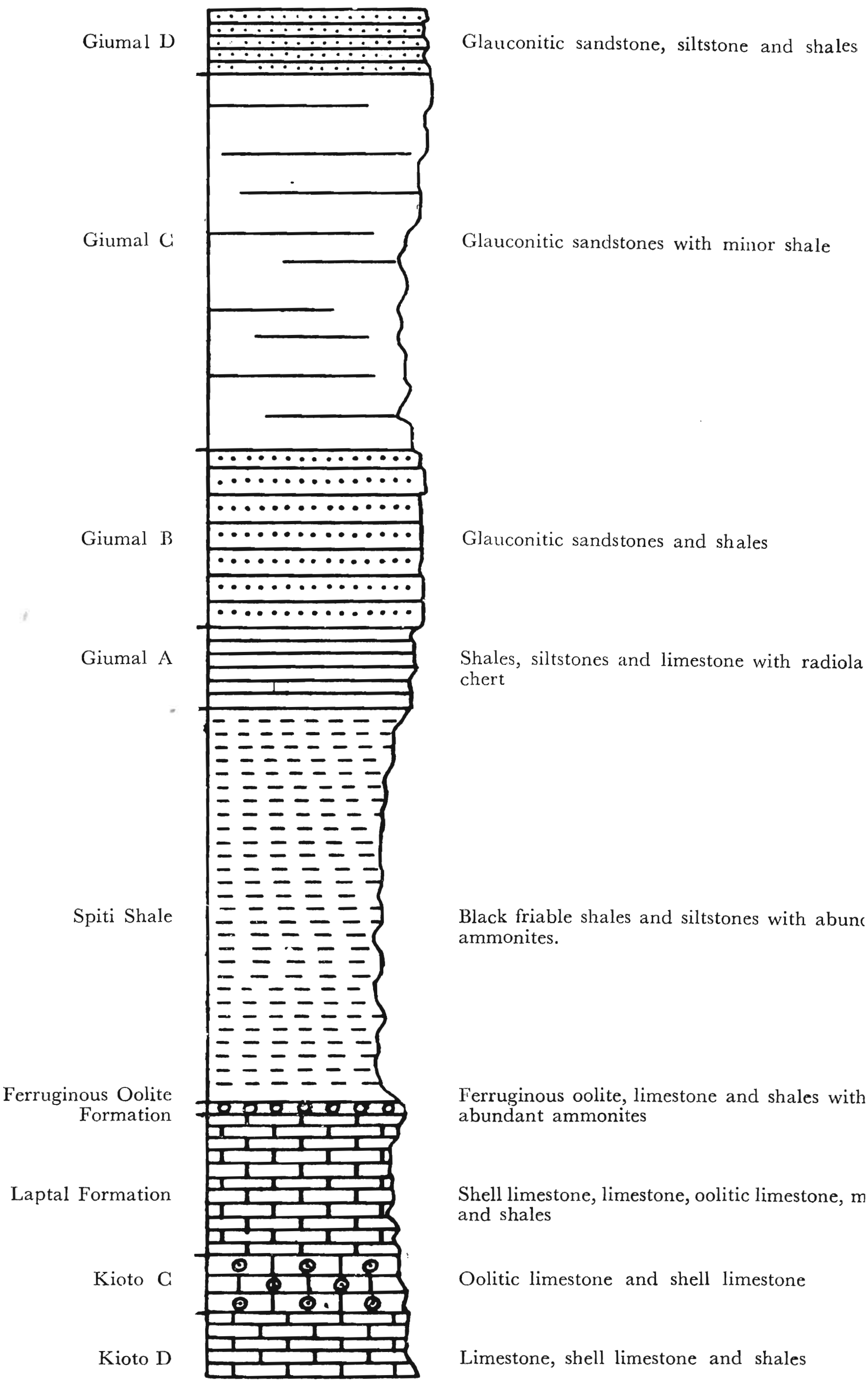
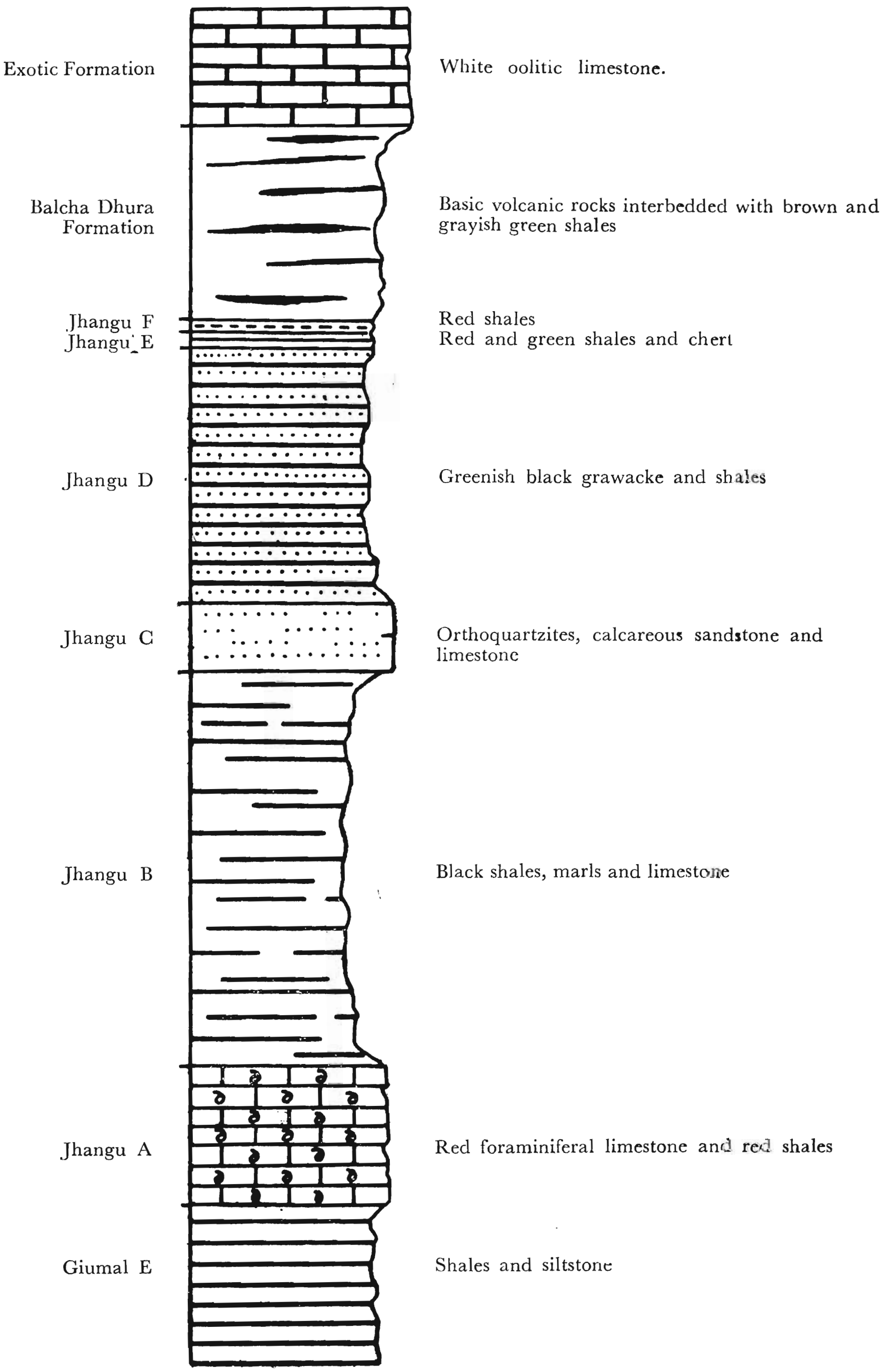


Fig. 4. Litholog of the Tethyan Succession of Malla Johar area, Kumaon Himalaya, U. P.


Exotic Formation
White oolitic limestone.
Balcha Dhura Formation
Basic volcanic rocks interbedded with brown and grayish green shales
Jhangu F
Red shales
Jhangu E
Red and green shales and chert
Jhangu D
Greenish black grawacke and shales
Jhangu C
Orthoquartzites, calcareous sandstone and limestone
Jhangu B
Black shales, marls and limestone
Jhangu A
Red foraminiferal limestone and red shales
Giumal E
Shales and siltstone

of Malari. The sequence is repeated north of the bridge in the Girthi Valley due to Girthi Bridge Fault (Fig. 1). Heim and Gansser (1939) have given Basal Cambrian age to the Ralam Formation because of their conformable position below the Garbyang Formation of Cambrian age. The present authors prefer to give the Ralam Formation a Late Precambrian age.

Lithostratigraphically, the Ralam Formation is divisible into 4 members.

Ralam A—It is about 30 m thick sequence of essentially conglomerates along with some dark gray orthoquartzites and thin shale layers. The conglomerates are made up exclusively of quartzite pebbles of different sizes embedded in a sandy matrix (orthoquartizitic composition). (Plate I-1). Boulders of 20-30 cm diameter are common while upto 60 cm diameter have been encountered. Some of the pebbles show well preserved forceset laminae, suggesting their derivation from cross bedded orthoquartzites. The pebbles are subrounded and dominantly rod-shaped. The conglomerate is highly lithified and it is not possible to take out pebbles for precise shape analysis.

Preferred orientation of the pebbles is seen only in a few cases, where they are oriented with their long axes parallel to the bedding in N 30°E—S 30°W, often exhibiting low angle of imbrication in the NE direction. On the bedding surface boulders are often arranged in clusters and groups. Interbedded with conglomerates are deci-centimetre to 1 m thick sand layers, which show lateral pinching. The sandy horizons are mostly parallel bedded. Large scale cross bedding and small current ripples often with flattened crests, are sometimes seen. The rocks are poorly sorted with a high content of clayey matrix.

There are 1-2 m thick fining upward sequences, starting with conglomerate at the base, followed by poorly sorted sand and often with a thin shale layer at the top (Fig. 5). Such sequences are considered to be charac-

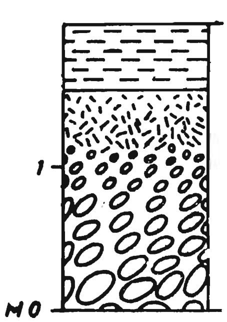


Fig. 5. Succession of sedimentary structures in Ralam A.

teristic of fluvial deposits (Allen, 1965). But, some of the conglomerate horizons show smaller pebbles near the base with increasing size of pebbles towards the top of the layer (Fig. 6).

Dominantly rod-shaped pebbles, their arrangement in clusters and faint imbrication, fining upward sequences

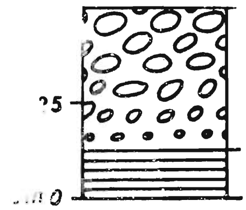


Fig. 6. Succession of sedimentary structures in Ralam A.

and poorly sorted sandy units, are indicative of a fluvial environment of deposition. The large-size of the pebbles demand a high gradient and rapidly flowing rivers of mountaneous type. It is suggested that the Ralam conglomerate was deposited by rapidly flowing streams near the shore line, with a provenance quite nearby which consisted mostly of orthoquartzite. It is highly probable that quartzite rich Central Crystallines served as the source rock.

Ralam B—On the top of Ralam A follows about 450 m thick sequence made up of about 30 cm thick quartzite bands alternating with 1-4 cm thick (green to black) shale layers. The quartzite bands show large scale cross-bedding and parallel bedding (Plate II-2). The shale layers often contain thin sand layers with ripples (Fig. 7).

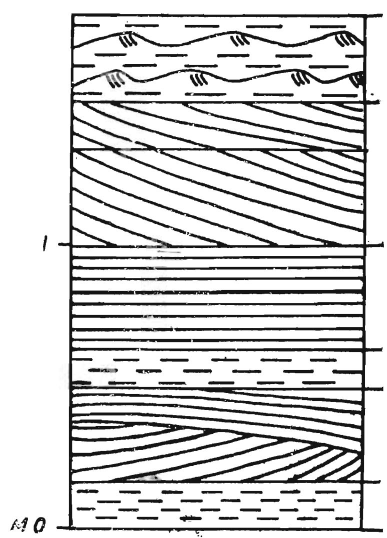


Fig. 7. Succession of sedimentary structures in Ralam B.

The change from Ralam A to Ralam B is very significant and it marks a change in the realm of sedimentation from fluvial to shallow marine. The Ralam B lacks any conglomerate horizons, moreover, the sandy units are well sorted without any appreciable clay matrix. Ripples are quite common. The Ralam B seems to represent deposits of sand flats in a coastal complex with moderate energy of sedimentation.

Ralam C—It is represented by purely arenaceous facies and attains a thickness of about 90 m. It gradually looses its shale content and acquires quartzitic character which is marked by prominence of large scale-cross bedding. The cross-bedding is dominantly megaripple bedding of both planar and trough type. Beach bar cross bedding with low angle of foresets and parallel bedding are commonly present. Planes of discontinuity, large channels, small trough shaped channels, and horizons of mud pebble conglomerate are quite common. Mud pebbles are often present at the base of cross bedded units. The sandy sequences are interrupted by few cm thick shale layers, showing rhythmite characters. The ripple marks of the type wave ripples, small current ripples, washed ripples, and ripples with rounded crests are often seen which are indicative of falling water level and subaerial emergence of the sedimentation surface.

The sedimentary structures of Ralam C indicate its deposition as coastal sand under the active influence of tidal currents. They represent deposits of a beach shoal complex with moderate to high energy.

Ralam D—The upper part of Ralam C gradually acquires more shaly layers and grades into 30 m thick succession of Ralam D. This succession shows 50 cm—1 m thick quartzite bands showing large scale cross bedding and parallel bedding alternating with about 50 cm thick units of lenticular/flaser bedding and tidal bedding. Upwards in the sequence the thickness of quartzitic layers decreases and they show dominance of various types of small ripples. Few cm thick ripple bedded sandy units alternate with mm thick shaly units. Channeling is quite well developed. The Ralam D represents deposition in a tidal flat complex of moderate energy.

SUMNA GROUP

The development of calcareous facies marks the beginning of the Garbyang Formation which has been assigned Cambrian age by Heim and Gansser (1939). From Garbyang Formation (Cambrian) upto Muth Formation (Devonian), the uninterrupted thick sequence of rocks has been designated as Sumna Group after the place Sumna (Fig. 1). The upper contact of this Group with the Kuling shales (Permian) is well marked.

The Sumna Group has been subdivided into four lithostratigraphic formations.

4.	Muth Formation	(Devonian)
3.	Variegated Formation	(Silurian)
2.	Shiala Formation	(Ordovician)
1.	Garbyang Formation	(Cambrian)

GARBYANG FORMATION

The shales of Ralam D grade into calcareous facies of the Garbyang Formation represented by varied lithologic units. The Garbyang Series of Heim and Gansser (1939) has been redesignated as Garbyang Formation by Gansser (1964). In the Kali Valley, Heim and Gansser (1939) have considered the Garbyang Formation to be of Cambrian age on the basis of the presence of flat gastropods and crinoid limestone, and also on the fact that the overlying rocks contain typical Ordovician brachiopod *Rafinesquina*. However, in the present area no well preserved fossil could be recognised in the Garbyang Formation except some shell fragments, flat gastropod and a few trace fossils. Thus, the lower boundary of this Formation is demarcated purely on lithological characters while the upper boundary with the Shiala Formation is gradational and marked on the basis of the presence of crinoid limestone. This Formation attains a huge thickness of about 726 m in Kio Valley between Deepak Nagar and Sappers Lake.

The Garbyang Formation is subdivided into 7 lithologic members with gradational contacts.

Garbyang A—The rocks of Ralam D grade into Garbyang A. This is essentially about 46 m thick carbonate succession. The lower part is made up of recrystallized ferruginous carbonate with black shale alternations. 1-2 m thick red carbonte bands showing faint large scale cross bedding are interbedded with thinly laminated black shale and black pyritiferous carbonate alternations. Thin carbonate layers mostly exhibit small ripple bedding and herringbone cross bedding. This succession is well exposed on the hill top west of Deepak Nagar.

Upwards, the succession is made up of dark coloured compact carbonates interbedded with thin layers showing vuggy structure. The carbonates are partly sandy, and show cross-bedding. Sandwitched within the succession are a few cm thick sand/shale alternations. The carbonate often contains pyrite crystals.

This sequence is marked by the presence of thin and thick veins of barytes. In parts, barytes seems to be present in bands parallel to bedding. Moreover, some of the limestone bands appear to be unusually heavy due to some barytes content. It is contended that barytes is of primary sedimentary origin, and has been partly mobilized during deformation and formed veins etc.

It seems that the deposition of Garbyang A took place in a shallow tidal sea where chemical precipitation dominated in somewhat exceptional chemical milieu leading to the development of various carbonates and primary barytes.

Garbyang B—This approximately 110 m thick succession of evaporite facies is made up of dolomites, marls and gypseous shale. There are about 30 cycles, each starting with bedded dolomite at the base and culminating with gypseous shales with thinly bedded dolomite (Plate I-4). Thickness of individual cycle varies from 1-5 m. Some of the cycles are complete, while others are incomplete.

The dolomite succession sometimes shows large scale cross-bedding, ripple bedding etc. (Fig. 8).

This evaporite sequence seems to be a continuation of the Garbyang A. Most probably due to increased salinity in the area of deposition, gypsum was precipitated. Each cycle seems to represent an intertidal—supratidal deposit.

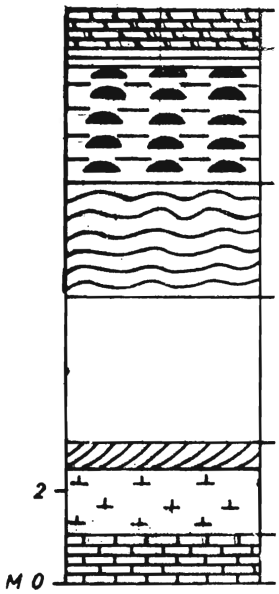


Fig. 8. Succession of sedimentary structures in Garbyang B.

The dolomite may be a deposit of intertidal zone while gypseous shale represents deposits of supratidal zone.

Garbyang C—This about 165 m thick unit stands out in contrast to the underlying evaporitic succession as it is made up of calcareous sandstone/shale alternations and bedded limestone. 1-2 m thick sandy horizons show small ripple bedding, channeling and planes of discontinuity (Plate II-1). Thicker sandy layers exhibit large-scale cross-bedding. Horizons of oolitic limestone show small scale cross-bedding and herringbone cross-bedding. Near the top of this unit carbonate content decreases. In this succession worm tracks are present in several horizons.

The Garbyang C represents deposits of a tidal flat complex, particularly in sand bar-shoal areas of an open shallow sea dominated by tidal currents and strong wave activity.

Garbyang D—About 70 m thick arenaceous sequence is made up of 1-1.5 m thick sandy units alternating with thin sand/shale alternations. Thick sandy units are made up of low-angle cross-bedding, parallel bedding, and trough cross-bedding. They also exhibit beach bar cross bedding with 5-6 cosets. Thin sand layers show small ripple bedding, minor channels, washed ripples, and rill marks. There are thin units of sand/shale alternations, where often cm thick sand layers show graded bedding. A few bands of 1-2 m thick arenaceous limestones show extensive cross-bedding. Scattered in the succession are 3-5 m thick sequences of thinly laminated sand/shale bedding (tidal bedding/rhythmite). In the shale rich units (1.5 m thick) lenticular bedding becomes very prominent. Planes of discontinuity are also quite common.

This sequence represents essentially deposits of a tidal flat environment. The major part of the succession denoting deposition in mixed intertidal flats while parts of the succession were certainly laid down in subtidal zone and in tidal channels.

Garbyang E—This about 45 m thick shale-rich terrigenous sequence starts with a thick horizon of thinly bedded shale/sandstone alternations showing well developed tidal bedding. Upwards it becomes essentially a sand/shale sequence in which sand layers are invariably graded, which is the most characteristic feature of this unit (Plate II-7). The sand layers may show ripple foreset laminae or parallel laminae, but they always grade to shale layer towards the top. Major part of this succession is developed as lenticular and flaser bedding, even though the sand layers show grading. There are also a few thick sandy horizons showing cross-bedding and channeling. Wrinkle marks, washed out ripples and rill marks are also seen (Plate I-2). A few worm tracks are present.

Except for the graded nature of the cm thick sand layers all other characteristics of this succession point towards sedimentation in a tidal flat environment. It is believed that the major part of this succession was deposited in the subtidal zone of an open tidal sea extending over transition zone and upper part of the shelf mud. However, a few horizons showing signs of subaerial exposure are certainly deposits of intertidal zone.

Garbyang F—This approximately 120 m thick succession is marked by alternating arenaceous and carbonate horizons. The carbonate is essentially oolitic limestone (5-7 m thick) showing large scale cross-bedding, sometimes of herringbone type. Marly beds exhibit wavy bedding, lenticular/flaser bedding, and often tidal bedding. Arenaceous horizons show small ripple bedding, lenticular and flaser bedding and a few cm thick layers of oolitic limestone. Various types of ripples of shallow water origin are quite common. This succession exhibits mud filled channels which laterally grade into sandy units showing longitudinal cross-bedding and mud pebble conglomerates. Several varieties of burrows, with abundance of furrowed types, are recorded.

This succession is characteristically a tidal flat deposit with pronounced channeling, and has been deposited mostly in intertidal zone and subtidal minor channels. The area of sedimentation received enough detrital material from the land, as well as the milieu was suitable for precipitation of carbonates.

Garbyang G—The rocks of Garbyang F grade into Garbyang G, the topmost unit of the Garbyang Formation. It is essentially about 140 m thick silty sandstone/shale sequence marked by dominance of graded rhythmites and penecontemporaneous conglomerate bedded with few carbonate horizons. Sand/shale alternating sequence is most common. The sand layer invariably shows graded bedding; the thicker graded sandstone units grade upwards into laminated shale. Thin sand layers (approx. 1 cm.)

are often developed as ripples and ripple bedding. The lenticular and flaser bedding, and wavy bedding in which sand layers are always graded are also recorded (Fig. 9). The topmost horizon of this succession is purely arenaceous. Certain horizons show extensive bioturbation marked by well developed vertical burrows.

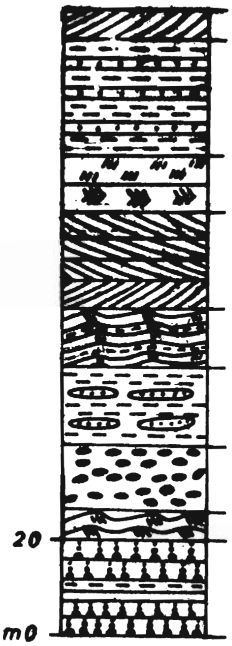


Fig. 9. Succession of sedimentary structures in Garbyang G.

This succession is similar to Garbyang E. It is considered to be a deposit of transition zone—shelf mud (upper part) area of an open tidal sea. The sedimentation mostly took place below wave base; however, some parts were also deposited in intertidal zone.

SHIALA FORMATION

Heim and Gansser (1939) have named about 400-500 metres thick variegated shales with intercalations of sandy limestones or crinoid breccia of brown weathering, overlying the typical Garbyang sequence at Shiala Pass, as Shiala Series. It has been redesignated as Shiala Formation by Gansser (1964). The Garbyang Formation grades into Shiala Formation without any marked lithological change. However, the lower boundary of this Formation is taken from where there is a regular development of horizons of fossiliferous crinoid bearing limestone. The upper contact of the Shiala Formation with the overlying Variegated Formation is rather sharp. This Formation is best developed around Sumna near the confluence of Yong and Kio valleys.

The Shiala Formation has been subdivided into 7 lithostratigraphic members, all showing gradational contacts.

Shiala A—This essentially a green shale-rich succession, about 140 m thick, is similar to Garbyang A, except for the presence of horizons of fragmental fossils. Sand/shale alternating sequence is most abundant in which sand layers mostly show grading. Ripple bedding is often present.

This may be considered as a deposit of the transition zone (subtidal) of a shallow sea.

Shiala B—In this about 40 m thick succession 10-15 m thick muddy units alternate with 3-5 m thick mud/carbonate sand units. It is marked by the increase in sand content and frequent presence of shell limestone layers. The sand layers often show channeling at the base and are made up of parallel bedding showing low angle discordances. The top most part of the sand layer is often rippled, mostly exhibiting ripples of wave origin.

This may be a deposit of the intertidal-subtidal zone.

Shiala C—This approximately 165 m thick carbonate succession is characterised by the dominance of shell conglomerate, and intraclast conglomerate (Plate II—4, 5). Convolute bedding, small ripple bedding and ripples are common (Fig. 10) (Plate II-3). Small channels are usually present.

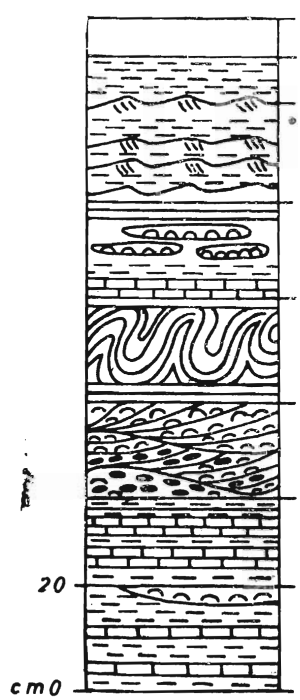


Fig. 10. Succession of sedimentary structures in Shiala C.

The Shiala C represents deposition in a rather shallow-water condition of the coastal area with moderate energy, preferably in the subtidal to intertidal zone.

Shiala D—This about 180 m thick succession represents arenaceous sandy facies and is made up of orthoquartzite alternating with subordinate shale layers. It contains abundant ripples of various types, namely current ripples, ripples with rounded crests and interference ripples of tadpole type. Wrinkle marks and spring pits are also present. The lower and upper parts of the succession consist of a few thin bands of shell limestones (Fig. 11) while the middle part contains mostly yellowish and reddish quartzite and is devoid of shell limestone bands.

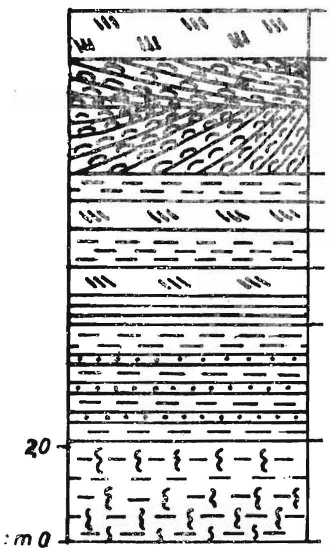


Fig. 11. Succession of sedimentary structures in Shiala D.

The succession denotes deposition in a sandy tidal flat/shoal complex of medium energy, with increased supply of sandy material from the land.

Shiala E—This about 40 m thick succession is made up of extremely hard and compact decimetre thick shell limestone, alternating with thin to thick calcareous shale. The shell limestone is partly developed as nodular limestone. Large scale cross-bedding is commonly present.

It represents deposits of a medium to high energy coastal area where sand supply from the land was almost negligible.

Shiala F—This about 70 m thick succession is marked by the dominance of shell limestone layers along with the presence of thin green shale and thin sand layers. The shell limestone bands show large-scale cross-bedding with low angle discordances. Thin sand layers show parallel bedding and small ripple bedding. Penecontemporaneous deformation structures and mud pebble conglomerate horizons are often present.

The Shiala F represents deposits of a medium to high energy coastal area with poor supply of terrigenous clastics from the land, which have been subjected to much reworking at the site of deposition.

Shiala G— It represents about 75 m thick topmost part of the Shiala Formation and is made up mostly of sandy shell limestone and black to gray shale. Some of the shell limestones represent just concentration of shell debris without any matrix. The concavity of the shells does not show any preferred orientation. This may be ascribed to quick deposition and residual concentration due to continuous reworking. Small ripples are usually present. Shale layers are often extensively burrowed.

This succession represents deposits of medium energy coastal sand areas. The shale horizons represent deposits of protected areas with slow rates of sedimentation which led to extensive burrowing of these layers by benthonic organisms. Black colour of the shale, due to abundance of organic matter, points to partially anaerobic conditions.

VARIEGATED FORMATION

A thick succession of variegated shales and limestone with crinoid fragments has been referred to as Variegated 'Silurian' by Heim and Gansser (1939). The Variegated 'Silurian' has been redesignated as Variegated Formation in the present area. 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. It is poorly developed in the present area and the exposures can be seen only in Yong Valley, north of Sumna. In Kio Valley, the Muth quartzites are lying directly over the Shiala Formation and the Variegated Formation is completely missing due to a thrust fault. The Variegated Formation has been subdivided into 3 lithostratigraphic members.

Variegated A—It is about 46 m thick succession of black nodular limestone containing thin intercalations of black calcareous shale. The nodular limestone contains corals and bryozoa in abundance. Some algal structures are also present (Plate VI—8). This succession does not show any evidence of current or wave activity.

It is suggested that the succession represents deposits of a zero-energy carbonate flat, where corals and bryozoa flourished.

Variegated B—This about 20 m thick succession is made up of purple to brown limestone with greenish shale/siltstone intercalations. The limestone fails to exhibit well developed primary sedimentary structures.

Variegated C—This about 33 m thick succession is charcterized by 1 m thick carbonates intercalated with 2-3 m thick shale layers of different colours, e.g., violet, brown, green. The succession is extensively jointed and fails to exhibit any primary sedimentary features.

Except for lower part of the nodular limestone, the Variegated Formation fails to exhibit any primary sedimentary structure for environmental analysis. Nevertheless, they most probably represent low energy shallow water carbonates.

MUTH FORMATION

In Kuti region about 800 m thick brownish weathering quartzites with dolomitic layers, and white quartzites of Devonian age are designated as Muth Series by Heim and Gansser (1939). This has been redesignated here as Muth Formation. In the present area, only about 140 m thick Muth Formation is exposed in Kio and Yong valleys. It is one of the most conspicuous lithologic horizon of the area and can be marked even from a distance. It has a gradational lower contact with the Variegated Formation and a sharp upper contact with the black Kuling shales.

The Muth Formation has been sub-divided into 3 lithostratigraphic members having gradational contacts.

Muth A—This about 60 m thick succession is made up of light brown, ferruginous calcareous quartzite, shaly sandstone and shale. Mostly 1-2 m thick brown dolomitic quartzite alternates with 20—30 cm or thicker sand/shale alternations. Thick quartzite units show large-scale cross-bedding, mostly bar cross-bedding of lenticular shape. There are also 2-3 m thick units showing low-angle cross-bedding, parallel bedding, ripple bedding with herring-bone structure and well developed ripples (Fig. 12). Ripples of both wave and current origin are quite commen in this horizon. Amongst them, the ripples with washed crests, rounded crests and pointed troughs, and small current ripples of very low height are commonly seen.

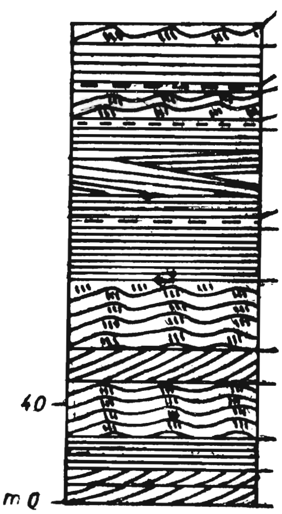


Fig. 12. Succession of sedimenary structure in Muth A.

This succession represents deposition in a coastal sand complex with moderate to high energy conditions where both wave and current activities were operative. Deposition took place mainly on an open sandy tidal flat and sand bars.

Muth B—This about 20 m thick succession is characterized by dominance of sandy shales and siltstones over quartzites. The quartzite layers are thin, showing faint cross-bedding. Sandy shales are most abundant and commonly show thinly interlayered sand/mud banding. Ripples are rare. The siltstones often show extensive burrowing producing bioturbated horizons. This zone has also yielded silicified fossils-bryozoa, corals and lamellibranchs.

This member represents deposits of a rather-low energy environment of a coastal complex, and must have been deposited in a protected, mixed tidal flat environment.

Muth C—This about 80 m thick unit is made up dominantly of pure quartzites. Shaly and silty horizons are extremely rare and only a few mm in thickness. The quartzites show generally large-scale cross-bedding, mostly of planar type with low-angled foreset laminae (Plate III-7). Interbedded with these are parallel bedded and 1-2 m thick megaripple bedded quartzite layers (Fig. 13).

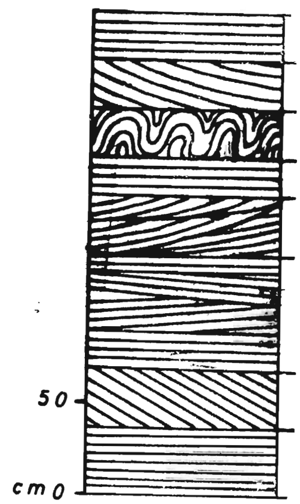


Fig. 13. Succession of sedimentary structures in Muth C.

Megaripples are also recorded. Thin horizons showing wave ripples, large-scale herringbone cross-bedding are often seen (Plate III-6).

This succession must have been deposited as a sand bar/shoal complex of a tidal sea with high energy conditions which led to almost complete winnowing of clay size particles.

RAWALIBAGAR GROUP

There is a well marked lithological break between the Muth Formation (Devonian) and overlying Kuling shales (Permian). Heim and Gansser (1939) and Kumar *et al.* (1972) have considered a hiatus between the two formations. The thick shale/limestone sequence overlying the Muth Formation and underlying the Spiti Shale, ranging in age from Permian to Callovian, is placed under one lithostratigraphic group and is named after the place Rawalibagar in Kio Valley as Rawalibagar Group. The oldest formation of this Group is the Kuling Shale and the youngest is the Ferruginous Oolite Formation. The Group has a sharp lower contact with the Muth Formation and an upper gradational contact with the Spiti

Shale. The rocks of this Group are well exposed on the scarp overlooking Rawalibagar in Kio Valley.

The Rawalibagar Group has been subdivided into 8 lithostratigraphic formations :

8. Ferruginous Oolite Formation
7. Laptal Formation
6. Kioto Limestone
5. Passage Formation
4. Kuti Shale
3. Kalapani Limestone
2. Chocolate Formation
1. Kuling Shale.

KULING SHALE

The black Kuling shale rests over white quartzites of the Muth Formation with a sharp contact. This contact is very conspicuous and can be marked even from a distance. However, no marked angular unconformity could be seen between these two formations in the present area. The upper contact of the Kuling Shale with the Chocolate Formation is gradational. Though these shales are well exposed in both Yong and Kio valleys, the exposures in the latter valley are on higher reaches and it is very difficult to study them.

Heim and Gansser (1939) have considered Kuling shales to be of Permian age, while Kumar *et al.* (1972) have assigned them upper Permian age. Valdiya *et al.* (1971) and Valdiya and Gupta (1972) have named this formation as Kringkrong Series in northeastern Kumaon and have given middle to upper Permian age.

The Kuling Shale is sub-divided into two lithostratigraphic members having gradational contact.

Kuling A—This about 7 m thick succession is made up of gray siltstone/fine sand with horizons of shell limestone. The succession shows decimetre to 1-2 m thick units of silt-stone, silty clay, shell limestone and fine sand. The siltstone horizons show parallel bedding, ripple bedding, low-angle discordances and bioturbated horizons (Fig. 14). The brachiopod rich horizons are also recorded.

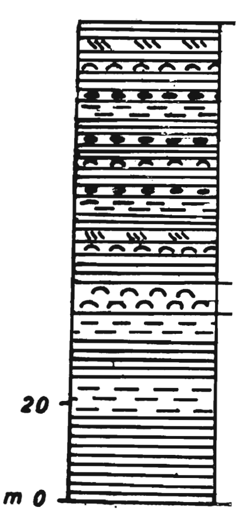


Fig. 14. Succession of sedimentary structures in Kuling A.

This succession represents deposits of a transgressive sea. The deposition took place in low-energy areas of a shallow open sea most probably in the transition zone and upper part of the shelf mud region.

Kuling B—This is about 20 m thick succession made up of black shales with a few thin silty layers. Small carbonate nodules are distributed sparingly in the succession. The brachiopod-bearing horizons are present.

It represents deposits of a shallow shelf mud zone of an open sea. This succession was laid down in slightly deeper water than the sediments of Kuling A.

CHOCOLATE FORMATION

Heim and Gansser (1939) have described brown weathering limestone and shale of Lower Triassic age as Chocolate Series. This has been redesignated as Chocolate Formation in the present study. It is poorly developed and attains a thickness of about 7 m. It shows gradational contacts with the underlying and overlying formations. No recognisable megafossils could be recorded from this horizon. However, the limestones have yielded conodont assemblage of Lower Triassic age (Sahni, A., personal communication). It is exposed only at the confluence of Shalshal and Yong valleys.

It is made up of 15-20 cm thick limestone bands alternating with 15-30 cm thick shell limestone/gray-black shale alternations. Limestone bands are lenticular in shape and pinch out laterally. Small ripple bedding is present. Thin bands of shell limestone, showing convex upward orientation of the shells are also recorded. Topmost part of this succession becomes rich in sandy layers alternating with shale layers.

This succession also represents deposit of a shallow sea, laid down in upper part of the shelf mud and in the transition zone.

KALAPANI LIMESTONE

The Chocolate Formation ultimately grades into 25 m thick Kalapani Limestone. Besides megafossils, the Middle Triassic conodonts have also been recovered from these limestones (Chhabra *et al.*, 1975). Heim and Gansser (1939) have considered this horizon as condensed sequence of Middle Triassic age (Anasic, Ladinic and Carnic). It shows gradational contact with the overlying Kuti Shale. Good exposures are seen in Yong Valley.

This Formation is made up of black, compact limestone, partly nodular, interbedded with thin bands of dark coloured shale (Fig. 15). The middle part of this succession is made up of oolitic limestone. In the upper part, black shale content increases, and is intercalated

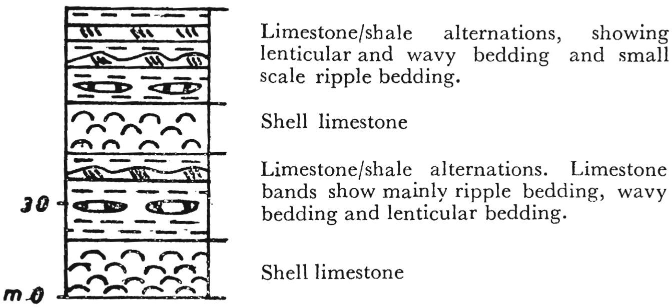


Fig. 15. Succession of sedimentary structures in the Kalapani Limestone.

with bands of shell limestone. The succession is very rich in ammonites along with some brachiopods and crinoids. Bioturbated horizons showing different types of burrows are recorded.

Presence of oolitic limestone in thick succession indicates deposition in wave affected zone of high energy shoals and sand bars. Part of the succession must have been laid down in transition zone to shelf mud below wave base.

KUTI SHALE

A thick sequence of rhythmic alternation of black friable shale and hard calcareous shale conformably succeeds the Kalapani Limestone which was designated as Kuti Shales by Heim and Gansser (1939). In the present study, these rocks have been given the rank of a formation. The best exposures can be seen in Yong Valley, and on the scarp north of Rawalibagar in Kio Valley.

Generally, the fossils are rare, but badly preserved ammonites and other fossils have been recovered. Heim and Gansser (1939) have assigned Noric age to these shales.

In Kio Valley, the Kuti shales are subjected to intense folding and faulting and often very tight folding is displayed by them in this part of the Himalaya.

The Kuti shales are lithostratigraphically subdivided into 3 members having gradational contacts.

Kuti A—About 130 m thick succession is made up of black friable shale alternating with black shaly limestone (Fig. 16). Thinly laminated black shale dominates over shaly limestone. This succession is extremely rich in small ammonites and lamellibranchs.

These sediments seem to represent deposits of the upper part of shelf mud.

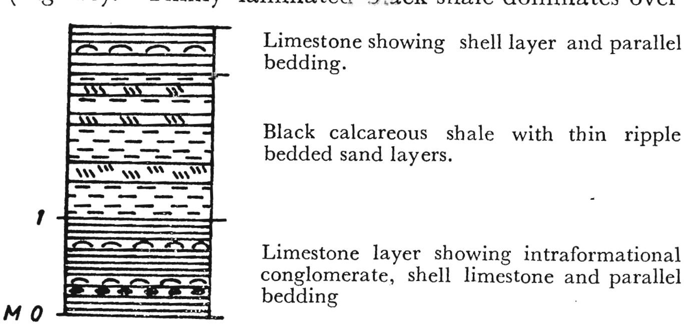


Fig. 16. Succession of sedimentary structures in Kuti A.

Kuti B—It is made up of rhythmically interlayered 50 cm—1 m thick grayish black friable shale and decimetre thick hard calcareous shale. This member is about 280 m thick. The bedding features are not clear.

These sediments probably represent deposits of a low energy area, where contemporaneous precipitation of carbonate and deposition of fine-grained material were taking place. Fluctuation in the supply of terrigenous material and precipitation of carbonate led to the rhythmic nature of the deposits. The deposition must have taken place in the transition zone.

Kuti C—This approximately 100 m thick succession is more sandy than the underlying Kuti B succession. 20-30 cm thick bands of silty shale alternate with equally thick bands of sandy limestone with calcareous nodules. Bedding features are not very clear, but small ripple bedding, parallel bedding and flaser bedding have been recognized. Bioturbation horizons are quite common. Near the top of this succession there are thick limestone bands showing penecontemporaneous conglomerate and shell limestone bands.

This succession represents an increase in the energy of deposition depicted by the presence of sandy layers, shell limestone and penecontemporaneous conglomerates. The site of deposition must have been in transition zone and subtidal to intertidal zone of a coastal complex.

PASSAGE FORMATION

Heim and Gansser (1939) mentioned a Passage Zone between the underlying argillaceous sequence of Kuti Shale and overlying calcareous sequence of Kioto Limestone. Kumar *et al.* (1972) have also identified this horizon. The Passage Zone is redesignated as Passage Formation. This Formation is best exposed on the escarpment overlooking Rawalibagar in Kio Valley.

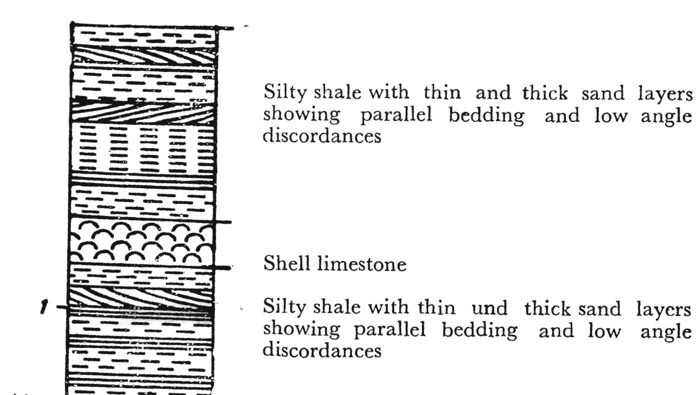


Fig. 17. Succession of sedimentary structures in the Passage Formation.

This 90 m thick succession is made up of shell limestone, fine-grained limestone, silty shale and orthoquartzite. The orthoquartzite layers are frequent and up to 40-50 cm thick, showing mainly parallel bedding with low-angle discordances (Fig. 17). Several metre thick sand layers show large-scale cross-bedding, planes of discontinuity and channels. Limestone bands also show cross-bedding. Bioturbated horizons are recorded.

This sequence represents deposits of a tidal flat complex, where both carbonate flats and sand flats were present. There was sufficient supply of terrigeneous clastic material from the land.

KIOTO LIMESTONE

In the present study the Kioto Limestone of Rhaetic age (Heim and Gansser, 1939) has been given the rank of a formation. It is well exposed on the scarp north of Rawalibagar in Kio Valley. It shows gradational contacts with the underlying and overlying formations.

It is divisible into four lithostratigraphic members having gradational contacts.

Kioto A—This about 50 m thick succession is made up of predominantly oolitic limestone, in which few cm thick bands of shale and thinly laminated sand horizons are intercalated. Some bands of shell limestone are also seen. The oolitic limestone shows parallel bedding, herringbone cross-bedding, and penecontemporaneous intraclast conglomerate (Fig. 18). Shaly limestone shows

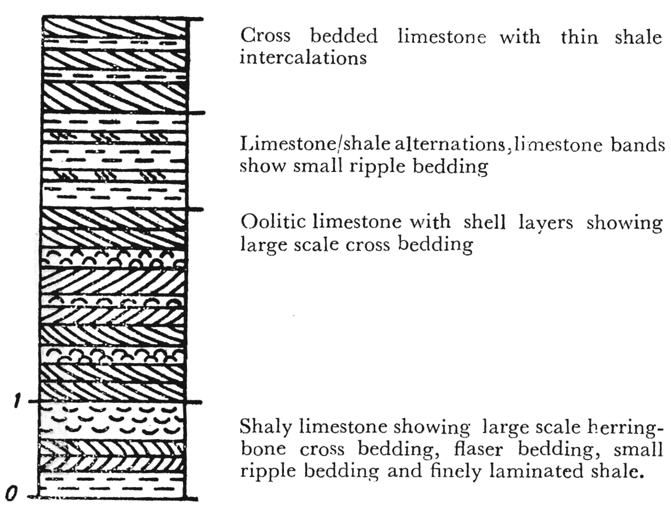


Fig. 18. Succession of sedimentary structures in Kioto A.

flaser and lenticular bedding. Thin sand layers often show small ripple bedding.

This sequence represents deposits of a shallow tidal sea in shoal/sand bar to tidal flat complex, with rather high energy conditions.

Kioto B—This 30 m thick succession is represented by compact nodular limestone without any significant sand/shale layers and contains shell layers showing lamellibranchs and belemnite.

This sequence represents deposition in a coastal carbonate sedimentation area. Because of the lack of diagnostic primary sedimentary structures it is not possible to interpret precise locale of deposition.

Kioto C—This about 30 m thick succession is made up of well bedded limestone, shell limestone, and thin shale layers. Limestone shows mostly parallel bedding and small ripple bedding. Most characteristic feature of this succession is the presence of 50 cm—1 m thick bioturbated limestone horizons showing extremely irregular pattern of burrows filled with clear sparry carbonate. This horizon has been referred by Heim and Gansser (1939) as 'problematica' horizon. On the bedding surface due to dissolution process knobby structure has developed. Stylolites are common.

This succession represents deposition in a coastal carbonate complex. The deposition took place in areas with rather slow rate of sedimentation, so as to produce bioturbation horizons due to burrowing activity of benthonic organisms.

Kioto D—It is about 30 m thick succession dominantly made up of oolitic limestone with some bands of pisolitic limestone and shell limestone. The limestone is without shale or sand content. Large scale cross bedding, channel fill structure, and planes of discontinuity are common.

This succession represents deposits of an oolitic sand bar with a rather high wave and current energy in a shallow tidal sea.

LAPTAL FORMATION

About 60—80 m thick sequence of limestone of Lias age overlying the Kioto Limestone has been named as Laptal Series by Heim and Gansser (1939). It is redesignated here as Laptal Formation having lower gradational contact with the Kioto Limestone and upper sharp contact with the Ferruginous Oolitic Formation (Plate III-5). It is well exposed in Kio Valley near Laptal.

It represents a sequence of dominantly shell limestone, associated with well bedded black limestone, oolitic limestone, marls and shale layers. Few centimetre to several decimetre thick shell limestone bands dominate the sequence. A few small channels filled with shell debris are recorded. The conglomerate horizons made up of large shells, broken pieces of shell limestone and clay nodules are often seen. The lower part of this succession is sandy. A few gypsum stringers have been recorded. Thin units of graded beds of both normal and reverse type are present. Large scale cross-bedding and megaripple bedding are quite common in the thick limestone units (Plate VII-1). In the shale/limestone, sequence, limestone bands show small ripple bedding parallel bedding, and wavy and lenticular bedding (Fig. 19) (Plate III-1). In the middle part of the succession mud filled channels showing longitudinal cross-bedding are developed. Some shale units are intensively bioturbated ; a few *Thalassinoides* burrows are recorded.

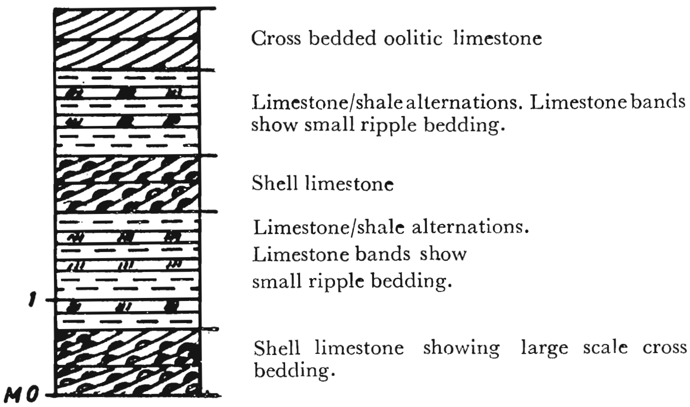


Fig. 19. Succession of sedimentary structures in the Laptal Formation.

This succession represents deposits of a shallow tidal sea with a rather high wave and current energy. Abundance of shell limestone and burrows points out that the conditions were well suited for the benthonic life and there was little supply of terrigenous clastic material. Oolitic limestone points to moderate to high energy deposition. Mud filled channels, conglomerate bands, lenticular and flaser bedding, and longitudinal cross-bedding indicate deposition in the intertidal flats with high tidal range. The site of deposition for the Laptal Formation seems to be mainly high energy shoals and channels, and associated tidal flats.

FERRUGINOUS OOLITE FORMATION

Overlying the Laptal Formation is a well defined litho-stratigraphic unit of Ferruginous Oolite of Heim and Gansser (1939). In the present study this unit has been redesignated as Ferruginous Oolite Formation. It attains a maximum thickness of about 10 m and is well exposed on the pasture land of Laptal camping ground. It shows lithologically gradational lower contact and more or less sharp to gradational upper contact. The age of this Formation is given by Heim and Gansser (1939) as Callovian.

This sequence is characterized by the presence of horizons of ferruginous oolites. The Laptal Formation is capped by a 10-15 m thick succession of ferruginous carbonate sediments which stands out as yellowish brown band. The ferruginous oolite horizon is not very persistent. Other lithic types include reworked intraformational conglomerates and thinly laminated shale. Large articulated shells, ammonites, belemnites, septarian nodules, and shell pieces are abundantly recorded. The sedimentary structures present are large scale cross-bedding, small ripple bedding, parallel bedding with low angled discordances, channels, ball and pillow structure, and intraformational conglomerate bands (Fig. 20).

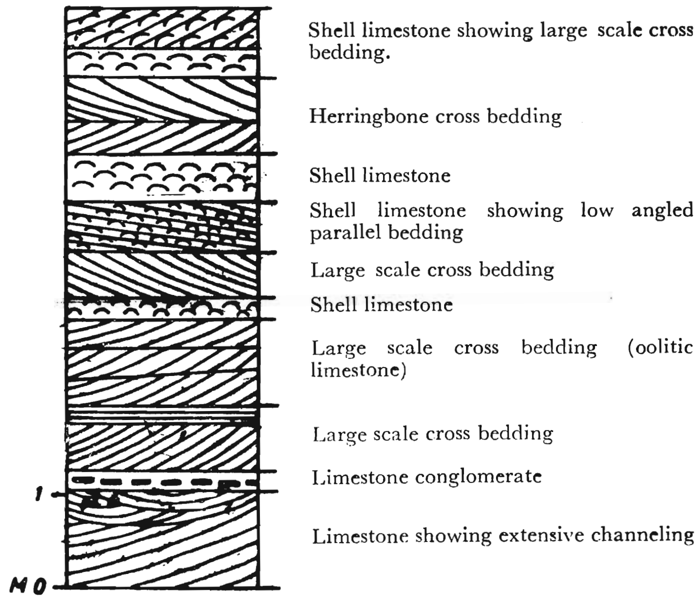


Fig. 20. Succession of sedimentary structures in part of the Ferruginous Oolite Formation.

The succession represents deposits of high energy carbonate shoals with high degree of reworking and penecontemporaneous deformation activity. In the upper part of this horizon shale layers are common suggesting a decrease in the energy of deposition.

SANCHA MALLA GROUP

The black Spiti Shale marks a definite lithological change from the underlying rocks of the Rawalibagar Group. From the Spiti Shale (Jurassic) to the Balcha Dhura Formation (? Lower Eocene) there is a continuous sedimentation in the deeper parts of the basin. These sediments are included in the Sanch Malla Group, the name being derived after the Sanch Malla camping ground, where the rocks of this Group are well exposed. It is subdivided into four lithostratigraphic formations :

4. Balcha Dhura Formation
3. Jhangu Formation
2. Giumal Sandstone
1. Spiti Shale.

SPITI SHALE

The Spiti Shale constitutes the most well known horizon of the Tethyan sequence for the abundance of well preserved ammonite fossils. It is basically an argillaceous sequence developed between Ferruginous oolites and the overlying argillo-arenaceous rocks of the Giumal Sandstone. It attains about 200 m thickness. It has somewhat gradational lower and marked gradational upper contacts. Heim and Gansser (1939) have suggested a disconformity between the Spiti shales and underlying Ferruginous oolites and have assigned Portlandian age to this Formation. It is well exposed around Laptal.

This succession is made up essentially of black friable shales. Due to friable nature of the shales continuous exposures with bedding features are extremely rare. The lower part of this Formation (few metres) contains thin sandy intercalations. The Spiti Shale contains horizons showing concretionary layers, iron-rich shales with septarian nodules, hard calcareous shales, iron rich shale with limestone, chert nodular bands, and black shale with a few centimetre thick sand layers. The sand layers show parallel bedding in the lower part and ripple bedding near the top (Fig. 21). The topmost part of the Spiti

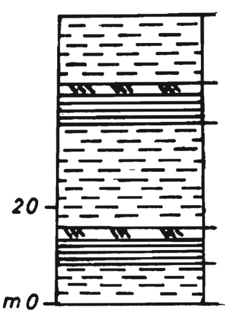


Fig. 21. Succession of sedimentary structures in the Spiti Shale

Shale shows sand and chert layers. The chert layers show streaky character. Throughout the succession fossils are abundant. There are horizons extremely rich in belemnites while other contain abundant ammonites. The ammonites mostly occur enclosed within calcareous nodules some of which are phosphatic. The other fossils recorded are lamillibranchs and gastropods. Some of the ammonite shells seem to have acted as hard grounds and show evidences of boring, and are encrusted with serpula tubes.

The deposition of Spiti Shale took place in the shelf mud region of an open sea. Mostly pelagic organisms (e.g., ammonites, belemnites) are present. Rate of sedimentation must have been slow, so that dead ammonite shells on the shelf bottom served as hard grounds. Some thin sand layers were laid down during storms, which brought material from the coast. Such storm sand layers are a common feature in the present day shelf mud. Towards the top of this Formation deposition of chert took place along with increased supply of sandy material.

GIUMAL SANDSTONE

The Spiti Shales grade into Giumal Sandstone. These sandstones were referred to as Lower Flysch by von Kraft (1902) and Giumal Sandstone by Heim and Gansser (1939). Latter term has been retained and given the rank of a formation. The Giumal Sandstone is apparently a shale dominant sequence with sandy parts showing gradational contact with the underlying Spiti Shale and overlying Jhangu Formation. In the present work, the upper contact of the Giumal Sandstone is taken below the red foraminiferal limestone. This contact is well marked and can be located even from a distance. Thus, 50 m sequence of greenish shale of the Upper Flysch of Heim and Gansser (1939) is included in the Giumal Sandstone. This Formation is well exposed around Sancha Talla and Shalshal, and has been assigned a Lower Cretaceous age by Heim and Gansser (1939) (Plate IV-3).

The Giumal Sandstone has been subdivided into 5 lithostratigraphic members with gradational contacts.

Giumal A—The contact between the Spiti Shale and the Giumal Sandstone is not well exposed. However, it seems that upwards the Spiti Shale grades into a succession of chert, siltstone and shale showing some turbidite-characteristic. This sequence is about 40 m thick. The Giumal A member is shale rich along with bands of siltstones, limestone, silty shale, sandstone and streaky chert. Streaky chert is very abundant near the basal part and shows presence of radiolarians in thin sections This succession also contains parallel turbidite sequences showing graded bedding, parallel bedding and rarely small scale ripple bedding (Fig. 22). The shale layers of turbidite sequences are invariably bioturbated.

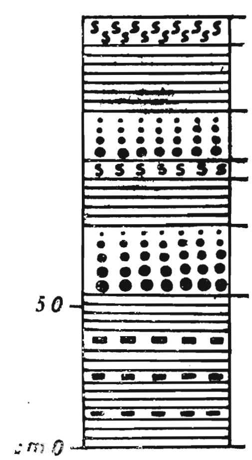


Fig. 22. Succession of sedimentary structures in Giumal A.

The domain of sedimentation for this succession seems to be the lower part of the continental shelf-continental slope. The presence of cherty bands with black streaks is a characteristic feature. The sand was brought to the site of deposition by low energy, low density turbidity currents. Profusely bioturbated shale horizons point to a dense benthonic population and low rates of sedimentation.

Giumal B—The chert rich shaly facies passes upward into about 90 m thick glauconitic sandstone succession with shale rich part near the top. The glauconitic sandstone shows poorly preserved sedimentary features. Faint graded bedding and parallel bedding are most common bedding features with convolute bedding near the top of the bed (Fig. 23) (Plate IV-5). The cherty bands as

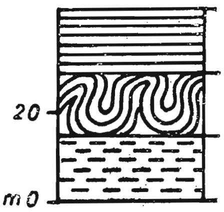


Fig. 23. Succession of sedimentary structures in Giumal B.

thick beds are common. The upper shaly part is made up of silty calcareous shale of varied colours, e.g., purple brown or green, with 2-5 cm thick limestone bands showing graded bedding on small scale. The silty bands show convolute bedding, parallel bedding and small scale ripple bedding. Scoured surfaces are also present.

The domain and conditions of sedimentation of Giumal B are quite similar to those of Giumal A, except for an increased sand supply by the low density turbidity currents and deposition of limestone. Rate of sedimentation was high as evidenced by rarity of bioturbated shales.

Giumal C—This about 160 m thick succession is represented by arenaceous facies made up predominantly of 30-50 cm thick glauconitic sandstone alternating with 2-5 cm thick shale layers. Occasionally sand layers are up to 2 m or more thick, and devoid of any visible bedding features. The sandy units are usually massive in lower part, where as in upper part parallel bedding and contorted laminations are seen. Thinner sand layers are dominantly parallel bedded. Near the top of a few sandy bands small ripple bedding is visible (Fig. 24) (Plate

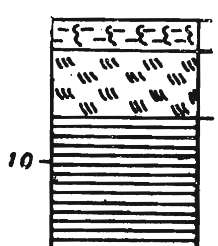


Fig. 24. Succession of sedimentary structures in Giumal C.

I—5). Some of the sandy layers show concentration of mud pebbles near the base. The shale layers sometimes contain silty bands showing faint ripple bedding and are extensively bioturbated with well developed burrows. This succession is sand rich near the base and gradually becomes shaly near the top.

The succession represents deposition in continental margin (probably continental slope), where sandy material was coming from the coastal region by the low density low velocity turbidity currents, as scouring and sole markings are rather uncommon. The shale sedimentation was rather slow, so as to allow benthonic organisms to churn it extensively.

Giumal D—This about 30 m thick succession is also made up mostly of glauconitic sandstone and siltstone with shale intercalations and is very similar to Giumal C. However, it is mainly a silty sequence with dcm thick fine silty sand layers alternating with 1 cm thick shale layers. The sandy units show parallel bedding, or parallel bedding near the base followed by small ripple bedding (Plate IV-6). Rarely medium to coarse grained sandstone horizons are also present showing sole markings, shale pebbles, cross bedding and parallel bedding (Plate III—2, 4). Streaky sandy layers are quite common. Near the top, thickness of the shale layers increases, where as the intercalated silty and sandy layers are thin and few in number.

This succession also represents deposits of the continental margin with a decreased sand supply than during the deposition of Giumal C. The turbidity currents were of very low intensity which resulted in poorly developed turbidite sequences.

Giumal E—This about 80 m thick succession is essentially shale dominant. The lower part is rather silty and contains 10-15 cm thick silty bands alternating with 1-2 cm thick shale bands. The silty bands show parallel bedding in lower part and small ripple bedding in upper part with a top clay layer. Some of the silty layers show lenticles of fine sand. Rarely a few medium to coarse-grained glauconitic sandstone units are present. The shale layers are full of fucoid markings. In the upper part of this unit shale content increases. Thickly bedded (20 cm) shale alternates with 2-3 cm thick thinly laminated shale. In some horizons 10-15 cm thick fine sand—silty units alternate with 15-20 cm thick thinly laminated shale. Some thick horizons (20-30 m thick) are made up of thinly laminated shale. The silty/fine sand units show parallel bedding, contorted bedding and small ripple bedding. Near the top of this unit a horizon of black shale with cherty bands is present.

This succession also represents deposition in continental margin (mainly continental slope) in which mainly shales were deposited with somewhat decreased supply of sandy material from the coastal region.

It may be pointed out that in the middle part of the Giumal Sandstone, there are three cycles (Giumal B, C and D) each starting with sand-rich facies grading upwards into shale rich facies. These three cycles may be related to three pulsations in the supply of sand from the land.

JHANGU FORMATION :

Heim and Gansser (1939) retained the term Upper

Flysch given by von Kraft (1902) for the thick succession of shales, sandstones, limestones and radiolarian chert overlying the Giumal Sandstone. Kumar *et al.* (1972) have referred to this sequence as Flysch Series. This sequence in the present study is named as Jhangu Formation. The name is derived from Jhangu Gad (Valley) in which the rocks of this Formation are exposed. The lower boundary of this Formation is taken at the base of well marked red foraminiferal limestone, because this red foraminiferal limestone is the most conspicuous lithic unit of the Cretaceous succession of the area under consideration and its contact with the underlying rocks is most convenient to locate in the field. Thus, the green shale member of Upper Flysch of Heim and Gansser (1939) is considered as the upper most member of the Giumal Sandstone. The upper boundary of the Jhangu Formation is marked by the volcanic rocks of the Balcha Dhura Formation. Heim and Gansser (1939) have assigned Upper Cretaceous age to these rocks.

The Jhangu Formation has been subdivided into six lithostratigraphic members.

Jhangu A—It is made up of red shaly foraminiferal (*Globotruncana*) limestone, showing 2 cm-1m thick limestone bands embedded in red shale. It attains a total thickness of about 65 m. In its lower part it shows a gradational contact with shaly part of the Giumal Sandstone, i.e., gray green shales grade into red brown shales of Jhangu A member. In this part 50 cm-2m thick limestone bands are intercalated with red brown paper thin laminated shales. Thick limestone bands show swelling and pinching laterally, and contain thin shale layers. Thin limestone bands (2-5 cm) show graded bedding. This is followed by essentially a shale—succession in which thinly-laminated red shale alternates with thick hard calcareous shale containing chips and pieces of violet and reddish brown shale (Plate IV—4). Thin horizons of shale pebble conglomerate are sometimes present. This shale sequence passes upwards into limestone/shale alternations. The limestone bands are cm to dcm thick, and exhibit sometime load structure, flute structure, and trace fossils in the form of sole markings. 2-3 cm thick limestone bands show graded bedding followed by parallel bedding (Fig. 25). The limestone with shale flasers are seen near the top of these bands. Some of the thicker limestone bands show channeling, low angle discordances, and small scale ripple bedding. 2-3 cm thick limestone bands alternate with 15-20 cm thick shale layers.

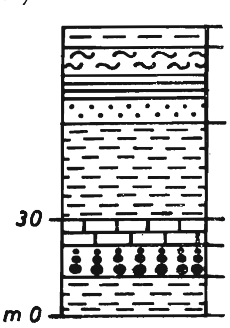


Fig. 25. Lithologic succession in part of Jhangu A.

This succession represents foraminiferal ooze deposits. The limestone bands consist of tests of *Globotruncana* and other planktonic foraminifers. The shales also contain foraminiferal tests, but their frequency is rather low. Thus, they are typical deposits of a deep sea. The presence of flute structure, scoured surfaces, ripple bedding points out intermittent current activity which also led to reworking and concentration of foraminiferal tests in graded limestone units, and production of the shale chips.

It has yielded well preserved coccoliths which belong to *Tetralithus avifidus* Zone (Jafar, S. A., personal communication). The boundary between the Companion and Maestrichtian falls within this Zone.

Jhangu B—It is made up of thinly laminated black shale with intercalations of carbonate nodules, marls and limestones. It attains a thickness of about 200 m. In the lower part 15 cm thick iron rich black shale alternates with equally thick parallel bedded limestone. Limestone/shale ratio varies strongly in the succession. Sometimes 2-5 cm thick limestone bands show parallel bedding, and rarely small ripple bedding. The limestone bands are extremely rich in trace fossils, especially in feeding burrows of which several types have been recorded (Plate III—3).

This succession represents deposits of reducing milieu with high organic matter content in an area devoid of any current activity. Limestone was precipitated in relatively deeper water. The burrows are typical of deep sea regions. These facts suggest that the deposition of this unit took place in some restricted basin within the continental margin.

Jhangu C—This about 35 m thick succession is characterized by the presence of 1-2 m thick orthoquartzite and quartzitic shales, which are interbedded with calcareous sandstone, limestone, ferruginous finely laminated shale, red and greenish shale and siltstone. The limestone bands in different stratigraphic horizons show development of cone-in-cone structure (Fig. 26). A few bands of carbonate nodules are also recorded. The quartzite shows parallel bedding and faint cross-bedding. Sand/shale alternations rarely show presence of ripples. A few shale bands are bioturbated.

It is very difficult to assign a domain of sedimentation for this succession at the present state of our knowledge. However, because it is sandwitched between typically deep sea sediments, it seems logical to assume that this succession was also deposited in continental margin areas under some special conditions in an unstable basin, where pure sand was supplied from the coastal areas.

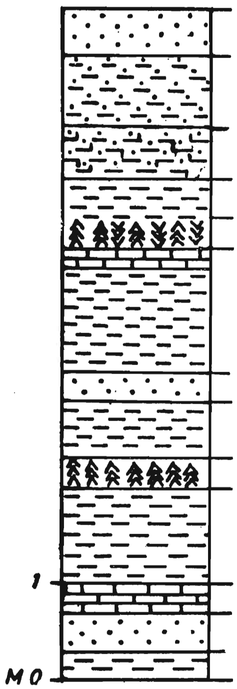


Fig. 26. Lithologic succession in part of Jhangu C.

Jhangu D—It represents a fine-grained flysch turbidite sequence of about 120 m thickness. 30-50 cm thick sandy units alternate with 2-3 cm thick shale layers. Thicker shale layers (up to 15 cm) are also seen. The shale layers are extensively bioturbated, and exhibit mostly feeding burrows of *Zoophycus* and *Rhizocorallium* affinity. The sand layers show faintly developed graded bedding and parallel bedding. Convolute bedding and small ripple bedding are also seen in thin sand layers. A few layers showing cone-in-cone structure are also recorded. The lower part of this succession is more shaly, where bioturbated silty clays alternate with finely laminated shale.

This succession was deposited on the continental margin (mainly continental slope and rise), where fine sand and silt were brought from the nearby coastal region. The rate of sedimentation was very slow which resulted in extensive bioturbation. The turbidity currents were rather weak, without any power of scouring, a fact supplemented by the absence of sole markings in the sandy units.

Jhangu E—It is made up of complexly alternating red and green shales and cherts and is about 5 m thick. The rocks generally represent foraminiferal and radiolarian oozes.

This succession represents deposition in deep sea basin and continental margin areas, in which little or no terriginous material was coming, and where the tests of dead planktonic organisms accumulated.

Jhangu F—This is about 5 m succession of crimson red fine shale, and probably represent deposits of deep sea clays.

BALCHA DHURA FORMATION

Kumar *et al.* (1972) have designated basic rocks and associated serpentinites exposed in the region of Balcha Dhura Pass as Balcha Dhura Volcanics. It is redesignated as Balcha Dhura Formation. This about 90 m thick succession includes volcanic rocks and associated shales and radiolarian cherts. The lower contact is marked by the presence of volcanic flows where as the upper is a thrusted contact with the Exotic Formation (Exotic Blocks of Griesbach, 1893). However, Heim and Gansser (1939) have included these volcanic rocks with the thrusted blocks of Exotic Formation.

The Balcha Dhura Formation is made up of green coloured volcanic rocks (1-2 m thick) alternating with dcm to 2-3 m thick red shales. The red shales also contain a few cm thick green shales. The volcanic rocks are mostly devoid of vesicles etc. But, some horizons are full of vesicles and also exhibit pillow-lava structure (Plate IV—1, 2). von Kraft (1902) have also observed at two places, spheroidal or sack like structure in solid lavas. These must be the pillow lava structures but he ascribed them due to the result of weathering and also assigned to these volcanic rocks a subaerial origin. Some flows show porphyritic texture. There is a well developed layering in the flows. Upwards, it is made up exclusively of volcanic rocks of different character, which show a patch work distribution.

This succession can be termed as an ophiolite succession, as deep sea clays occur interbedded with basic to ultrabasic volcanic rocks.

As the lowermost member of the Jhangu Formation is Upper Cretaceous (*Tetralithus avifidus* Zone), the possibility of the Balcha Dhura Formation being Palaeocene or even Lower Eocene can not be ruled out.

EXOTIC FORMATION

Griesbach (1893) used the term Exotic Blocks for the detached blocks generally crowning the culminating points of the hills in the Chitchun range, overlying the dark coloured volcanic rocks. The lithology of these blocks are quite different with respect to the underlying sequence. von Kraft (1902) studied these Exotic Blocks in great detail. Heim and Gansser (1939) have regarded these Exotic Blocks as remnants of the thrust sheet.

In the present study, the rocks of the Exotic Blocks have been redesignated as Exotic Formation. The rocks of the Exotic Formation occur partly embedded in the upper part of the volcanic rocks, though, most of them are on the top of them. They are made up dominantly of white coloured oolitic limestone. The shale content is negligible.

The oolitic nature of the limestone points out that these rocks represent dominantly shallow water carbonates. Since these rocks mark the border of India with Tibet, it was not possible to study them in detail.

STRUCTURE

Regionally the area is divisible into three main tectonic units which are separated by thrust faults. The first tectonic unit comprises of highly metamorphosed rocks of the Central Crystallines represented by augen gneisses. The second tectonic unit is made up of the rocks of Malla Johar Supergroup and the third tectonic unit is represented by the rocks of the Exotic Formation. In general, the structure of the Trans-Himalaya north of the Central Crystallines is far more simple and is characterized by the development of anticlinal hills and synclinal valleys indicating a juvenile landscape as compared to the Lesser Himalayas with synclinal hills and anticlinal valleys denoting a very mature landscape.

FAULTS

The oldest horizon of the Malla Johar Supergroup, the Martoli Formation is exposed around Malari in the southwestern extremity of the area. The thickness of the Martoli Formation is only of the order of a few hundred metres. However, further east of the present area in Gori Ganga Valley, the Martoli Formation attains a considerably large thickness of several thousand metres (Heim and Gansser, 1939 ; Kumar *et al.*, 1972). The omission of a large thickness of strata near Malari is apparently due to WNW—ESE trending Dar-Martoli Fault (Kumar *et al.*, 1972). This fault is well exposed at Malari, where mylonization, crushing, minor faulting and folding are conspicuously developed.

Another fault affecting the Martoli Formation is seen across the bridge in the Girthi Valley at 8 Km point from Malari towards Deepak Nagar (Plate I—3). It appears to be a(?) normal fault trending N 10°W—S 10°E and diping 45° in westerly direction. It has a throw of not less than 500 m. In this section, this fault has brought the Martoli quartzites and carbonaceous phyllites in contact with the Ralam quartzites besides a considerable thickness of the Martoli Formation is repeated again in Girthi Valley. This fault has been named as Girthi Bridge Fault.

Further north of this bridge, in Girthi Valley, the contact of the Martoli Formation and the Ralam conglomerate is again faulted. This is a high angled reverse fault due to which the Martoli phyllites have overridden the Ralam conglomerate. And possibly due to this only about 6 m thick Ralam conglomerate is present in contrast to about 35 m thick horizon seen near Malari. This fault strikes, N 20° E—S 20° W and dips 60° in the easterly direction. Along this fault much copper mineralization in the form of malachite and azurite stains is seen. Evidences of old copper mining activity are still noticeable.

East of Sumna in Kio Valley, a major reverse fault trending approximately N 10° W—S 10° E is mapped, dipping 40° in the easterly direction (Plate I—6). It has affected the three formations of the Sumna Group, namely Shiala, Variegated and Muth. Due to this fault the entire succession of Variegated Formation, which is well exposed in Yong Valley, is completely missing in Kio Valley and the Muth quartzites are directly overlying the rocks of the Shiala Formation. The estimated throw is about 100 m.

There are two parallel faults affecting the Muth quartzites in Kio Valley which strike approximately NNW-SSE (Fig. 1).

Two faults have been traversed in Yong Valley, which have made the tectonic position in this section quite complicated. These faults have affected the position of the Shiala Formation, Muth quartzites and Kuling shales. The Kuling shale pinches out near the confluence of Yong and Shalshal valleys due to a fault striking N 35° E—S 35° W and another fault striking E-W has brought the Muth quartzites directly in contact with the Shiala Formation on the upper reaches of the right bank of Yong Valley.

The most intense folding and faulting is manifested by the Kuti shales near Rawalibagar in the Kio Valley in which some magnificent examples of different types of faulting on mesoscopic scale is seen. These faults are not mappable on 1"—1 mile scale.

The northeastern region of the area near the contact with the Exotic Formation is quite disturbed and the intensity of the deformation is comparatively much more. The work in this region involves some difficulties ; firstly the region constitutes the northern border of India with Tibet and secondly the field work is quite difficult which involves climbing up to the height of about 5,800 m. Nevertheless, two important faults are mapped in this part of the area. The contact between the Giumal Sandstone and the Spiti Shale is faulted with former seen directly abutting against latter northeast of Sancha Talla. The second fault is seen north of Sancha Malla in the Jhangu Valley which follows the fault plane. It is striking N 10° W—S 10° E and is almost vertical. Due to this fault the stratigraphic succession of the two sides of the valley does not correspond to each other. The foraminiferal red limestone (Jhangu A) is seen only on the eastern side of the valley.

The most puzzling problem is connected with the Exotic Formation (Exotic Blocks of Griesbach, 1893) which is predominantly made up of white coloured oolitic limestone. Overlying the greenish gray to grayish black Balcha Dhura volcanic flows these white coloured limestones present a contrasting picture.

These limestone blocks occupy the different Kiogarh peaks of more than 5,800 m and form the water divide between India and Tibet. Thus, all exposures are generally inaccessable. In the present work only one exposure lying east of Balcha Dhura Pass is studied.

The Exotic Formation is overlying the Balcha Dhura volcanic rocks which are interbedded with radiolarian and foraminiferal oozes, and red shales. The pillow structures are recorded from the basic volcanic flows. All this suggests that the volcanic activity was penecontemporaneous with sedimentation in an abyssal region.

von Kraft (1902) has postulated the theory that these blocks were brought by the volcanic flows from the area far from the site of the occurrence possibly from somewhere north in Tibet. Heim and Gansser (1939) have demonstrated that these blocks are thrusted over the rocks of Jhangu Formation (Upper Flysch). They have presumed a thrust between the Upper Flysch (Jhangu Formation) and the volcanic rocks (Balcha Dhura Formation). However, in the present work the thrust is taken between Balcha Dhura Formation and the Exotic Formation. The well developed slicken sides in the basic volcanic rocks just underlying the Exotic Formation also point to the tectonic disturbances. However, the problem of root zone and the mechanism of thrusting of the rocks of the Exotic Formation are still open questions. It is contended that the thrusting must have started penecontemporaneously with the dying phase of volcanic activity and which witnessed the end of a depositional basin at the close of Mesozoic or beginning of the Cenozoic era.

FOLDS

From the Martoli Formation to the Muth Formation, the folding is of minor scale and no large scale repetition of beds due to folding is seen. On small scale, however, very tight folding is recorded at different places in Girthi Valley. Flexture folding is quite common. The general trend of the fold axes is mostly NW-SE.

The folding of larger magnitude is recorded in the succession between Kuti Shale and Spiti Shale. Some of the most spectacular folding is seen between Rawalibagar and Laptal affecting Kuti Shale, Passage Formation, Kioto Limestone, Laptal Formation, Ferruginous Oolite Formation and Spiti Shale. In this part, the axes of the folds are generally trending NNW—SSE. The most prominent folding and faulting is depicted by the Kuti shales. In all, there are two major syncline and three anticlines, plunging towards north (Kumar *et al.*, 1972). This folding pattern may be due to the fact that the limestone and shales of the Rawalibagar Group have been caught between very hard quartzites of the Muth Formation and thrusted blocks of Exotic Formation.

PALAEOCURRENT STUDIES

The palaeocurrent studies can be quite helpful in determining the direction of sediment supply, i.e., provenance, paleo-slope, shore line orientation and basin geometry (Potter and Pettijohn, 1963). They can also be utilised in the study of sedimentary tectonics and evolution of a sedimentary basin.

The palaeocurrent studies have different emphasis and significance in different environment of deposition. For example, in fluvial environment the direction of palaeocurrent corresponds broadly with the palaeoslope and can be successfully utilized in reconstruction of palaeogeography and determination of source area. In turbidite deposits also palaeocurrent can be correlated with the palaeoslope. However, in a shallow marine environment, the palaeocurrent patterns are rather complex and do not correspond to palaeoslope (Reineck, 1963 ; Singh, 1976). In a shallow marine environment, there are a number of factors like morphology of the coast line, wind direction and intensity, tide patterns, etc., that influence the current system. Nevertheless, in the shallow marine environment the palaeocurrent studies can be quite useful in determination of the various current patterns and to a certain extent in determination of palaeogeography, if carried out together with detailed environmental analysis and facies distribution on a regional scale.

The Malla Johar Supergroup attains a huge thickness of 5,000 m, and represents deposits of mostly shallow marine environments, though some parts are deposits of deep sea region and fluvial environment. The palaeocurrent studies have been made in different lithostratigraphic units of the Malla Johar Supergroup, and have been interpreted in the light of depositional environment.

However, there are some inherent problems connected with the palaeocurrent analysis of the Malla Johar Supergroup. This succession is exposed in a very unfriendly terrain, and the outcrops are accessible only along few paths. The palaeocurrent data presented below has been recorded along a single profile. Thus, this data can not be interpreted in the broader palaeogeographic framework.

There are a number of sedimentary structures, which have directional significance and are used in palaeocurrent studies. In the present study small scale cross-bedding, large-scale cross-bedding, and ripple marks have been utilized. The rocks of the Malla Johar Supergroup generally dip in NE direction ; thus all the readings for the palaeocurrent have been reoriented for NE direction. Since most of the rose diagrams are atleast bimodal (Fig. 27), the vector mean is not considered for interpretation. The statistical parameters of the palaeocurrent analysis for the Malla Johar Supergroup are given in Table 2. In

Table 2.

(Statistical parameters of the palaeocurrent analysis)

Serial Number	Stratigraphic Horizon	Number of Readings	Mean Vector Azimuth	Magnitude of Mean Vector	Vector Strength	Dominant Current Direction
1	Lower Ralam B ..	16	97	11.9	74.5	NE
2	Upper Ralam B ..	42	91	20.4	48.5	E15°S
3	Ralam C ..	27	58	18.1	67.1	N75°E
4	Ralam D ..	5	75	3.4	69.2	NE
5	Garbyang A ..	20	80	6.7	33.5	N30°E
6	Garbyang B ..	9	75	1.0	11.0	NE-SW
7	Garbyang C ..	25	17	13.8	54.8	NE
8	Garbyang D ..	46	36	19.9	43.3	N60°E
9	Garbyang E & F ..	18	56	3.9	21.8	NE
10	Garbyang E & F (Ripple marks) ..	33	59	4.5	13.8	SW
11	Shiala A, B & C ..	27	357	17.8	66.0	N45°W
12	Shiala D ..	34	40	11.0	32.3	N60°E
13	Shiala E, F & G ..	18	75	15.1	83.9	N75°E
14	Muth Formation ..	29	67	11.0	37.8	N75°E
15	Kuling Shale ..	3	345	2.7	90.0	N15°W
16	Passage Formation ..	25	337	11.8	47.2	N15°W-SW
17	Kioto Limestone ..	61	16	42.5	69.7	N15°E
18	Laptal Formation ..	13	6	7.0	54.2	NE-W15°N
19	Ferruginous Oolite Formation ..	27	49	13.2	49.1	NE
20	Giumal A ..	2	45	1.6	78.0	NE
21	Giumal C ..	18	46	11.1	64.7	NE
22	Giumal D ..	7	330	1.4	20.1	SW
23	Jhangu Formation ..	3	9	1.2	40.6	N15°W

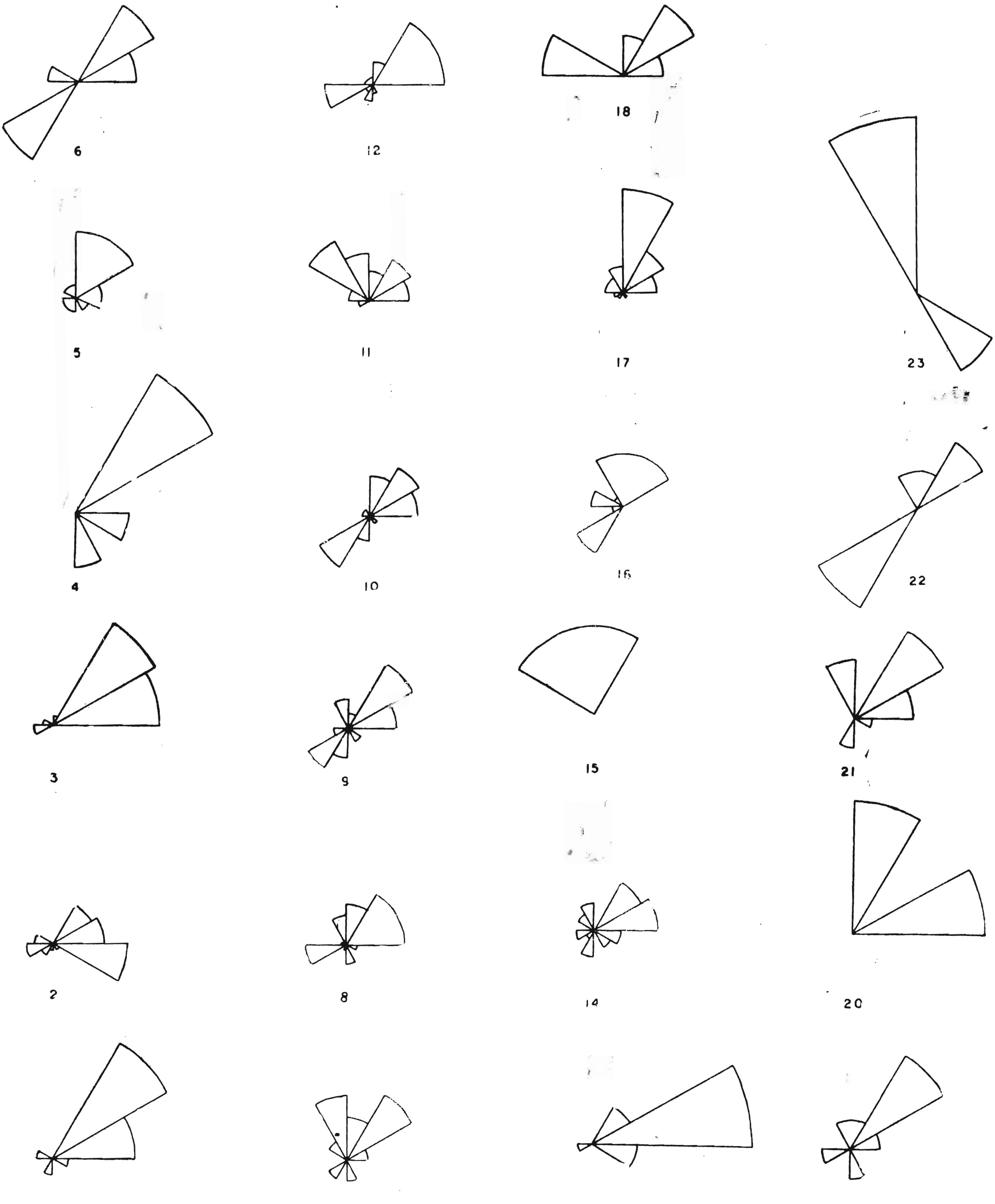
the following, palaeocurrent data of different lithostratigraphic units is discussed.

Martoli Formation—The sedimentary structures with vectoral significance are rather rare. Only small ripple bedding is present, showing a NE current direction. However, no systematic palaeocurrent analysis has been done.

Ralam Formation—The Ralam A (Ralam conglomerate) member rarely shows vectoral attributes. The faint imbrication of the pebbles shows NE direction of flow. The Ralam conglomerate has been assigned a fluvial environment of deposition, where sedimentation took place by rapidly flowing rivers near the shoreline. The regional strike of the beds is NW-SE, and flow of rivers in NE direction. Thus, provenance must have been in SW direction, possibly the quartzite rich Central Crystallines.

The Ralam B member is a deposit of sand flat in a coastal complex. The lower part of this member shows a dominantly unimodal distribution of the palaeocurrent data, with main current direction in NE, and insignificant modes in W and SSW directions(Fig. 27—1). The rose diagram for the upper part of the Ralam B member is bimodal, showing main current in ESE direction and a minor current in WSW (Fig. 27—2).

The Ralam C member is a deposit of beach shoal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complex of a tidal sea. The palaeocurrent pattern is dominantly unimodal with the main current direction in east, and a minor insignificant mode in the west (Fig. 27—3).

The Ralam D member is a tidal flat deposit. There are only 5 readings. The main palaeocurrent mode is in NE direction and minor modes in SSE and ESE directions (Fig. 27—4).

Garbyang Formation—The Garbyang A member shows polymodal distribution of palaeocurrent with main current direction in ENE. The environment of deposition is a shallow tidal sea (Fig. 27—5).

The Garbyang B member is a deposit of intertidal-supratidal zones in evaporatic conditions. The rose diagram is dominantly bimodal with the main current directions in NE and SW, and with an insignificant mode in WNW direction (Fig. 27—6).

The Garbyang C member represents deposit of a tidal flat sand bar complex. The palaeocurrent pattern shows dominantly polymodal distribution with two prominent current directions in NE and NNW (Fig. 27—7).

The Garbyang D member is essentially a tidal flat deposit. The rose diagram shows polymodal distiibution with wide scatter, the main current direction is in NE (Fig. 27—8).

Combined palaeocurrent data for Garbyang E and F members has been recorded. They represent deposits of the subtidal to intertidal zone of a tidal sea. The rose diagram based on cross-bedding directions shows a polymodal character (Fig. 27—9). However, for practical purposes it can be considered as bimodal with two main directions opposing each other, i.e., NE and SW. The rose diagram based on the measurements of the asymmetrical ripples also shows polymodal distribution with main modes in NE and SW directions(Fig. 27—10).

The palaeocurrent data for Garbyang G is not available.

Shiala Formation—The lower part of the Shiala Formation corresponding to Shiala A, B and C, represents deposits of subtidal to intertidal zone. The rose diagram for this part shows bimodal distribution of the palaeocurrent with current directions in NW and NE i.e., at right angles to each other (Fig. 27—11).

The middle part of the Shiala Formation (Shiala D member) shows dominantly a bimodal distribution (Fig. 27—12). The two main current directions are ENE and WSW, where ENE mode is very prominent. There is also an insignificant mode in SW direction. The rocks are deposits of a sandy tidal flat-shoal complex.

The upper part of the Shiala Formation (Shiala E, F and G) is the deposit of a shallow tidal sea in subtidal to intertidal zone. The palaeocurrent pattern shows a dominantly unimodal distribution with main direction in ENE and an insignificant mode in WSW direction (Fig. 27—13).

Variegated Formation—No palaeocurrent data is recorded for this Formation.

Muth Formation—It represents deposits of sand bar/shoal complex of a tidal sea. The palaeocurrent pattern is characteristically polymodal with wide scatter. The main current direction is in ENE (Fig. 27—14).

Kuling Shale—It is a deposit of the shelf mud zone. There are only 3 readings of palaeocurrents. The rose diagram shows a unimodal distribution in NNW direction (Fig. 27—15).

Chocolate Formation, Kalapani Limestone and Kuti Shale—No palaeocurrent data is available for these lithostratigraphic units.

Passage Formation—It represents tidal flat deposits. The palaeocurrent pattern is polymodal with two dominant modes in NE and SW directions, and a minor mode in WNW direction(Fig. 27—16).

Kioto Limestone—The Kioto Limestone, represented mainly by oolitic limestones, is a deposit of a carbonate sand bar—tidal flat area. The rose diagram shows a polymodal palaeocurrent pattern with wide scatter, and one very prominent mode in NNE direction (Fig. 27—17) The current in southerly direction, though present, is very insignificant.

Laptal Formation—The palaeocurrent pattern shows a bimodal distribution with two directions approximately at right angles to each other, in NE and WNW (Fig. 27—18). These sediments are deposits of a shallow tidal sea in subtidal to intertidal zone.

Ferruginous Oolite Formation—This succession represents deposits of a high energy carbonate shoals. The rose diagram shows a polymodal distribution of

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Fig. 27. Rose diagrams for the different lithostratigraphic horizons of the Malla Johar Supergroup:

1. Lower part of Ralam B
2. Upper part of Ralam B
3. Ralam C.
4. Ralam D
5. Garbyang A
6. Garbyang B
7. Garbyang C
8. Garbyang D
9. Garbyang E & F
10. Garbyang E &F (for Ripple marks)
11. Shiala A, B, & C
12. Shiala D
13. Shiala E, F & G.
14. Muth Formation
15. Kuling Shale
16. Passage Formation
17. Kioto Limestone
18. Laptal Formation
19. Ferruginous Oolite Formation
20. Giumal A
21. Giumal C
22. Giumal D
23. Jhangu Formation.

palaeocurrent with main current direction in NW (Fig. 27—19).

Spiti Shale—No palaeocurrent data is available.

Giumal Sandstone—It represents deposits of continental margin laid down by low-density turbidity currents. The lower part of the Giumal sandstone shows NE palaeocurrent direction (Fig. 27—20). The palaeocurrent pattern of middle part of the Giumal sandstone shows a polymodal distribution with main current direction in NE (Fig. 27—21). Upper part of the Giumal sandstone shows bimodal palaeocurrent distribution with opposite current directions in NE and SW, where SW direction dominates (Fig. 27—22).

Jhangu Formation—It represents deposits of a deep sea basin and lower part of continental margin. Sedimentary structures indicating current direction are extremely rare in this Formation. Only 3 readings are available. The rose diagram shows a bimodal distribution with more or less opposite current directions in NW and SE (Fig. 27—23).

DISCUSSION

Fig. 27 shows the rose diagram of various rock units of the Malla Johar Supergroup. As already pointed out, the general palaeoslope of the area was towards north and the Central Crystallines probably served as provenance. However, the succession represents mostly deposits of a shallow tidal sea and the vector mean automatically cannot be taken as corresponding to the palaeoslope.

The succession of the Malari and Sumna groups shows mostly polymodal palaeocurrent patterns. Often, there are two main current directions opposing each other. Nevertheless, the NE remains the most dominant direction. The rose diagrams for these tidal flat deposits show pattern ranging from unimodal and bimodal to polymodal.

The Rawalibagar Group also exhibits mostly bimodal to polymodal palaeocurrent patterns with NE as the dominant direction. Often, the second mode is developed at right angle or in the opposite direction. The deposits are mostly of carbonate tidal flats and shoals.

Since the palaeocurrent data of tidal deposits of the Malari, Sumna and Rawalibagar groups shows polymodal distribution, the various modes seem to correspond to the tidal current directions (ebb and flood direction), wave direction and longshore current directions. At present, it is too early to try to correlate the various modes with the specific types of currents. However, in the case of dominantly bimodal patterns with opposite current directions, it is logical to think that they correspond to the ebb and flood currents of the tidal cycle. It is interesting to note that dominant mode is in NE direction, which is also probably the palaeoslope. It is astonishing to note that NE dominant current is present from Precambrian (Ralam Formation) upto Jurassic (Ferruginous Oolite Formation). It is suggested that NE direction may correspond to a strong ebb-current direction which dominated the basin of deposition.

The Sancha Malla Group represents deposits of the deeper part of the sea, ranging from continental shelf to continental slope and ocean basin. The Giumal Sandstone also shows bimodal current directions ; one in NE and the other in SW directions. However, in the upper part of the succession of the Giumal Sandstone SW direction dominates. Thus, for the first time in the depositional history of the Tethyan basin in Malla Johar area during the deposition of the Giumal Sandstone (Giumal D), the dominant current direction changes from NE to SW. As the palaeogeographic picture of the area is not clear and the palaeocurrent data is restricted to a single profile, it is difficult to assign these two directions the nature of current, yet it opens an interesting possibility. In contininental margin deposits, the turbidity currents are often active and palaeocurrent as deduced from the sole markings often corresponds to the direction of turbidity current. However, in the present case the palaeocurrent data is based on the small-scale ripple bedding which might have been produced by ocean bottom currents like contour currents or even weak turbidity currents. Most probably the small ripple bedding has been produced by weak turbidity or bottom currents. In the Jhangu Formation the dominant palaeocurrent directions are in NW and SE. Thus, the monotony of NE dominant direction of Malari, Sumna and Rawalibagar groups is broken by NW and SE directions in the Jhangu Formation.

It is an interesting feature of the basin of sedimentation of the Malla Johar Supergroup that the same palaeocurrent directions were maintained throughout the sedimentation period (from Precambrian to Cretaceous), except in the Cretaceous when basin changed from a shallow domain (tidal flats) to a deeper domain (continental margin). The palaeocurrent patterns of the succession are characteristically polymodal, though mostly bimodal patterns dominate. The most dominant mode is always in the NE direction, except for the Sancha Malla Group where it changes partly to SW direction.

TRACE FOSSILS

The activity of the living animals may produce certain features within the sediment or on the sediment surface, termed as bioturbation structures (RICHTER, 1936). If these structures are well-formed with well-defined shape etc., they are generally termed as trace fossils. The trace fossils can be studied from taxonomic, ecological and stratinomic point of view, out of which ecological approach is most significant (see Seilacher, 1953). The pattern of burrows generally reflect the ecological conditions and tend to characterize an environment (Seilacher, 1964, 1967). Moreover, mostly trace fossils occur at the site of their formation and provide a reliable criteria in the interpretation of palaeoecology.

The trace fossils are quite commonly present throughout the sequence of the Malla Johar Supergroup and in the following a systematic description of them is given. Identification of the trace fossils has been done following the taxonomic procedure of HÄNTZSCHEL (1962). The work of CRIMES (1970) and FREY (1975) have also been useful in the identification of some of the forms. Several forms seem to be entirely new ; however, in the present paper they have been assigned only non-formal designations A, B, C etc. The present study of trace fossils is preliminary but quite significant, as this provides the first systematic data on the trace fossils from this sequence.

An attempt has also been made to interpresent the palaeo-ecological significance of these trace fossils in the light of environmental reconstruction.

In all 36 trace fossils have been described. Their stratigraphical distribution is given in Table 1.

DESCRIPTION OF THE TRACE FOSSILS

GARBYANG FORMATION

Ichnogenus Rouaultia de Tromelin, 1877
(Plate VII—3)

Smooth bilobate crawling trail bifurcating at one end. About 1 cm wide with a distinct median furrow. Lateral furrow indistinct. Seen over rippled surface.

Ichnogenus Form A
(Plate VII—6)

4 mm wide trail running parallel to the bedding with broad curves. Bifurcation seen. One end of the trail shows sharp bend with small undulations.

Trail probably made by an annelid.

Ichnogenus Form B
(Plate VI—7)

Single and bilobed burrows, overlapping. Width varies from 0.5 to 2.5 cm.

SHIALA FORMATION

Ichnogenus Dimorphichnus Seilacher, 1955
(Plate V—6)

Longitudinal series of tracks, slender, straight or curved. Each track thick in the middle and tapering on either side. Seen on the bedding plane and probably produced by raking movement of trilobites.

Ichnogenus Fucusopsis Vassoievitch, 1932
(Plate IX—6)

Stretched burrows with thread like structure, slightly curved, crossing each other. Maximum width 0.4 mm. Seen on the bedding plane.

Ichnogenus Helminthopsis Heer, 1877
(Plate V—8)

Simple and broad meandering tracks on the bedding plane.

Ichnogenus ?Tomaculum Groom, 1902
(Plate VI—6)

Strand of elleptical feacal pellets (?) 1 cm wide lying on the bedding surface.

Ichnogenus ? Planolites Nicholson, 1873
(Plate VIII—8)

Thin branched overlapping burrows rounded in cross section. These burrows are quite thin and slender in appearance as compared to *Planolites* Nicholson, though the form very closely resembles in other characteristics.

Ichnogenus Form C
(Plate II—6)

Numerous slender trails, irregularly branched, seen on the rippled siltstone.

Trails probably made by small worms.

VARIEGATED FORMATION

Ichnogenus Volkichnium Pfeiffer, 1965
(Plate V—1)

Radiating burrows parallel to bedding plane. Burrow system slightly irregular, overlapping and branched. Presence of scratches suggests that the burrows have been produced by some arthropod.

PASSAGE FORMATION

Ichnogenus Laevicyclus Quenstedt, 1879
(Plate VIII—1)

Nearly cylindrical burrow almost at right angle to the bedding with a central canal. Diameter variable.

Ichnogenus Form D
(Plate VI—5)

Single or double, parallel, semicircular burrow system. In cross section ellipsoidal with 2-3 cm diameter. Burrows extend for more than 50 cm. Surface nearly smooth. Dwelling and feeding burrows probably made by an arthropod.

KIOTO LIMESTONE

Ichnogenus Form E
(Plate VI—1)

The burrows commonly spindle shaped, straight or irregular in outline distributed irregularly. Thickness varies from 1-2 cm and length is variable.

In vertical section, the overall pattern shows affinity with *Thalassinoides* type burrows. Borings resembling the present form have been reported from Muschelkalk limestone by Kaźmierczak and Pszczólkwoski (1969). Similar structures have also been reported from Triassic by Soergel (1923) and Mägdefrau (1932).

Due to the presence of these spindle shaped white calcite bands which stand out prominently in a dark limestone background, Heim and Gansser (1939) have considered the Kioto Limestone as a marker horizon. They have called them as 'Problematica'.

It is suggested that the irregular pattern in the Kioto Limestone is due to burrows similar in form to the *Thalassinoides* burrows, but is comparatively less organised.

SPITI SHALE

Ichnogenus Zoophycus Massalongo, 1855
(Plate IX—1, 7)

Spreiten structures with thin tubes at various angles. Spreite curved and are very close.

Ichnogenus Chondrites Sternberg, 1833
(Plate VIII—4)

Plant like regularly ramifying tunnel structures, which neither cross nor anastomose, width of a tunnel uniform in a system.

Ichnogenus ? Gyrolithes deSaporta, 1884
(Plate VIII—6)

Coiled burrows, vertical or inclined with a diameter of 2 cm, some showing fine striations on the surface similar to sphinctur muscle scars on coprolites. The form is not very clear due to high degree of silification but resembles *Gyrolithes* Desaporta.

Ichnogenus Form F
(Plate VIII—2)

Simple and broad meandering tracks. The form resembles with *Helminthopsis* Heer.

GIUMAL SANDSTONE

Ichnogenus Saportia Squinabol, 1891
(Plate V—5)

Plant like branches, short, rarely cross each other, usually of uniform thickness. Some forms give flattened appearance with increasing width. Feeding burrow.

Ichnogenus aff. *Stellascolites* Etheridge, 1876
(Plate IX—4)

Stellate, disc-like trails of some what unequal lengths, 11 rays counted in half of the specimen (poor preservation) radiating from a rather central rounded space. Rays becoming broader at the extremities and terminating with a rounded tip. Visible diameter 4 cm.

The size of the form is quite small as against *Stellascolites* Etheridge described from the Ordovician rocks of England and similar forms described from the present day sea.

Neonereites biserialis Seilacher, 1960
(Plate V—4)

Hyporelief showing two rows of pustules, somewhat irregular in shape with a shallow median furrow. Trains are about 1 cm in width and run nearly straight.

Ichnogenus Zoophycus Massalongo, 1855
(Plate IX—5)

Various shaped spreiten structures with thin tube and large but variable radius of curvature. These appear as feeding burrows made by worms.

Ichnogenus Rhizocorallium Zenker, 1836
(Plate IX—3, 5)

U shaped tubes with transverse packing and nearly parallel legs. Tubes thick. Prolongation of dwelling tube by removal and redeposition of sediments in the vortex. Feeding burrows.

Ichnogenus Taenidium Heer, 1877
(Plate IX—2)

Cylindrical tunnel fillings with segmentation in the form of constrictions.

Ichnogenus Phycosiphon Fischer-Ooster, 1858
(Plate VIII—9)

Elongate U shaped loops connected by constructed spreite, frequently branched in large numbers to form antler shaped system.

Ichnogenus Form G
(Plate V—3)

Central area raised, wide and irregular with a (?) hole in the centre with long narrow radiating ridges 1-2 mm thick. The radiating ridges are of unequal width and are beaded at places. Resting and feeding burrows.

The present form approaches in description to *Ichnocumulus* Seilacher, (1956) described as resting trace of unknown animal from Lower to Middle Jurassic.

Ichnogenus Form H
(Plate VIII—3)

Stellate rays radiating out from a central rounded area of about 3 mm diameter. Rays long, becoming broader at the distal end, terminal portion not seen (One ray shows maximum width in the centre and tapers away becoming angular. Width of the rays not uniform, maximum visible length of a single ray is 5 cm.

Probably the form is much bigger (present specimen is broken) and is comparable in description to the recent star like traces described from the Pacific Ocean (Ewing and Davies, 1967) ; from the Polish Carpethean Flysch (Nowak, 1961) and from the Indian Ocean (Risk, 1973).

In the present specimen two star like forms are present. One ray of the smaller form enters into the ray of the bigger form, but does not cross it. Probably, the animals in question have greater phobotactic sensitivity to their own secretions than to others of the same type.

Ichnogenus Form I
(Plate VIII—7)

Flat, parallel to the bedding, 13 cm long and about 1.5 cm wide, tapering to 0.8 cm, consists of straight to slightly curved segments in the form of transverse flat ridges, each segment at an interval of 0.5 to 0.6 cm.

The form shows some similarity to *Plagiogmus*, Roedel.

JHANGU FORMATION

Ichnogenus Nereites MacLeay, 1839
(Plate VII—2)

Meandering trail 1 cm wide with a central furrow. Trail rarely branched. On each side of the furrow extending laterally are curved prod marks. Each prod mark at a distance of 1 to 1.5 mm.

Ichnogenus Planolites Nicholson, 1873
(Plate IX—9)

Crowded burrows 0.5 to 1 cm in diameter showing irregular pattern, branched and overlapping. Surface unornamented. Dwelling and feeding burrows probably made by an annelid.

Ichnogenus Zoophycus Massalongo, 1855
(Plate VI—4)

As described previously.

Ichnogenus Rhizocorallium Zenker, 1836
(Plate VI—4)

As described previously.

Ichnogenus aff. *Sublorenzinia* Ksiażkiewicz, 1968
(Plate VI—2)

Almost circular ring with lobate, periphery rays broad and thick, irregular in shape and distribution, radiating from a not distinctive centre. Diameter about 6 cm.

Ichnogenus Olivellites Fenton and Fenton, 1937
(Plate VII—5)

Ribbon like, flattened 'gill" like transverse structures with a median depression. The gill like thin laminae arise on either side from the median depression.

Ichnogenus Form J
(Plate VI—3; VII—5 and VIII—5)

Circular depression 0.5 to 0.8 cm in diameter, in most cases with a raised central knob. Form extends down in the form of a cone which may curve a little to a depth of about 1 cm. In cross section spiral laminae are visible. Dwelling and feeding burrows probably made by an annelid.

On the surface the form resembles *Laevicyclus* Quenstedt, but differs in vertical section.

Ichnogenus Form K
(Plate V—2)

Large 0.5 cm wide vertical or inclined burrows which bifurcate downwards forming inverted Y shape. The burrows show transverse partings and have an almost uniform thickness. They may be straight or with slight undulation. Maximum visible length 12 cm. Possibly represent dwelling burrows.

Ichnogenus Form L
(Plate IX—8)

Nearly circular in outline with a central depression or hole with five trigonal areas not clearly demarcated, separated by five nearly straight lines in the form of grooves radiating from the central depression. Periphery not clear but appears to be nearly smooth. Diameter 3 cm.

PALAEOECOLOGICAL SIGNIFICANCE OF TRACE FOSSILS

SUMNA GROUP

In the Garbyang Formation, the trace fossils are present, though not abundant. All the forms recorded are long horizontal burrows representing crawling traces made by the organisms while moving on a soft sediment surface. Others are small, vertical burrows, denoting dwelling structures. Bioturbation horizons are very rare, and are associated with vertical burrows indicating dense, closely spaced population of some organisms.

The Shiala Formation is dominated by horizontal burrows of considerable extent, denoting crawling traces. A few horizontal burrows are short and stout, and may represent feeding or resting traces. A characteristic trace fossil of this Formation is *?Planolites* about 2-3 mm in diameter and showing dense network of slightly overlapping burrows in a horizontal plane. It may represent feeding cum dwelling structure.

In the Variegated Formation the trace fossils are rare. Only one form of radiating horizontal burrows is present corresponding to browsing or crawling traces.

RAWALIBAGAR GROUP

The Passage Formation shows horizontal burrows of considerable extent, which represent crawling traces, and some short vertical browsing cum dwelling traces.

The Kioto Limestone shows irregular burrow patterns, which correspond to dwelling structures.

SANCHA MALLA GROUP

The Spiti shales contain a few hard siliceous and calcareous bands, which show dominantly feeding structures. The *Zoophycus* runs horizontally in endichnia position.

The Giumal Sandstone shows a variety of trace fossils in much abundance. These trace fossils mostly correspond to the horizontal feeding structures of deep sea affinity. A few small vertical feeding burrows are also present.

The Jhangu Formation also shows abundant feeding structures, mostly horizontal, a few of them in endichnia position. Most characteristic is the presence of *Zoophycus* and *Rhizocorallium*. A typical trace fossil of this Formation is *Planolites* with short stout burrows overlapping each other. The *Planolites* of this Formation shows larger diameter in comparison to ?*Planolites* of the Shiala Formation.

DISCUSSION

Seilacher (1964, 1967) attempted to differentiate the trace fossils of deep sea environment from the shallow water environments. Attempts have also been made to distinguish the various subenvironments of a shallow sea on the basis of trace fossils, both in the rocks (Howard, 1966) and in the modern sediments (Frey and Howard, 1969, Hertweck, 1972).

In the present study, as the available data is insufficient, it is not possible to assign trace fossils various subenvironments. However, it may be pointed out that the sediments of the Sumna Group and Rawalibagar Group representing deposits of a shallow sea are characterized by the horizontal crawling traces along with some vertical dwelling and feeding traces. Whereas, the deep sea deposits of Sancha Malla Group are characterized by abundance of feeding structures, e.g., *Zoophycus, Rhizocorallium, Chondrites*. This distribution of trace fossils in the Malla Johar Supergroup corresponds to the scheme proposed by Seilacher (1967).

EVOLUTION OF THE SEDIMENTATION BASIN OF THE TETHYS ZONE IN MALLA JOHAR AREA

The sediments of the Malla Johar Supergroup 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 in the northern limits of the Himalaya.

On the basis of the sedimentological information the history of depositional basin in the Malla Johar area can be subdivided into four phases, corresponding to the four lithostratigraphic groups.

Phase I—It includes deposits of the Malari Group. A shallow basin with low-energy conditions came into existence on the northern margin of the Central Crystallines, where mainly fine-grained shaly sediments were deposited (Martoli Formation). The deposition took place mostly in the tidal flat complex including subtidal embayments, partly with reducing milieu. This phase of sedimentation was followed possibly with a break by a relatively short-lived period of fluvial sedimentation. This is again followed by coastal sand and tidal flat deposits (Ralam Formation). It seems that the basin was some what unstable with changing environment and energy conditions.

The Phase I denotes deposits of a shallow basin with fluctuating environmental conditions ranging from coastal fluvial, coastal sand, tidal flat, embayments in shelf mud zone. The deposits are essentially terrigenous clastics, i.e., shale and sandstones. The sandstones are mostly fine-grained, pure ; often orthoquartzite. The palaeocurrent patterns are mostly polymodal with NE as the dominant current direction. The deposits of the Phase—I sedimentation can be described as areno-argillaceous deposits.

Phase II—It includes deposits of the Sumna Group. With the beginning of the Garbyang time, the sedimentation basin became stabilized in the form of a shallow tidal sea with extensive development of coastal carbonate bodies, coastal sands, tidal flats, etc. The rate of sedimentation kept a good balance with the sinking of the basin, so that thick deposits of a single environment were produced. The lower part of the Garbyang Formation (Garbyang A and Garbyang B) represents deposits of an exceptional chemical milieu so that various types of carbonates, barytes, and gypsiferous evaporitic sequences were developed.

Later, tidal flat sedimentation with both terrigenous clastics and carbonates dominated the basin (upper part of the Garbyang and Shiala formations) in which the water depth never exceeded the upper part of shelf mud (approx. 30-50 m). However, deposits of the intertidal zone dominated the scene.

This period of dominantly medium to high-energy deposits changed to low-energy carbonate deposits of Variegated Formation. The black nodular limestone represents deposits of a zero-energy carbonate flat.

In the final period of Phase II, the basin developed extensive coastal sand bars and shoals with rather high energy. Continued reworking of these sediments over long periods led to the development of pure orthoquartzites (Muth Formation).

The palaeocurrent patterns of Phase II of sedimentation also show dominantly polymodal patterns, mostly with two opposing modes. The NE direction is the most prominent as in the case of Phase I sedimentation.

The sandstone units of the Sumna Group are rather pure sandstones, often orthoquartzite. The deposits of the Phase II sedimentation can be described as arenaceous-carbonate deposits of a coastal complex with medium to high energy. An important feature is the development of carbonate-evaporite sediments in the basal part of this phase.

Phase III—It includes the deposits of the Rawalibagar Group. The arenaceous-carbonate sedimentation of Phase II changes into argillaceous-carbonate sedimentation of Phase III. During this phase no significant thick sandy successions were deposited.

The change from Muth Formation to Kuling Formation represents a marked lithological change; however, it can not be correlated with any major break in sedimentation due to any orogeny. It may represent a period of non-deposition, whose extent cannot be ascertained due to poor preservation of fossils in the Muth quartzites.

During the sedimentation in Phase III thick successions of carbonates were deposited along with shales. However, the domain of sedimentation remained in tidal flat, coastal carbonate banks and bars and upper part of shelf mud.

The palaeocurrent patterns of the Rawalibagar Group also show bimodal to polymodal patterns, with a dominant NE direction. Thus, the domain of sedimentation and the palaeocurrent patterns of the Phase I, II, and III deposits are almost identical. This suggests that there is no significant break between the Sumna Group and Rawalibagar Group. Nevertheless, during the sedimentation of Rawalibagar Group coarse-grained terrigenous clastics show a marked decrease. It seems that due to changes in the palaeogeographic set up, supply of sand material decreased during sedimentation of the Rawalibagar Group. However, thin sand layers are sometimes present and are made up of almost pure quartz sandy material, suggesting identical source of sandy material during sedimentation of Phase I, II, and III.

Phase IV—This corresponds to the deposits of the Sancha Malla Group. The rocks of this Group represent deposits of terrigenous material in deep sea environment with unstable and changing tectonic set up during sedimentation. The domain of sedimentation is mainly continental margin. The Spiti Shale represents deposits of shelf mud of an open sea. The sedimentation basin started to become somewhat deeper with the beginning of the deposition of the Spiti Shale. With the beginning of the deposition of the Giumal Sandstone the sedimentation basin acquired a characteristically geosynclinal character, in which on the continental slope and rise the Giumal sandstones were deposited, partly under the influence of low density and low energy turbidity currents.

Further deepening of the basin is marked by the decrease in the supply of sandy material by the turbidity currents and the development of radiolarian and foraminiferal oozes. It is interesting to note that minor turbidite sequences, shales and oozes are interstratified, suggesting quick changes in the supply of material from land and fluctuations in the basin depth.

The palaeocurrent patterns show two main directions, i.e., SW and NW. This change from monotonous, dominant NE direction to SW and NW corresponds to the instability of basin and its deepening. The sandstones of this phase of sedimentation contain both pure sandstones and graywackes. It seems that the material was supplied from two different sources. It is postulated that pure sand was supplied from the Central Crystallines in the south, while the material for graywacks may have been supplied from the northern source.

During the last period of Phase IV sedimentation, sub-marine fissures appeared leading to outpouring of the basic and ultrabasic lavas, which became interbedded with the radiolarian and foraminiferal oozes.

DISCUSSION

The sediments of the Malla Johar Supergroup represent deposits of a single sedimentation basin, which was basically a shallow marine basin where sedimentation mostly kept pace with the sinking so that thick deposits of a single environment are present. The evolution of the basin and the nature of the sediments are not typically geosynclinal. During evolution of the basin from Precambrian to Cretaceous there were no effects of any orogeny. The basin started acquiring a deep-sea nature and geosynclinal character with the beginning of the deposition of the Spiti Shale and which continued during the sedimentation of the Giumal Sandstone and the Jhangu Formation, culminating with submarine eruptions of basic lavas and obliteration of the basin at the end of the deposition of the Balcha Dhura Formation. The period of volcanic activity also corresponded with the beginning of uplifting of the sedimentation basin and thrusting of the shallow-water facies (Exotic Formation) of the northern part towards south, to become engulfed in the basic flows. The movement of Exotic Blocks continued even after the uplift of the basin of deposition.

The material of the Malla Johar Supergroup was most probably supplied from the Central Crystallines. Thus, the Malla Johar sediments are genetically related to the Central Crystallines on which they have been deposited and which also served as the source rock. Considering the above, it is suggested that most probably the northern plate boundary must have existed somewhere north of the Tethyan sediments. The Malla Johar Supergroup also does not show development of geosynclinal cycle.

Following are the characteristic features of the sedimentation basin of the Malla Johar Supergroup sediments :

(i) Dominance of the shallow-water depositional environment until the last phase of the sedimentation.

(ii) More or less continuous sedimentation from Precambrian until ? Lower Eocene.

(iii) Retaining the similar palaeocurrent patterns, throughout the sedimentation until the last phase (Phase IV).

(iv) Dominance of pure sandstones as arenaceous facies until the last phase of sedimentation.

(v) Absence of Molasse-sediments at the end of the sedimentation history of the basin.

CONCLUSION

(i) The sediments of the Malla Johar Supergroup belong to the Tethyan sediments of the Himalaya and represent a succession from Precambrian to ?Lower Eocene.

(ii) The succession is divisible into four lithostratigraphic groups ; namely Malari, Sumna, Rawalibagar and Sancha Malla which are further divisible into well-defined formations and members.

(iii) Structurally, Malla Johar area is divisible into three tectonic units ; from south to north these are the Central Crystallines, the Malla Johar Supergroup and the Exotic Formation, separated from each other by thrust faults.

(iv) The thrusting of the Exotic Formation most probably started penecontemporaneously during the dying phase of the volcanic activity at the time of culmination of the sedimentation basin of the Malla Johar Supergroup.

(v) No large scale folding is seen in the rocks of Malari and Sumna groups. However, very tight folding is witnessed in the rocks of the Rawalibagar and Sanch Malla groups. The general trend of the fold axes is NW-SE with plunge in the northerly direction.

(vi) The whole succession of the Malla Johar Supergroup represents deposits of a single sedimentation basin without any significant intermittent breaks. There are no evidences of Caledonian or Hercynian orogenies. The Hercynian orogeny may correspond to an epierogenic change in sedimentation between the deposition of the Muth Formation and the Kuling Shale.

(vii) The sediments are dominantly shallow water deposits and do not show characteristics of a geosynclinal deposits, until in the last phase of sedimentation. On the basis of sedimentological characteristics, this succession is divisible into four phases corresponding to the four lithostratigraphic groups. Phase I is marked by arenoargillaceous deposits (e.g., tidal flats, coastal sand). Phase II begins with the deposition of a carbonate evaporite sediments, and represents an arenaceous-carbonate deposit of a coastal complex with medium to high energy. Phase III represents an argillaceous-carbonate sedimentation of carbonate coastal banks and bars, tidal flat and shelf mud. Phase IV represents deposits of argilloarenaceous succession of continental margin with various types of oozes, turbidites and basic lava flows.

(viii) The palaeocurrent studies through the sequence shows that mostly polymodal to bimodal distribution is present, with dominant current direction in NE, which may correspond to the strong ebb-current direction. This pattern is maintained with uniformity throughout the succession (from Precambrian to Jurassic) except in the last phases of sedimentation, i.e., Sancha Malla Group (Upper Jurassic—?Lower Eocene).

(ix) The trace fossils are commonly present throughout the succession. The shallow-water deposits of Sumna and Rawalibagar groups are characterized by crawling traces and dwelling structures. The Sancha Malla Group shows dominantly feeding structures, like *Zoophycus*, *Chondrites* of deep-sea affinity. The so-called '*Problematica*' in the Kioto Limestone of Heim and Gansser (1939) are nothing but burrow structures of *Thalassinoides* affinity.

(x) Pure sandstones dominate the arenaceous facies of the succession. Except for the graywackes of the Giumal Sandstone and Jhangu Formation, all the sandy units are pure sandstones, often orthoquartzites.

(xi) The rate of sedimentation kept pace with the rate of sinking of the sedimentation basin, so that thick deposits of the same environment developed.

(xii) The source material for the Malla Johar sediments was most probably supplied by the quartzite-rich facies of the Central Crystallines.

(xiii) In the Jhangu Formation basic lava flows are interbedded with the radiolarian oozes, and represent a sequence of ophiolites.

(xiv) The upper age limit of the Malla Johar Supergroup may be either Palaeocene or Lower Eocene.

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EXPLANATION OF PLATES

PLATE I

Scale is equal to 1 cm.

1. The Ralam conglomerate. Orthoquartzitic boulders and pebbles are seen in a sandy matrix.
2. Wrinkle marks in Garbyang E.
3. The Girthi Bridge Fault near the bridge on the motor road at 8 km from Malari towards Deepak Nagar. The Martoli phyllites (on the right hand side of the photograph) are overlain by the Ralam quartzites.
4. Evaporite succession in Garbyang B. The lower part is made up of dolomites and the upper part is made up of gypsiferous marls.
5. Ripple bedding in the Giumal Sandstone (Giumal C).
6. Reverse fault seen in Kio Valley. The Muth quartzites are directly overlying the rocks of the Shiala Formation.

PLATE II

Scale is equal to 1 cm.

1. Tidal channel in Garbyang C succession. Kio Valley.
2. Trough cross bedding in the Ralam quartzites (Ralam B). About 7 km from Malari on Malari-Deepak Nagar motor road.
3. Convolute bedding in the calcareous sandstone (Shiala C). Kio Valley.
4. Imbricated pebble conglomerate in Shiala C. Kio Valley.
5. In the lower part penecontemporaneous conglomerate is seen while in the upper part calcareous sandstone is showing low angle cross bedding. Shiala C. Kio Valley.
6. Ichnogenus *Form C* seen on the rippled surface. Shiala Formation. Kio Valley.
7. Graded bedding in Garbyang E. Kio Valley.

PLATE III

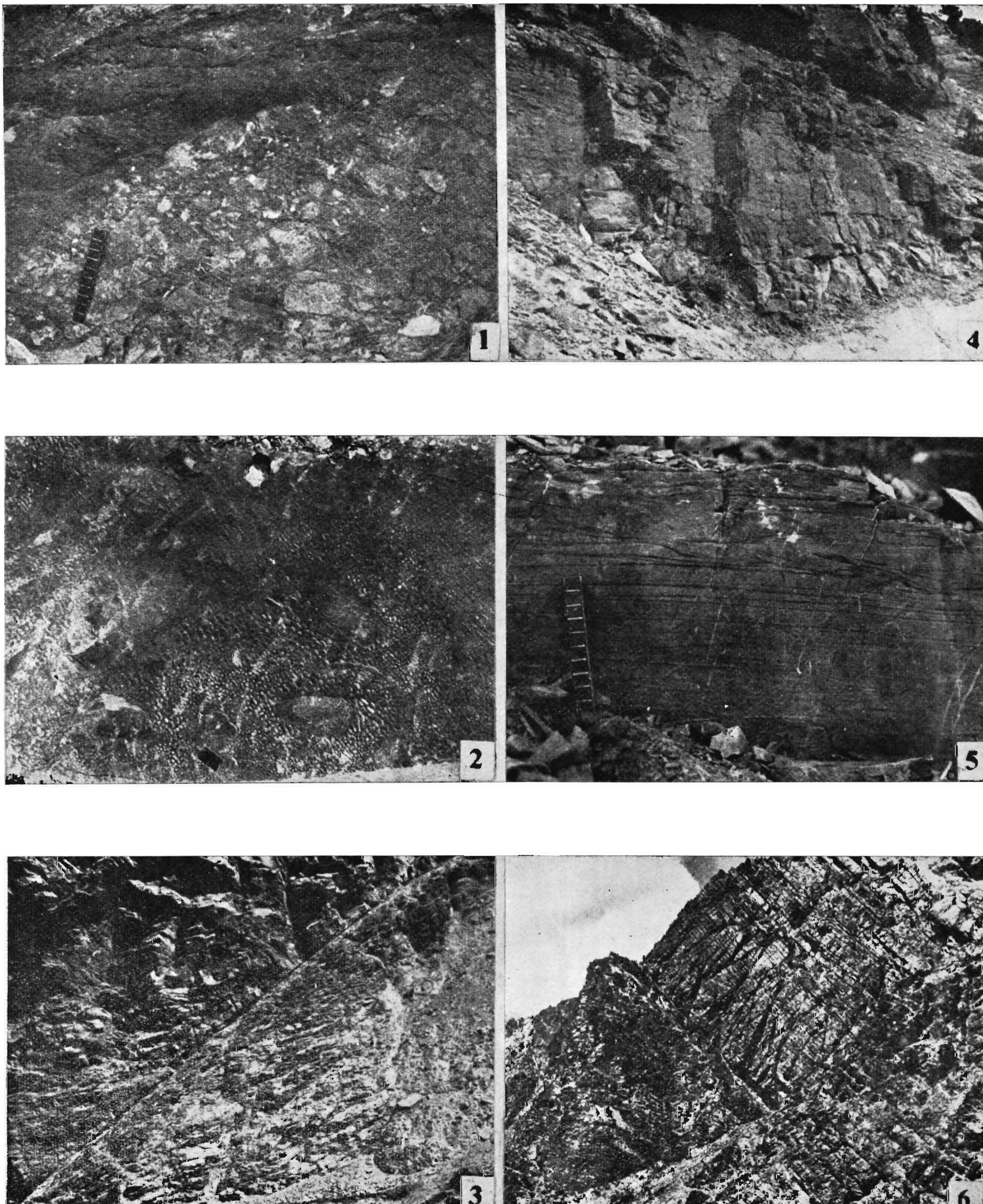
Scale is equal to 1 cm

1. Small scale current ripples in the lower part of the Laptal Formation. Laptal Camping ground.
2. Current lineations in the Giumal Sandstone (Giumal D). Near Sancha Talla in Jhangu Gad.
3. Various types of trace fossils on the bedding surface of black calcareous shales. Jhangu Formation. Near Sancha Malla in Jhangu Gad.
4. Scour markings seen on the sole of the bedding plane. Giumal D. Near Sancha Malla in Jhangu Gad.
5. Succession of the Laptal Formation. Upper thick layer is made up of the rocks of the Ferruginous Oolite Formation. On the Rawalibagar-Laptal mule track.
6. Planar cross bedding in the Muth quartzites (Muth C). Lower part also shows herringbone cross bedding. About 4 km east of Sumna in Kio Valley.
7. Beach bar cross bedding in the Muth quartzites (Muth C). About 4 km east of Sumna in Kio Valley.

PLATE IV

Scale is equal to 1 cm.

1. Pillow structure in the basic volcanic flows of the Jhangu Formation. SE of Balcha Dhura.
2. Pillow structure in the basic volcanic flows of the Jhangu Formation. Amygdales are conspicuously seen near the margin of the upper surface. SE of Balcha Dhura.
3. Succession of rocks of the Giumal sandstone. Near Sancha Malla.
4. Clay clasts in the foraminiferal limestone. Jhangu A. Near Sancha Malla.
5. Convolute lamination in the Giumal sandstone (Giumal B). Near Sancha Talla.
6. Lower part shows parallel bedding, middle part shows graded bedding while the upper part shows small scale ripple lamination. Giumal D. Near Sancha Talla.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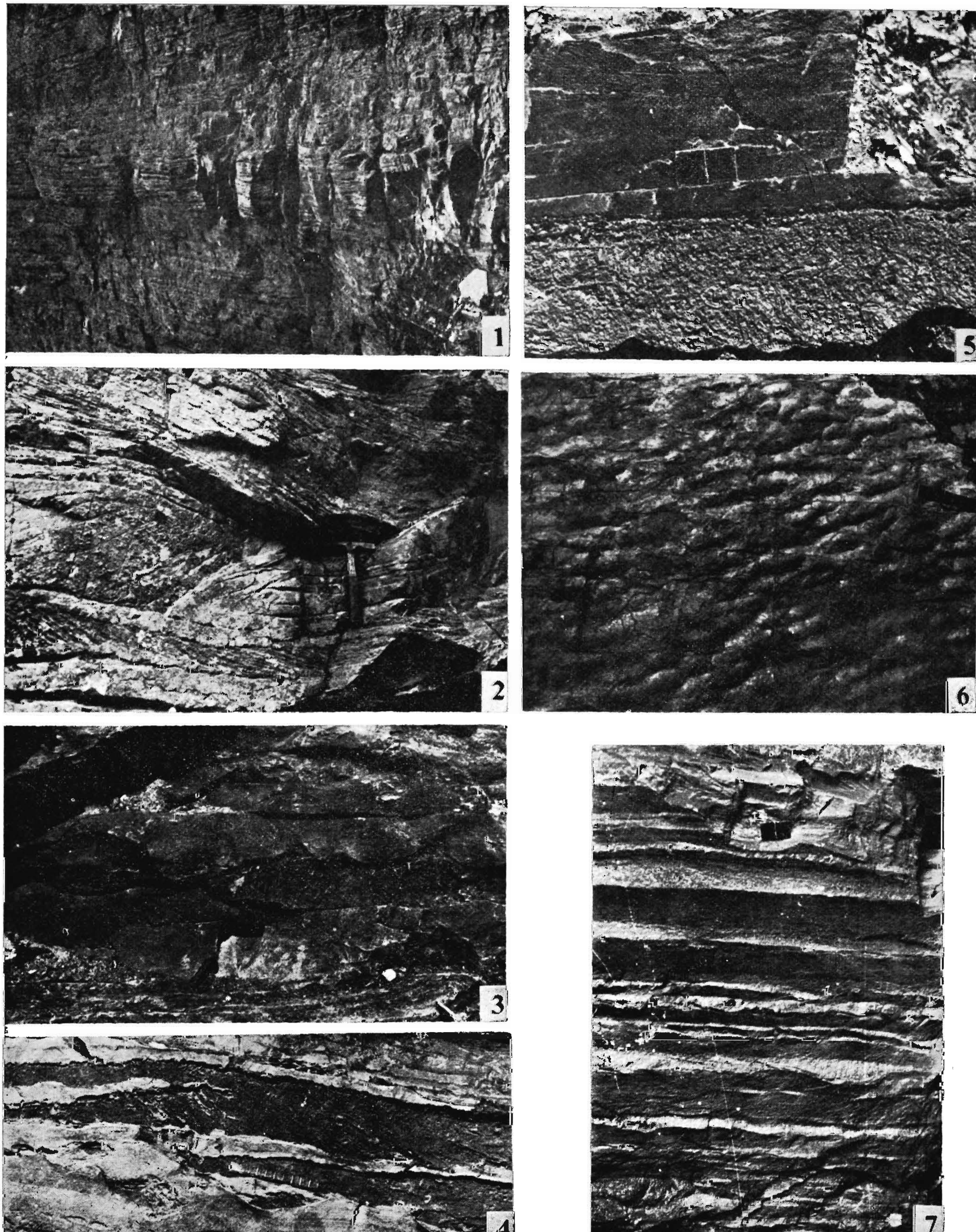
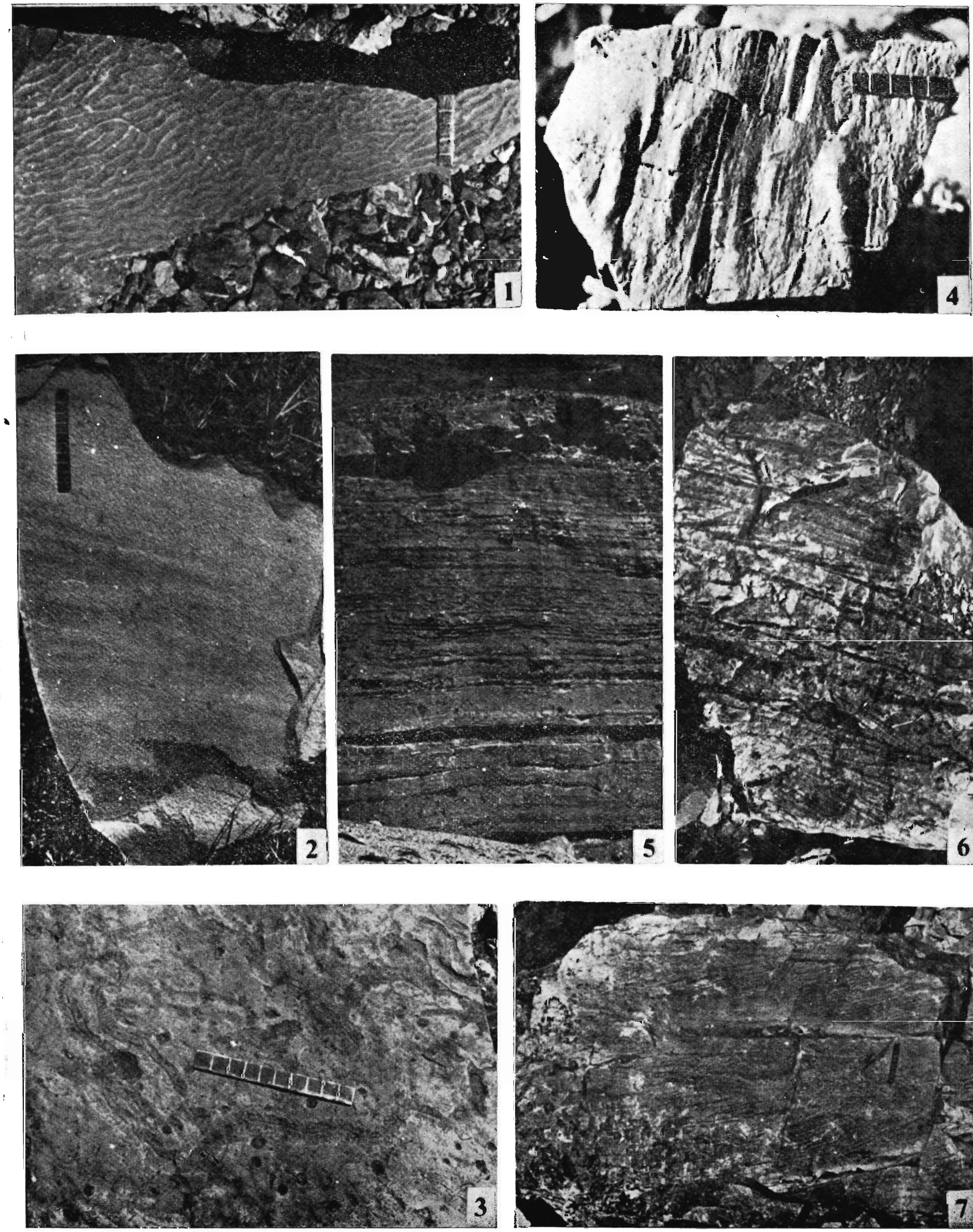


KUMAR, SINGH & SINGH



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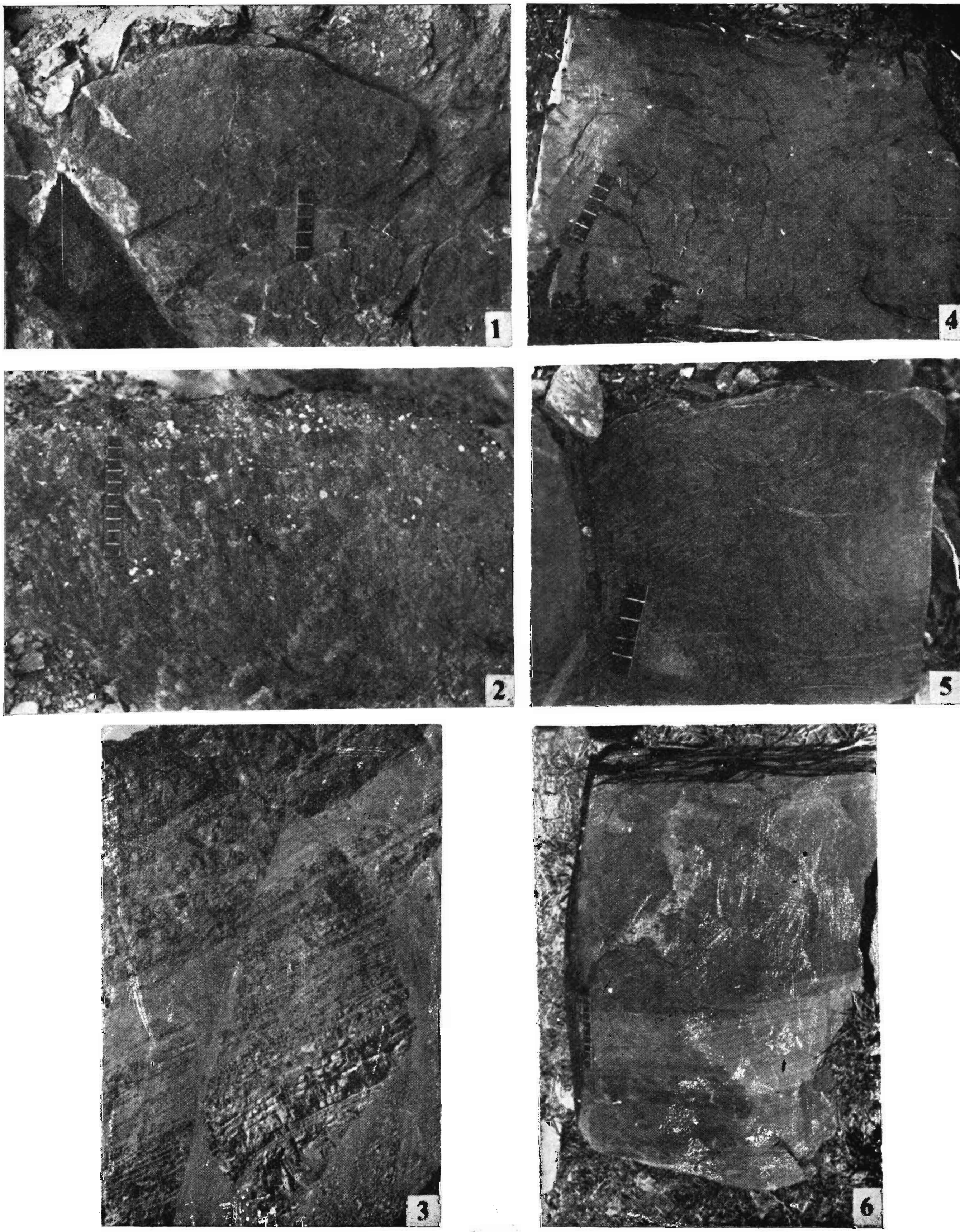
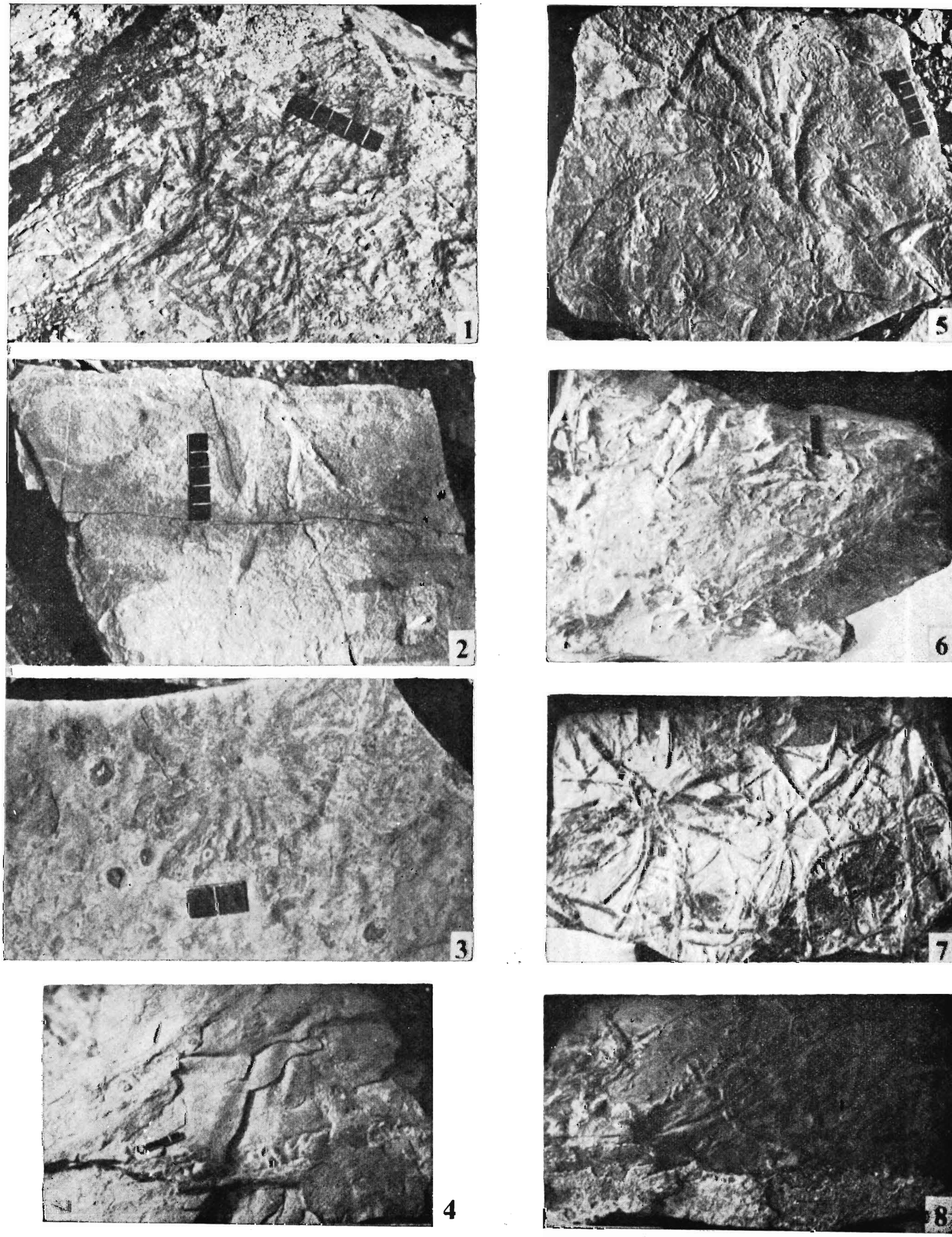


KUMAR, SINGH & SINGH

PLATE V



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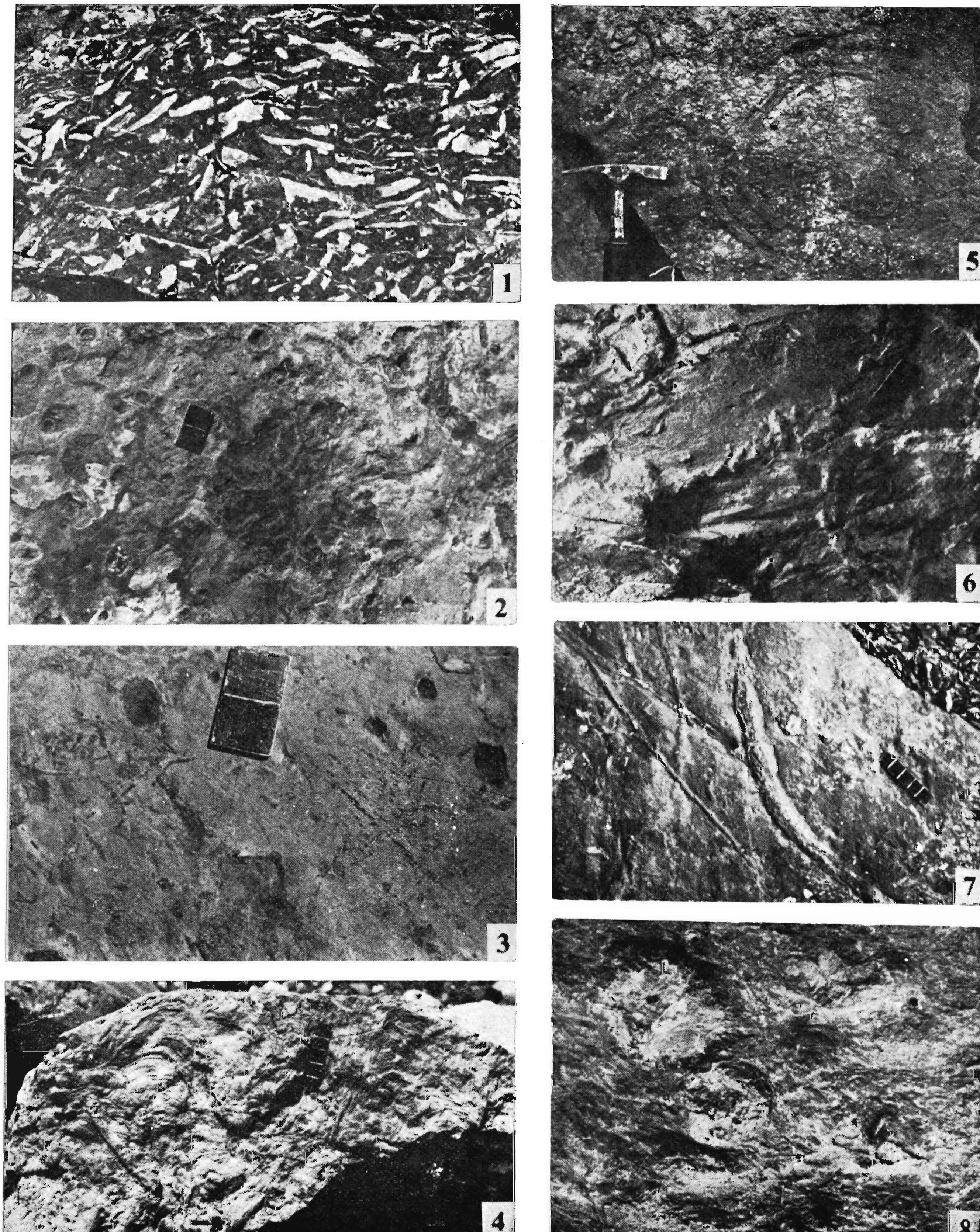
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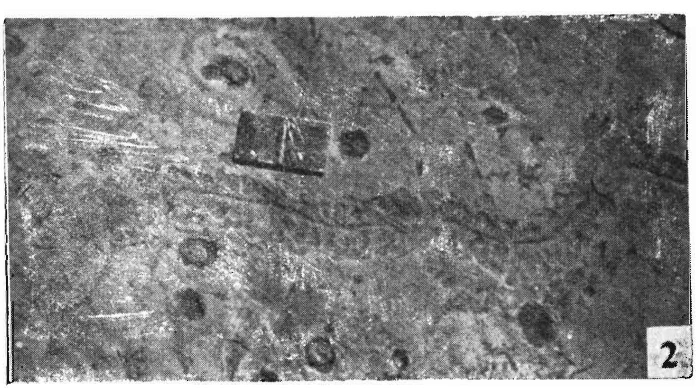

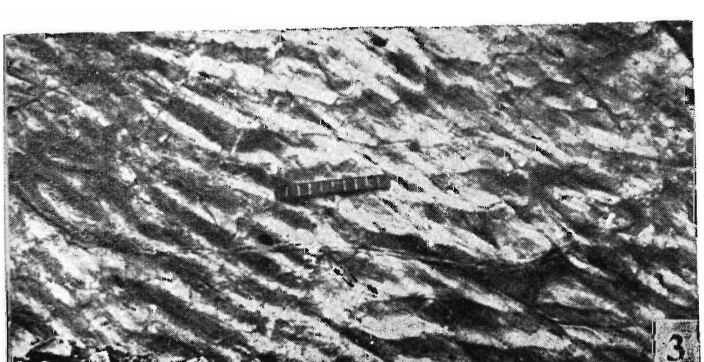

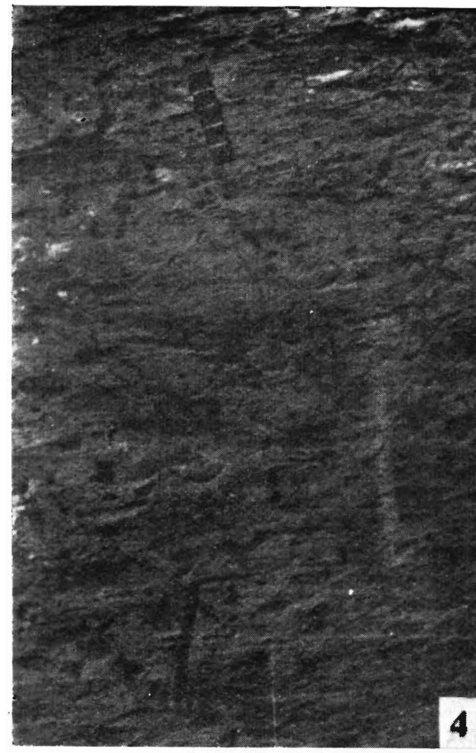

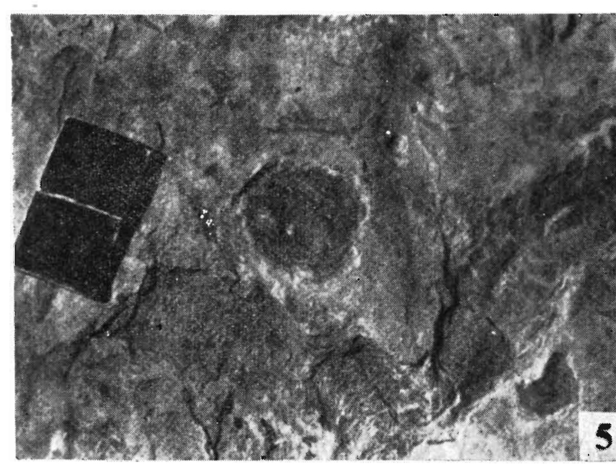

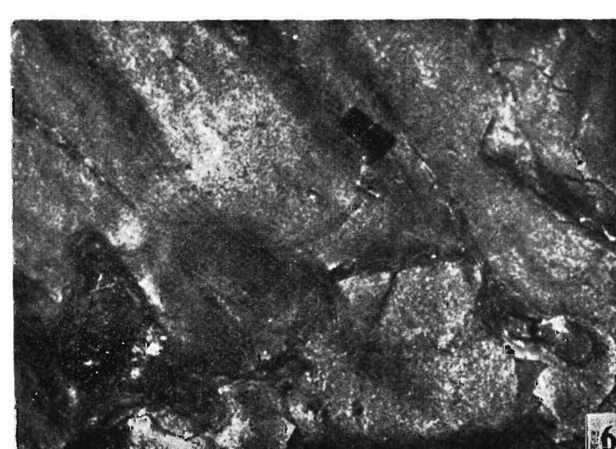

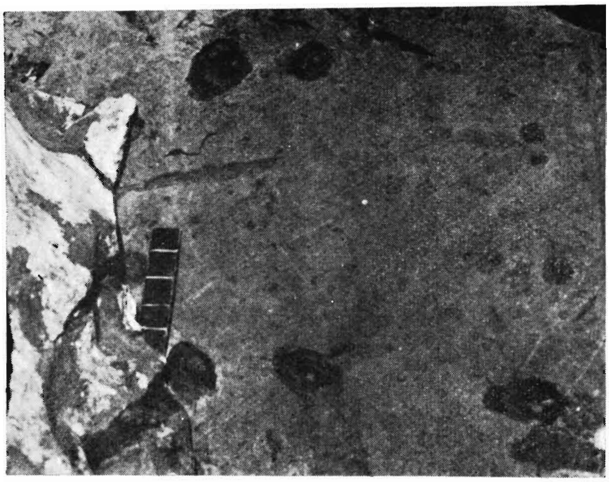

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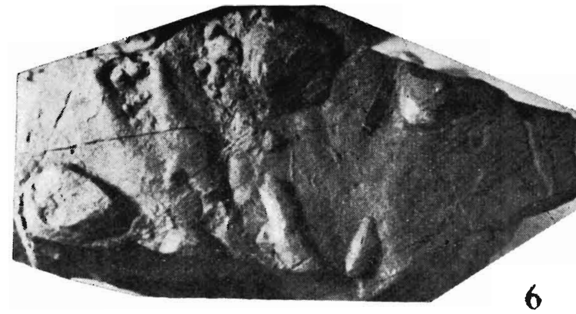

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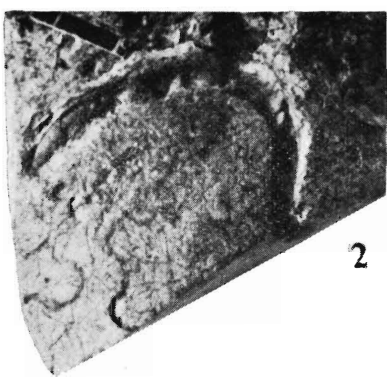

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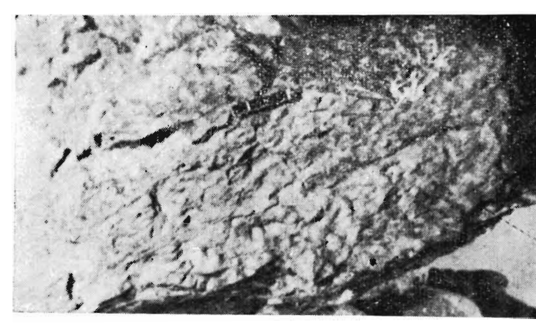

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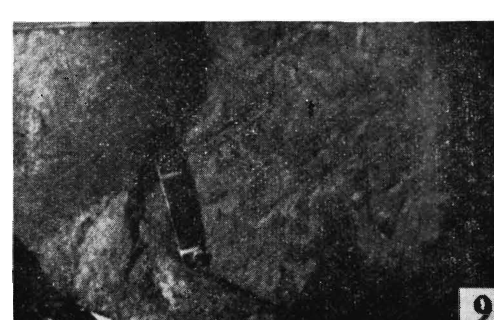

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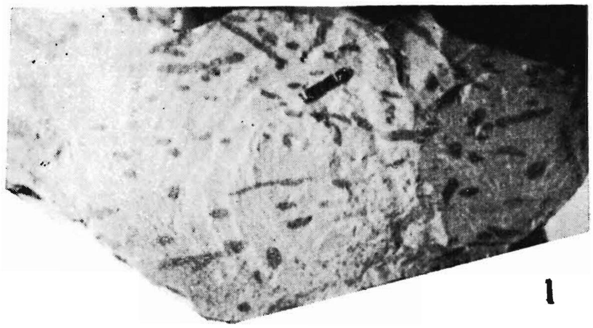

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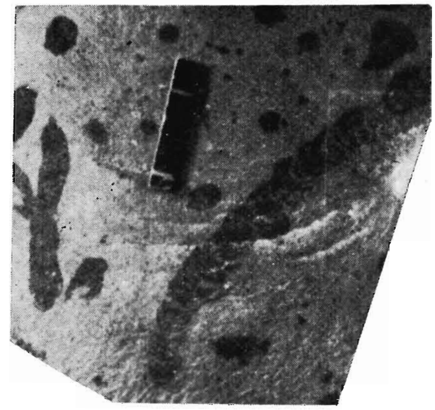

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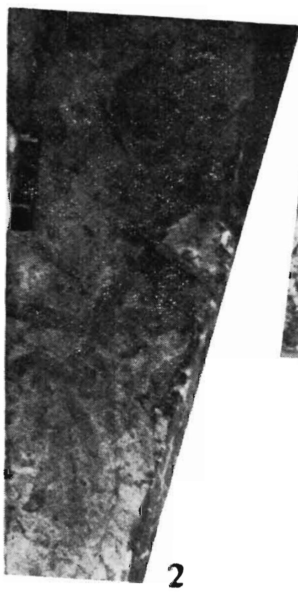

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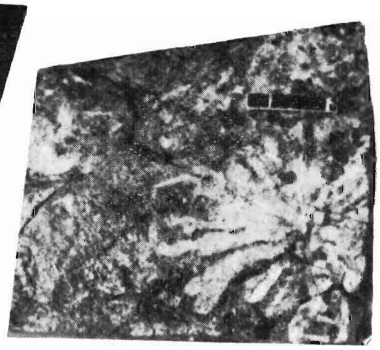

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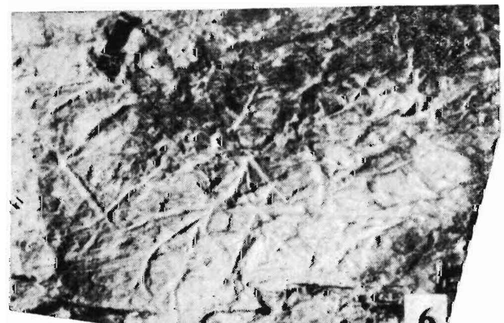

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Plate V

Scale is equal to 1 cm.

1. Ichnogenus *Volkichnium* Pfeiffer. Variegated Formation. Yong Valley.
2. Ichnogenus *Form K.* Jhangu Formation. Near Sancha Malla.
3. Ichnogenus *Form G.* Giumal Sandstone. Near Sancha Talla.
4. *Neonereites biserialis* Seilacher. Giumal Sandstone. Near Sancha Talla.
5. Ichnogenus *Saportia* Squinabol. Giumal Sandstone. Near Laptal camping ground.
6. Ichnogenus *Dimorphichnus* Seilacher. Shiala Formation. Near Sumna.
7. Various burrows seen on the bedding surface. Shiala Formation. Near Sumna.
8. Ichnogenus *Helminthopsis* Heer. Shiala Formation. Near Sumna.

Plate VI

Scale is equal to 1 cm.

1. Ichnogenus *Form E.* Kioto Limestone. Near Rawalibagar.
2. Ichnogenus aff. *Sublorenzinia* Ksiażkiewicz. Jhangu Formation. Near Sancha Malla.
3. Ichnogenus *Form J* with some trails and burrows. Jhangu Formation. Near Sancha Malla.
4. Ichnogenus *Zoophycus* Massalongo and Ichnogenus *Rhizocorallium* Zenker. Jhangu Formation. Near Sancha Talla.
5. Ichnogenus *Form D.* Passage Formation. Near Rawalibagar on Rawalibagar-Laptal mule track.
6. Ichnogenus *Tomaculum* Groom. Shiala Formation. Near Sumna.
7. Ichnogenus *Form B.* Garbyang Formation. Kio Valley.
8. Algal limestone. Variegated Formation. Yong Valley.

Plate VII

Scale is equal to 1 cm.

1. Parallel bedding and large scale cross bedding in the Laptal Formation. Near Laptal camping ground.
2. Ichnogenus *Nereites* MacLeay. Jhangu Formation. Near Sancha Talla.
3. Ichnogenus *Rouaultia* de Tromelin. Garbyang Formation. Kio Valley.
4. Vertical burrows seen in the Garbyang succession. Kio Valley,
5. Ichnogenus *Olivellites* Fenton and Fenton and Ichnogenus *Form J.* Jhangu Formation. Near Sancha Malla.
6. Ichnogenus *Form A.* Garbyang Formation. Kio Valley.

Plate VIII

Scale is equal to 1 cm.

1. Ichnogenus *Laevicyclus* Quenstedt. Passage Formation. Near Rawalibagar.
2. Ichnogenus *Form F.* Spiti Shale. Near Laptal camping ground.
3. Ichnogenus *Form H.* Giumal Sandstone. Near Sancha Talla.
4. Ichnogenus *Chondrites* Sternberg. Spiti Shale. Near Laptal camping ground.
5. Ichnogenus *Form J.* Jhangu Formation. Near Sancha Malla
6. Ichnogenus *Gyrolithes* deSaporta.. Spiti Shale. Laptal camping ground.
7. Ichnogenus *Form I.* Giumal Sandstone. Near Sancha Talla.
8. Ichnogenus *?Planolites* Nicholson. Shiala Formation. Yong Valley.
9. Ichnogenus *Phycosiphon* Fischer-Ooster. Giumal Sandstone. Near Sancha Talla.

Plate IX

Scale is equal to 1 cm.

1& 7. Ichnogenus *Zoophycus* Massalongo. Spiti Shale. Laptal camping ground.
2. Ichnogenus *Taenidium* Heer. Giumal Sandstone. Near Sancha Talla.
3&5. Ichnogenus *Rhyzocorallium* Zenker. Giumal Sandstone. Near Sancha Malla.
4. Ichnogenus *Stelloscolites* Etheridge. Jhangu Formation. Near Sancha Malla.
6. Ichnogenus *Fucusopsis* Vassoievitch. Shiala Formation. Near Sumna.
8. Ichnogenus *Form L.* Jhangu Formation. Near Sancha Malla.
9. Ichnogenus *Planolites* Nicholson. Jhangu Formation. Near Sancha Malla.