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हिमाचल हिमालय

GEOLOGY OF SPITI-KINNAUR HIMACHAL HIMALAYA

द्वारा
ओ० एन० भार्गव
एवं
यू० के० बस्सी

By
O. N. BHARGAVA
and
U. K. BASSI

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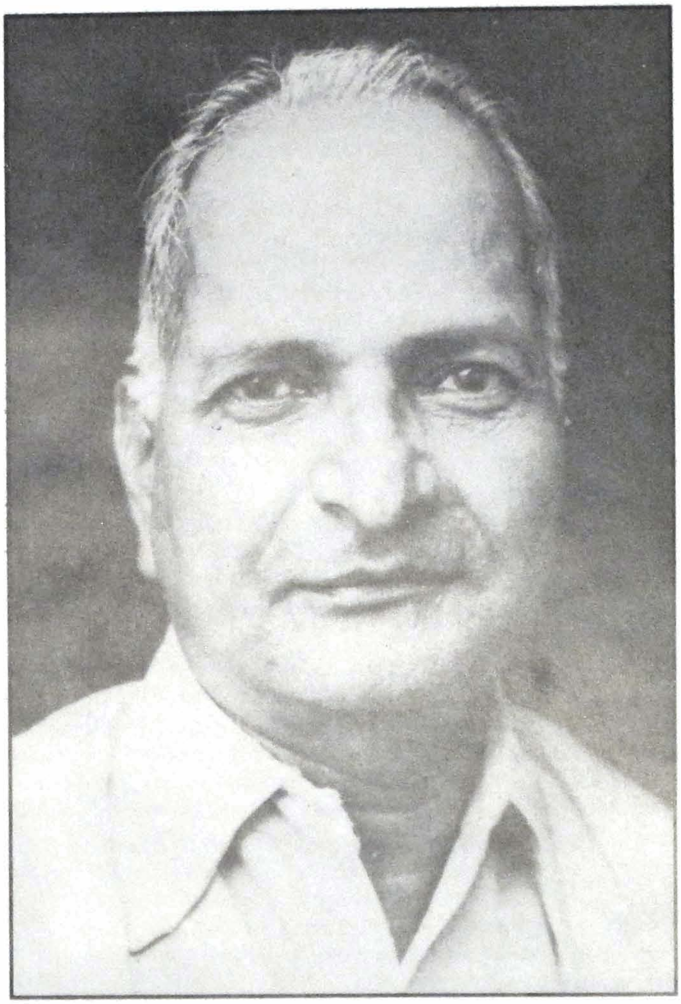


Dr. Maharajapuram Sitaram Krishnan — A Tribute

This volume entitled **GEOLOGY OF SPITI - KINNAUR, HIMACHAL HIMALAYA** is dedicated to Maharajapuram Sitaram Krishnan, former Head of the Geological Survey of India (GSI), whose birth Centenary is commemorated this year - 1998 by various organisations with which he was closely associated. It was generous of Dr. S. K. Acharyya, the present Head of the survey, to give me the privilege on this occasion, to offer a tribute to Dr. Krishnan, with whom I was closely associated.

Little is known of the early life of Dr. Krishnan except he was born of humble parentage in 1898, in the village of Maharajapuram (Tamil Nadu) and that he had his schooling in the district headquarters at Tanjore (Tamil Nadu) where by winning successive yearly scholarships he was able to complete his school education. He later joined the Presidency College, Madras and took his M.A. degree in Geology with high distinction that earned him a scholarship for higher learning in Geology at the Imperial College, London. He worked with Professors W. W. Watts and J. W. Evans and obtained his doctorate in Geology along with Associate of the Royal College of Science and Diploma of the Imperial College.

Dr. Krishnan joined the Geological Survey of India as an officer in 1924, when the department was a white man's preserve. His high academic qualifications, hard work and personal qualities, in a short time, earned him the respect of his white colleagues.

Among Dr. Krishnan's several monographs, scientific papers, reports, notes and his other professional attainments, the following stand out :

1. Field work in Gangpur State (GSI, Mem. Vol. II, 1987)
2. Being a man of strong convictions and foresight he gave a dissenting note in the Coking Coal Committee for adopting stringent conservation measures to stop rapid depletion of our Coking Coal resources.
3. Setting up and Organising the Southern Circle of the GSI at Madras and training a group of young geologists who later rose to eminent positions.
4. His continuing efforts for the exploitation of the then newly discovered lignite deposits in Tamil Nadu due to which, at present, part of the thermal power generated is met for this state.
5. The comprehensive compilation by him of the Mineral Resources of then Madras Presidency (including parts of present Andhra Pradesh and Karnataka) even today is very good reference book (GSI Mem. Vol. 80, 1952).
6. His studies on the Structure and Tectonic History of India (GSI Mem. Vol. 81, 1953).
7. His contribution on "Iron Ore Deposits of Middle East and of Asia and the Far East" (Survey of World Iron Ore resources : occurrence, appraisal and use. United Nations, Dept. of Economic and Social Affairs, New York, 1958).
8. His text book of Geology of India and Burma will ever remain his monumental contribution.
9. A firm believer in the dissemination of knowledge, he encouraged his daughter Mrs. Akhilandeshwari Subramaniam to translate his condensed version of Geology of India into Hindi for the benefit of those in the Hindi heartland of our country. It was the only book on the Geology of India in Hindi.

Dr. Krishnan was the first Indian Director of the GSI. He was either closely associated with or organised the undermentioned departments and was Head of most of them in the formative years. They are: (1) Indian Bureau of Mines, (2) Atomic Minerals Department, (3) Indian School of Mines, (4) National Geophysical Research Institute and (5) Dept. of Geology and Geophysics, Andhra University. He was for a while Officer on Special Duty at the Ministry in New Delhi to formulate plans for Mineral Development. He was a member of several learned societies.

As a man Dr. Krishnan rose higher than his enviable professional attainments. He was a valued friend to his colleagues and could be always available for help, if required. He inculcated the qualities of humility and believed in high thinking and simple living. He had no respect for the class distinctions in government service and was always considerate with those who worked with him. His door in the office was always open. High distinctions and honours had the least effect on him like water on a duck's back. His concern for poor students, I am personally aware and he was ever ready to help them with tuition or examination fees when approached. He earned respect without least expecting it.

Dr. Krishnan was endowed with clear thinking as is evident from his precise factual and lucid style of writing with crisp sentences. Being a master of condensation, he had the ability to separate the essentials from a host of bewildering details and present views without distortion or bias.

Dr. Krishnan, before his death, was conferred the title of Padma Bhushan by the President of India for his outstanding services to his country in the field of Earth Science.

Wherever Dr. Krishnan worked, he had set up exacting standards for his followers in the profession and it should be remembered that he did not spare himself either. For him his day began and ended with Geology.

His life is a beacon light and offers inspiration to succeeding generations of geologists to dedicate themselves to the cause of Earth Science in general and to India, in particular.

Chennai,
September 8th, 1998

(J. Swami Nath)
Former Director General
Geological Survey of India

FOREWORD

The Spiti Valley, which exposes an almost uninterrupted squence of the Eocambrian to the Certaceous sediments, has been a classical area for stratigraphers since the days of Gerard (1827, 1841). The Kinnaur area, on the other hand, was earlier believed to be essentially a Precambrian terrain. Recently, Palaeozoic and Mesozoic sequences have also been studied from this area indicating that the Kinnaur area probably constitutes the western limit of the Kumaon-Tethyan basin. Although Palaeontological accounts of various localities of the Spiti-Kinnaur belt have been provided by a number of workers from time to time, no detailed and systematic lithostratigraphic/biostratigraphic studies with adequate section measurements and sedimentological studies have been undertaken in the belt as a whole after Reed (1910, 1912) and Diener (1890-1915). Consequently, detailed classification of the sequence as per the International Code of Stratigraphic Nomenclature and precise age limits of the various units remained incomplete.

The present Memoirs Volume by O. N. Bhargava and U. K. Bassi provides a fairly comprehensive account of this relatively unknown part of the Himalayas and strengthens the foundation laid by Hayden (1904). The write-up is based on rigorous and painstaking mapping work undertaken for a period of more than one decade by the authors in the tough, inaccessible and inhospitable terrains of Spiti-Kinnaur, the northernmost outposts of Himachal Pradesh. The study provides a systematic lithostratigraphic classification of the sedimentary sequence into fairly well-defined "Groups" and "Formations" Efforts have been made to determine the age of the various formations on the basis of fossil assemblages. The classification takes into account the merits and demerits of earlier attempts put forward by various workers from different localities of the Spiti-Kinnaur belt. An attempt has also been made to work out the facies variations, environments of deposition of the various litho-stratigraphic units and the sequence of tectonic events that have shaped the geological evolution of the terrain. An interesting part of the work is the comparative analysis of the Tethyan sequence of the Spiti-Zanskar, Kinnaur-Kumaon and Kashmir-Chamba-Tandi areas and their broad correlation. The volume is expected to evince interest in the geoscientists, far and wide, and those working in the Himalayas, in particular.

(S. K. Acharya)
Director General

ACKNOWLEDGEMENTS

Thanks are due to the Director General, Geological Survey of India, for permitting to publish these data.

58 figures illustrated in this publication have been fully or partly reproduced with kind permission of the journals in which they were published. These are:

Journal, Geological Society of India, Bangalore. Figs. 2.9, 2.14, 2.67, 2.87, 2.89, 2.90, 3.17, 3.18, 3.36, 5.6.

Journal, Palaeontological Society of India, Lucknow. Figs. 3.33, 3.35-3.40, 3.45, 3.51, 3.53, 3.56-3.59, 3.61, 3.62.

Bulletin, Indian Association of Sedimentologist, Aligarh. Figs. 3.58, 3.59, 5.26, 5.27.

Current Science, Bangalore. Fig. 2.43.

Bulletin, Indian Geologists Association, Chandigarh. Figs. 2.6, 2.71, 4.29.

Journal of Glaciology, London. Figs. 1.6, 1.7.

Tectonophysics, Amsterdam. Figs. 4.32, 4.33.

Facies, Erlangen. Figs. 2.22, 2.28, 2.29, 2.31, 2.84, 2.88, 2.90, 3.11, 3.13, 3.17-3.19, 3.41-3.45, 3.47, 3.50.

A. K. Raina, Director, when posted at the Liaison Office, Delhi, expedited clearance of maps by the Ministry of Defence. B.K. Alok, Director, got a speedy clearance of maps from the Survey of India.

The line drawings and maps were drafted by Gulshan Kumar Luthra and Harmesh Singh.

The initial draft of the text was painstakingly typed by Rakesh Kumar. The final manuscript of this write up was meticulously prepared by Dr. J.U. Rao and S.C.Nagal and could be directly sent to press.

Prof. I. B. Singh was kind enough to accompany us to the Losar-Takche section during August, 1990. He provided a new insight in the study of broad environmental parameters of the Palaeozoic sequence. He also kindly loaned us 22 figures (photographs) illustrated in the present write up (Figs. 2.5, 2.18, 2.19, 2.21, 2.99, 2.100, 4.31, 5.1-5.5, 5.7-5.12 and 5.16-5.19).

Exciting discussions were held with S.V. Srikantia regarding facies and thickness variation of various sequences in Zanskar.

R. N. Srivastava and S.K. Gadhoke helped ONB in section measurement and petrography of the clastic rocks. S. Chopra, Des Raj, Inder Singh, A. Banerjee and late B.M. Dutta and late A.K. Chattopadhaya assisted UKB in various field and laboratory studies. These colleagues, besides technical help, provided excellent company in the field.

Timely meals were served by Mitter Lal, Bhim Bahadur and Bishambar Lal. Logistics were efficiently managed by Nasib Singh and Hardeep Singh, departmental drivers and Norbu, Nima Rani, Hira Singh and Surinder, the muleteers.

Our wives Malti and Sushma bravely put up with our long absence in field and prolonged working hours in office and laboratory at Chandigarh. That they provided encouragement instead of nagging is entirely due to their kindness and deep understanding. We are eternally grateful to them.

CONTENTS

PLATES
Plate 1 (Sheets 1-4). Geological map of Spiti-Kinnaur area with stratigraphic column and geological cross-sections in pocket.

1. INTRODUCTION

The Spiti Valley (Fig. 1.0) in geological literature was first referred by Gerard, A. (1827, 1841). Since then this valley, which exposes more or less an uninterrupted Eocambrian to Cretaceous sequence, became stratigraphers' delight. The geological details of the Spiti Valley in earlier years were furnished by Gerard (1833), Hutton (1839, 1840, 1841), Everest (1841), Cunningham (1844), Theobald (1862), Blanford (1863, 1864), Stoliczka (1864, 1865, 1868), Davidson (1864), Godwin-Austin (1864, 1865, 1866), Mallet (1865), McMahon (1879), Greisbach (1889), Diener (1895, 1897, 1903) and von Kraft (1899, 1900). Hayden (1904) mapped and presented an account of various formations which till this day provides a sound edifice for any detailed work. The Palaeozoic fossils of this region were studied mainly by Reed (1910, 1912) and those of the Mesozoic sequence by Mojsisovics (1899), Uhlig and Steiger (1903), Diener (1912, 1915), von Kraft and Diener (1909), Holdhaus (1913) and Spitz (1914). There was a lull in the geological studies in the Spiti Valley after the publication of Hayden's Memoir, till Jhingran *et al* (1950) traversed this area along with the Royal Danish Expedition led by Berthelsen (1951, 1953).

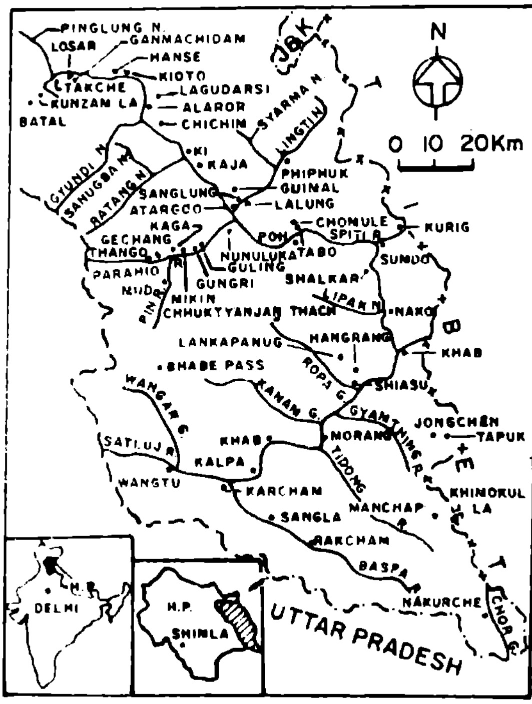


Fig. 1.0. Map of the Spiti Valley showing important localities

Besides Mallet (1865), the mineral investigations in the Spiti-Kinnaur area were carried out by Iyengar (1949), Kathiara and Bhargava (1962, 1963), Kathiara and Venugopal (1964) and Kathiara and Raina (1965).

The mapping on modern toposheets (1:50,000) of this terrain was first undertaken along the main Spiti and Parahio valleys by Srikantia (1974, 1981), who classified various sequences under standard lithostratigraphic subdivisions. These subdivisions, specially those of the Palaeozoic rocks, have been found to be valid upto Lahaul-Zanskar in the NW (Srikantia *et al*, 1978; Srikantia and Bhargava, 1982) and also in Kinnaur in the east (Bassi, 1989).

The entire Kinnaur area lying to the east of the Satluj in earlier maps was shown as a Precambrian terrain. The Palaeozoic and Mesozoic sequences in this area were first reported in the Baspa Valley by Bassi and Chopra (1978) and in the Gyamthing and Hojis valleys by Bassi *et al*, (1983). The Palaeozoic-Mesozoic sequence in Kinnaur shows elements common to both the Kumaon as well as the Spiti areas. The Kinnaur part forms the western limit of the Kumaon Tethyan Basin.

Practically no systematic palaeontological studies have been undertaken in this area after those by Reed (1910, 1912) and Diener (1890, 1907, 1908, 1912, 1915). Bhargava and Kathiara (1969), Jain *et al*, (1972), Jain and Gupta (1973), Jain and Mannikeri (1975), Bhatt and Joshi (1978a.b), Bhatt *et al*. (1981a, b), Shah and Paul (1987), Goel (1977), Goel and Srivastava (1978), Chopra *et al*, (1982), Mehrotra *et al*, (1982), Kato *et al*, (1987), Goel *et al*. (1981, 1984, 1987), Pant and Azmi (1983), Bhargava and Bassi (1985, 1986, 1987) and Bhargava and Gadhoke (1988) have provided local palaeontological details. Besides these, there are numerous publications on the palaeontology of Spiti-Zanskar and Kinnaur areas by V.J. Gupta and his associates (Talent *et al*, 1988, 1989, 1990 for detailed bibliography). However, none of these was found to be reliable during a review by the Geological Society of India (Anon. 1991) and Shanker *et al*, (1993), hence not quoted here. The biostratigraphic accounts of the Palaeozoic rocks are not enough to permit precise fixation of the age limits of several formations, hence unsuitable for modern zonations.

1.1 LOCATION AND COMMUNICATION

Spiti and Kinnaur (Fig.1.0) form the northernmost out-posts of Himachal Pradesh. Spiti is bound in the west by Lahaul, in the north by Ladakh and in the east by Kinnaur and Tibet. Kinnaur has a common border in the west with the Simla district, in the north with Spiti and in the east with Garhwal and Tibet. The NH-22 (Hindustan-Tibet Road) and the NH-21 (Manali-Leh Road) pass through Kinnaur, eastern Spiti and Lahaul-Ladakh areas. These roads are linked by the SH-30 (Sumdo-Kaza) and the SH-31 (Kaza-Khoksar) through 4547m high Kunzam Pass. The NH-22 between Simla and Narkanda is located along the physiographic divide between the Indus and Ganga systems. Beyond Narkanda, it descends to the Satluj Valley and passes through Nirth, Rampur, Wangtu, Karcham, Morang and Pooh, whereafter it follows the Spiti River and connects Khab, Chango, Shalkar and Sumdo. The NH-21 links the Lahaul Valley with Manali through 3978m high Rohtang Pass.

A few fair-weather link-roads connect Kaza, the sub-divisional headquarters of Spiti, with Kibber, Lalung, Guling and Dankar Gompha. The interior of the Valley has to be negotiated on foot.

Not even well defined mule-paths exist in the terrain where Palaeozoic-Mesozoic sequence is exposed in the Kinnaur area. Most of the areas in Kinnaur, except for a few roads linking Yangthang with Nako and Leo, Khab with Namgiya, Shiasu with Ropa, Spilo with Kanum, Morang with Thangi and Powari with Kalpa and Karcham with Chitkul, have to be approached on foot. The old Hindustan-Tibet Road between Powari and Lippa provides access to some parts of the steep gorge of the Satluj.

1.2 CLIMATE

The Spiti-Kinnaur stretch, situated to the north of the Great Himalayan Range, falls in the rain shadow zone. It receives but scanty rains during the monsoon. The annual rainfall in the area is less than 30cm which qualifies it to be classified under cold desert. Like any other desertic area, there are occasional heavy showers in Spiti-Kinnaur also.

This area witnesses prolonged winters between October and May, with frequent and heavy snowfall from November to February. The annual average snowfall is 350cm; in certain valleys it even exceeds 600cm. The average humidity for most part of the year is less than 30%; only during monsoon it locally touches 80% in the lower reaches of the Kinnaur district.

The southern part of the area, forming *venturi* between the broad Tibetan Plateau in the north and the broader valleys flanked by the lower hills of the Outer Himalaya, receives northerly winds. These, whipping up sand and dust, have an average velocity of 15 knots during the summer and 25 knots during the winter.

The snow starts melting around June. The summer months are, therefore, ideal for outdoor work. However, being devoid of bridges, the Gyundi (Hal), Ratang, Ullah, Pin (all in Spiti), Gyamthing, Tidong and Arsomang streams, due to melting of snow, swell to unfordable levels. The working period in these valleys is, thus, restricted between mid-August to September, when the melting of glacier is considerably arrested due to fall in atmospheric temperature.

1.3 HABITATION

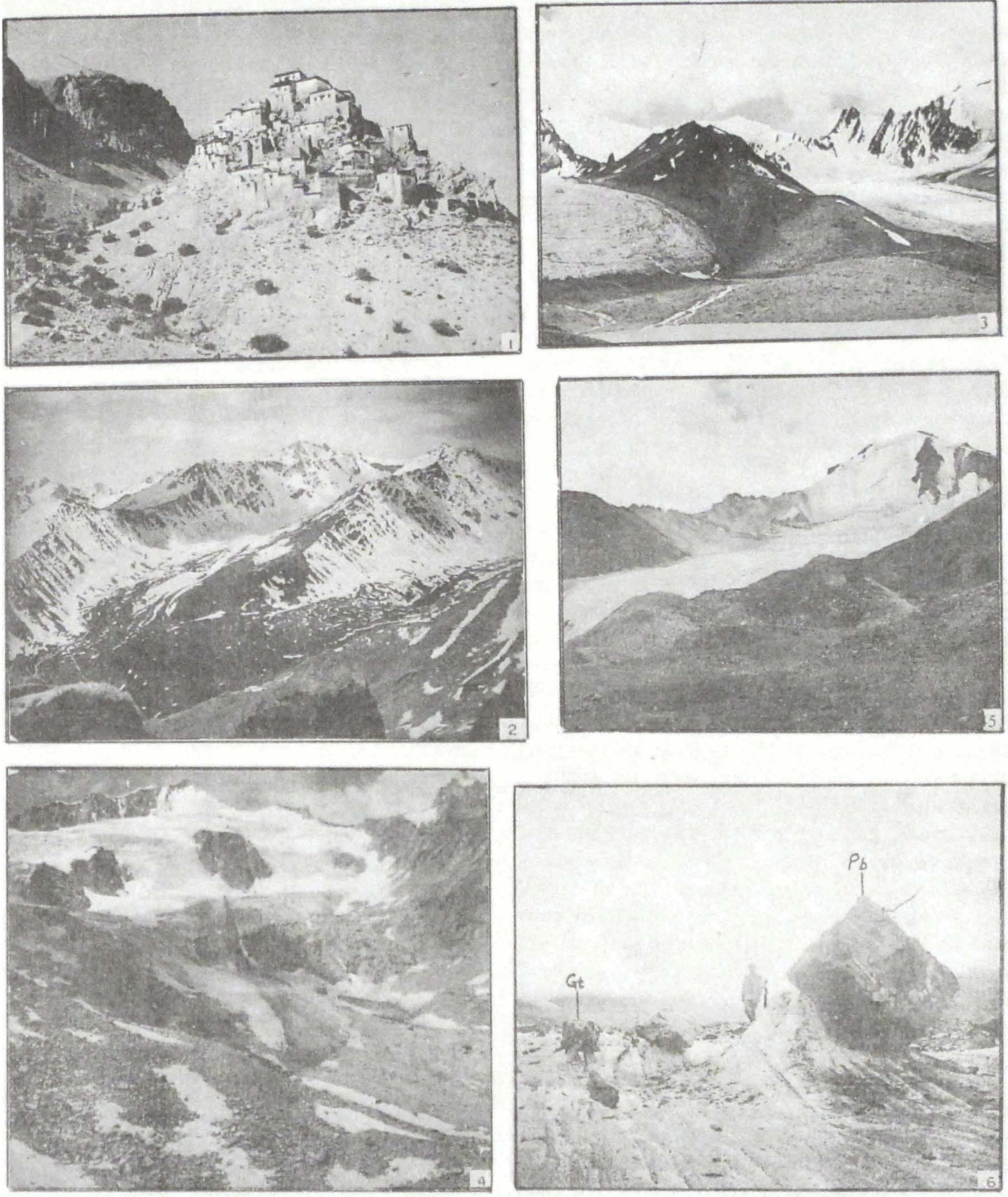
The villages in the area are far and few with sparse population. Both the Spiti and Kinnaur areas find mention in ancient Hindu scriptures. Hidimba, one of the wives of Mahabharat-fame Bhimsen hailed from Lahaul-Spiti district. The chiselled featured inhabitants of Kinnaur have been described as *Kinners* in the scriptures. The Pandavas, during their proverbial journey to heaven, possibly, passed through this area, leaving behind the tradition of polyandry.

The main religion in southern Kinnaur is Hinduism, while in the northern Kinnaur and whole of Spiti it is Buddhism. Traditionally the eldest son and daughter take to family life; the younger ones become *lama* (priest) and *chomo* (nun). The Spiti Valley has the pride of having a 1000 year old monastery at Tabo, which is now a protected monument. The Ki Gompha (Fig.1.2) in Spiti is a sort of university where hundreds of *lamas* are trained, who after graduation, are deputed to different monasteries in Lahaul, Spiti, Kinnaur and Ladakh.

1.4 PHYSIOGRAPHY

The Spiti-Kinnaur terrain, ensconced in between the Dhauladhar and the Great Himalayan Ranges in the south and the Zanskar Range in the north, constitutes one of the most rugged and inhospitable terrains in Himachal Pradesh. The Spiti and Kinnaur terrains are dissected by the mighty Satluj and its tributary, the Spiti (Fig.1.1). The general altitude of this area varies from 1500m to 6770m above m.s.l.

Figs. 1.1 – 1.6



Explanation of Figs. 1.1 - 1.6

Fig. 1. A view of Ki Gompha, Spiti Valley. Besides being a monastery it also serves as a seat of learning. **Fig. 2.** Glaciers south of the Larsa Pass, Spiti-Kinnaur divide. **Fig. 3.** Binary glacier, Gyamthing Valley. **Fig. 4.** Hanging Valley glacier, Mangsu *La*. **Fig. 5.** Semicircular cirque of a small glacier, Baspa Valley. **Fig. 6.** Glacial table (Gt) and perched boulder (Pb), Baspa glacier.

1.4.1 Ranges

The crests of three mountain ranges that variably encircle the region retain a perpetual snow cover. The twin Leo-Pargial peaks fall in the Zanskar Range. These soar to 6770m and 6608m respectively and represent the highest elevation in the area. The Manirang (6593m) and Kinner Kailash (6413m) peaks are sited in the Great Himalayan Range. The height of various peaks on the Dhauladhar Range varies between 4877m to 5791m.

The main ranges SW of the Kinnaur-Spiti divide trend in NW-SE direction with a gradual swing to E-W towards north. The trend continues upto Losar on the right bank of the Spiti River. On the left bank, beyond the Lingti *Nala*, the ridges reswerve to NW-SE. The northern slopes of the mountains are precipitous.

1.4.2 Glaciers

The Spiti and Kinnaur areas, specially the latter, are abode of numerous glaciers. These glaciers (Fig.1.3) mostly originate at 5500m or above and extend down to 4700m-4300m. The cirque floors, on an average, occur at an approximate elevation of 5000m. The Baspa, Gara, Hania, Chor *Gad* and Lingti are the most important glaciers of the area. All the glaciers are of the valley type, with a maximum length of 18 km (e.g. Hania, Baspa). The larger glaciers have one or more tributary glaciers, forming binary or compound glaciers respectively (Fig.1.4). Due to general recession, several tributary glaciers have become stranded and are confined to hanging valleys (*e.g.* Mangsu *La*, Fig. 1.5). In the zone of accumulation, the larger glaciers are virtually ice fields, having well defined semicircular cirques (Fig.1.6). The tributary glaciers are mostly replenished by avalanches and only a few have their own cirques. Bergschrunds are common along ice-cirque wall contact.

The ablation surfaces of glaciers from cirque to snout are replete with perched tables (Fig.1.7) as large as 3m x 3m x 1m, undisturbed morainic cones, dust wells as wide as 1.5m and 3m deep, crevasses and englacial lakes (Fig.1.8). The gaping and tapering longitudinal and transverse joints in the glacial body provide channel for surface streams. Some of these streams, due to greater depth and extension of longitudinal joints, become subsurface and re-emerge downstream along some other joint. Well rounded clasts found in typical morainic material are due to action of such intra-glacial streams.

The snouts of most of the glaciers are in the form of 15m-20m high steep walls (Fig.1.8). These are largely covered by rock fragments. The ice forming the snout face shows banding due to impregnated debris. These bands, owing to varying movement of different parts of snout, show conspicuous fold patterns. The snouts have one or more ice caves (Fig.1.8), from which the subglacial streams emerge.

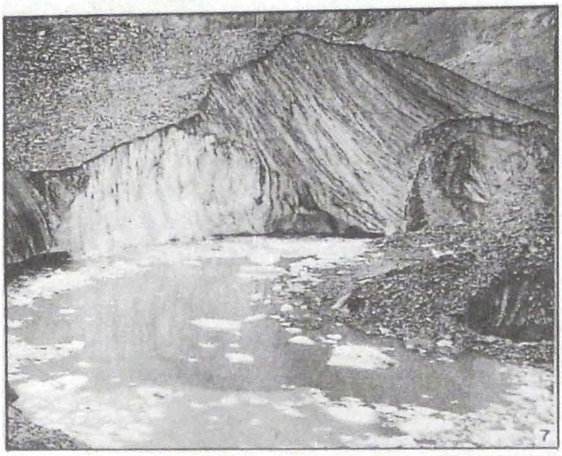
Seven terminal moraines, extending upto 200m downstream of the present snout, are identifiable in the Baspa Glacier. The lateral moraines, constituted of angular clasts, occur along the flanks of the glaciers. In the Baspa Bamak, undisturbed right lateral moraine is observed for a couple of hundred metres downstream of the snout. In the Tumur Glacier, a three kilometre long lateral moraine ridge is preserved. Palaeo-lateral moraines occur upto 200m above the present glacial surface indicating the extent of loss of ice volume. At the confluence of glaciers, the lateral moraines, if present, merge to form median moraine (e.g. Baspa, Arsomang, Hania, Gara etc.).

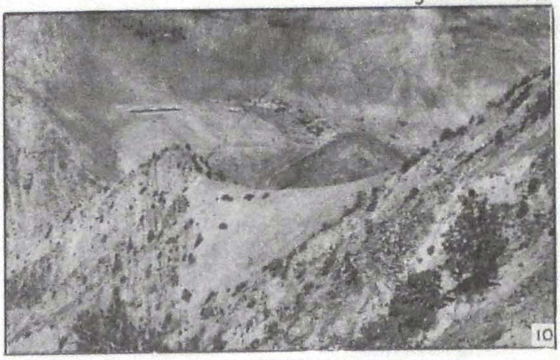
The glacial movement causes extensive polishing and grooving of the valley floor and the walls. In the present glacial valley, such polishing has been observed upto 2.5 km downstream of the snout of the Baspa Glacier. Features reminiscent of *roche moutonnee* have been carved over sandstone of the Kunzam *La* Formation by the Baspa Glacier. Polishing and striations are well preserved over the outcrops of the Takche and Muth Formations (Fig.1.9), exposed along the left bank of the Spiti River at Takche.

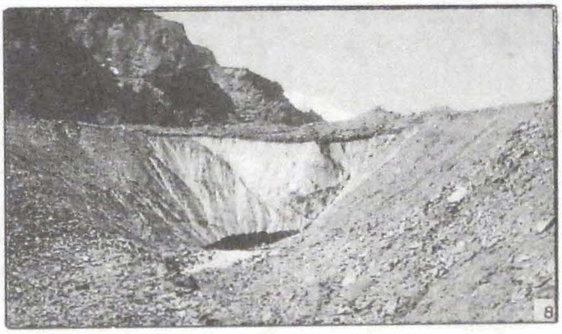
A series of moraines lower down the present day snout, stranded terminal moraines and glacial tables reveal that all the glaciers are retreating. The Jorya and Baspa glaciers have retreated at least by 300m (Ameta and Swain, 1982), and 750m (Bassi *et al*, 1981) in 14 and 33 years respectively. The average retreat rate, thus, works out to 20m per year. This annual rate of retreat is, however, cumulative and apparent, as the years of retreat are interspersed by glacial advance also.

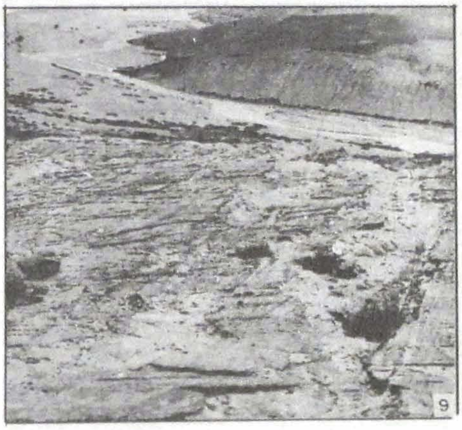
The present geomorphology evolved with remoulding of the pre-existing topography by glaciers at the onset of the ice age. Horns, cirques, serrated ridges and 'U' shaped valleys date back to this stage. Ameta and Swain (1982), based on floor level of the cirques in the area, suggested the existence of an active orographic 'Firn Line' at 5000 m in the Western Himalaya. The inflated and advancing

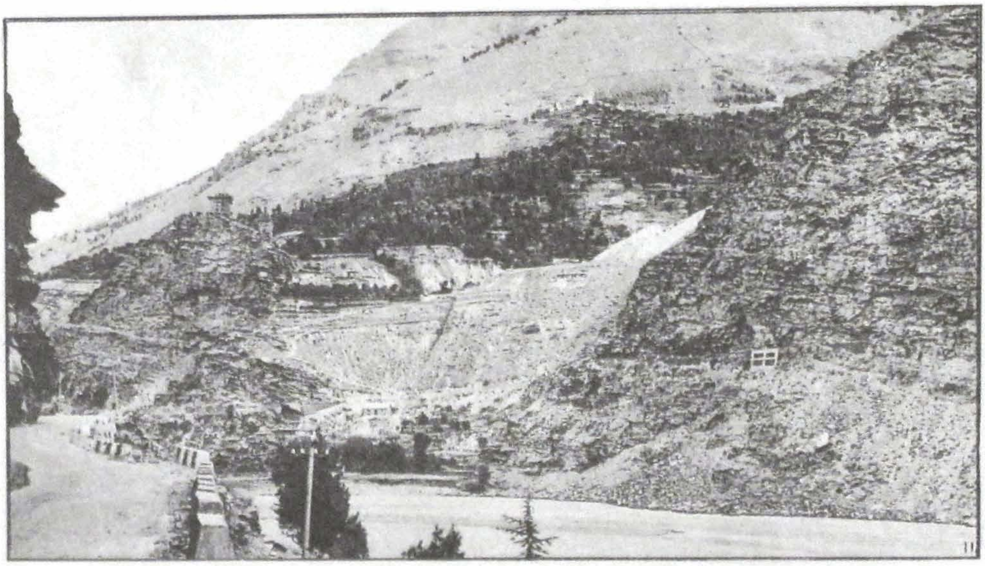
Figs. 1.7 – 1.11







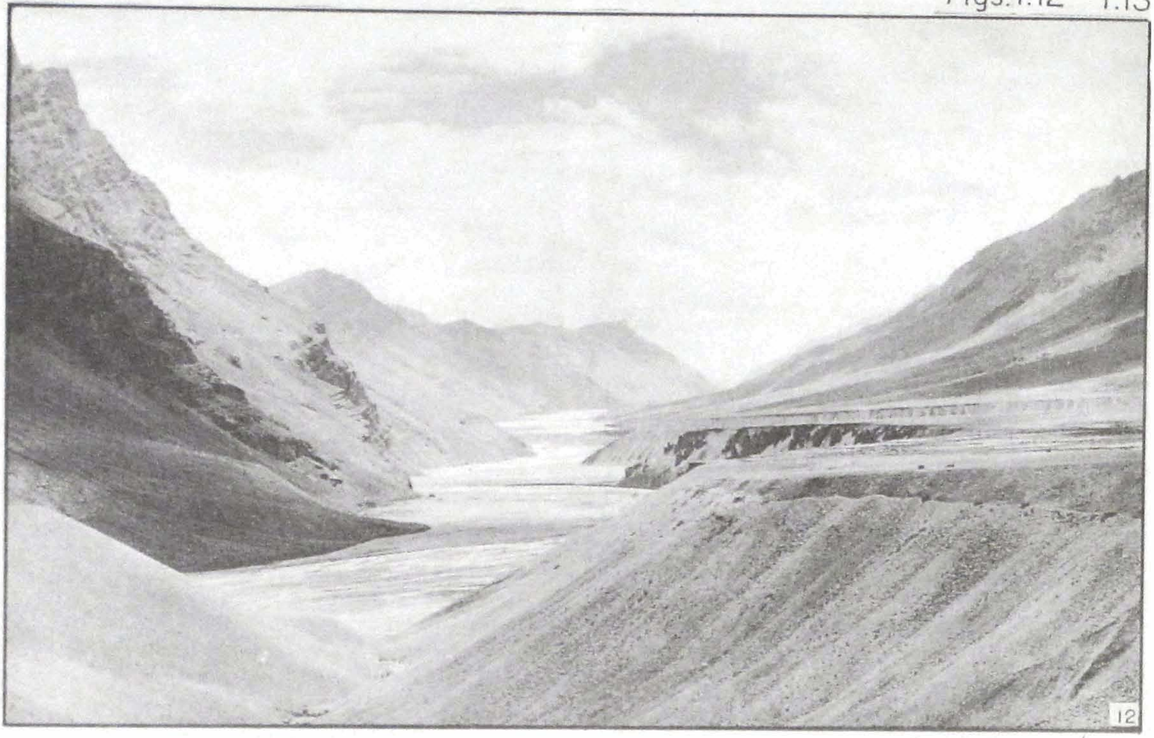




Explanation of Figs. 1.7 - 1.11

Fig. 7. Englacial lake, Baspa Glacier, Kinnaur. **Fig. 8.** Steep faced Snout with cave, Arsomang Glacier, Baspa Valley. **Fig. 9.** Quaternary glacial striations on the country rock, left bank of the Spiti Valley, near Takche. **Figs. 10-11.** Filled-up fossil Valley of the Satluj (10) at Hojis confluence, (11) at Morang.

Figs. 1.12 – 1.13



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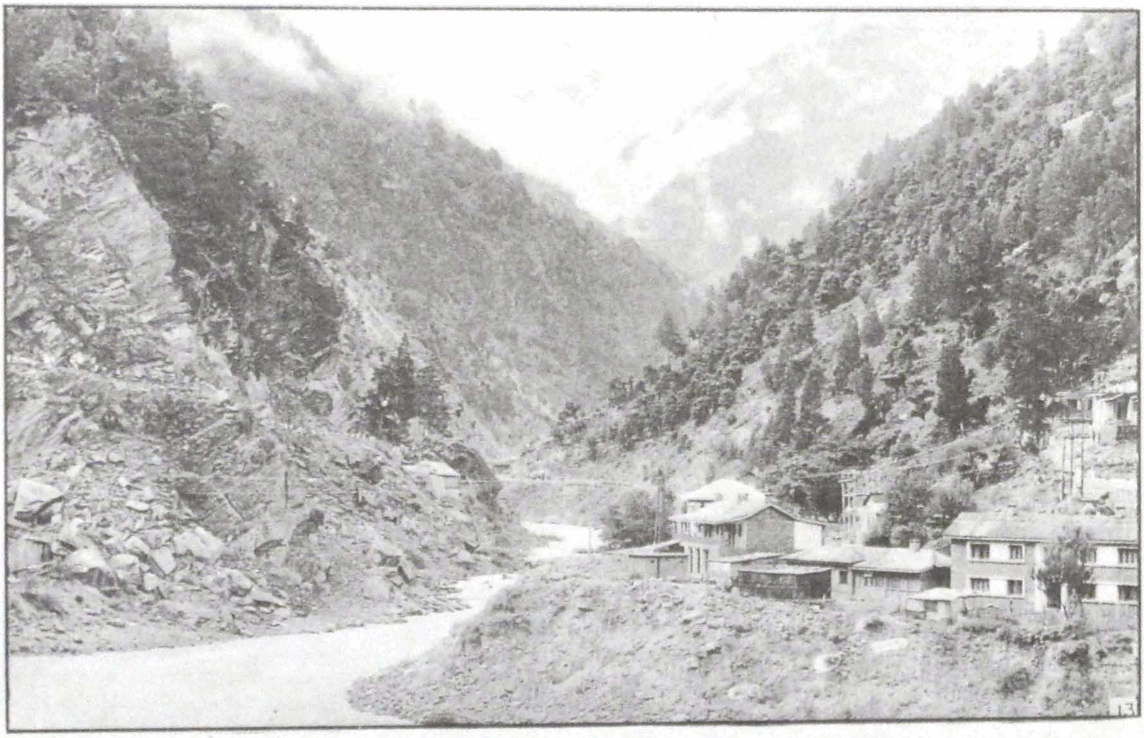

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Explanation of Figs. 1.12 and 1.13

Fig. 12. U-shaped Spiti Valley, showing wide lacustrine terraces, view from down stream of Hal. **Fig. 13.** Narrow V-shaped Baspa Valley in lower reaches, at Karcham.

glaciers extensively scoured and transported the rock-waste, thus, widening the valley. De-glaciation retreat in the lower reaches left large trails of morainic ridges, drumlins and hanging valleys.

1.4.3 Drainage

The Satluj and its tributary, the Spiti, constitute the main drainage of the area. The Satluj rises in Tibet and cuts across the Zanskar Range to enter India, close to the Leo-Pargial peaks and the Great Himalayan Range in the vicinity of the Kinner Kailash. The Satluj has an asymmetrical and oblique course as related to the Himalayan Ranges. It follows a NE-SW course,whereas, its tributaries flowing in NW-SE direction join it at right angles forming an orthogonal trend. The low order streams show dendritic, whereas, the Satluj and its principal tributaries form trellis patterns. The Satluj course is replete with fossil valleys, some of which can be observed at Pooh near Hojis confluence (Fig. 1.10), at Morang (Fig.1.11) and Shongtong. These occur at 5 m (at Morang) to 300m (at Hojis confluence) above the present day river bed. The fossil valleys mainly occur along the left bank. The Satluj shows erosional terraces along the eastern bank indicating a westward shift of the river. Major nick points exist between Pooh and Karcham.

The sharp elbow turn of the Satluj, at its confluence with the Spiti at Khab, indicates capturing of the valley of the latter by the former (Small, 1970). As the level of the Satluj bed is higher than that of the Spiti, the piracy, possibly, occurred due to headward erosion through some subsidiary tributary across the Zanskar Range. The observation tends to suggest that the Satluj, perhaps, is not an antecedent river in a classical sense.

The Spiti River rises along the eastern slopes of the Kunzam Range, from where upto Hal it flows in E-W direction, whereafter, it has a NW-SE course up to Dankar. Beyond Dankar, it reacquires an E-W course. From its source to Sonam (Soman), the Spiti occupies a broad U-shaped valley (Fig.1.13). Downstream of Sonam and upto Sumdo, it flows through a rather narrow gorge. At Sumdo, near its confluence with the Pare *Chu*, it takes an abrupt turn to south suggesting piracy of the Pare Valley (Ameta, 1979). The nick points in the Spiti and its tributaries, the Pin-Parahio and Lingti, occur between 3500-3700m.

The Baspa is the next important tributary of the Satluj. It originates in the Dhauladhar Range

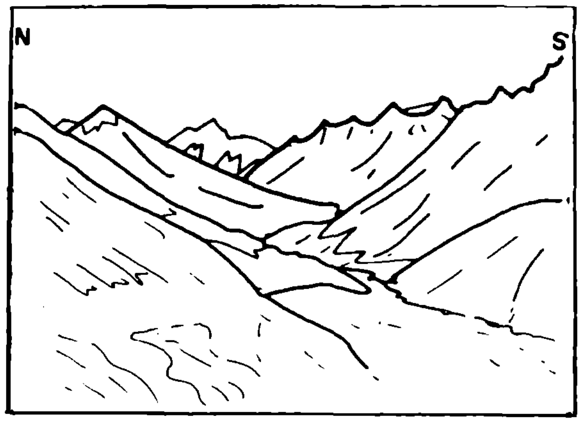


Fig. 1.14. Broad U-shaped Baspa Valley in upper reaches, upstream of Dunthi (Sketched from a photograph).

and has a wide 'U'-shaped valley in the upper reaches with local braided channels and 'V'-shaped in the lower reaches (Fig.1.14). The other important tributaries in Kinnaur are the Ropa, Taiti, Kashang, Mulgaon, Yula, Wangar, Tidong, Gyamthing, Hojis and Titan.

The main tributaries of the Spiti, in order of decreasing importance, are Pin-Parahio, Gyundi, Shilla, Lingti, Ratang, Yulang and Lipak. All these have 'U'-shaped valleys, especially in the upper reaches (Fig.1.15). Several of these show fossil valleys (Fig.1.16).

1.4.4 Lakes

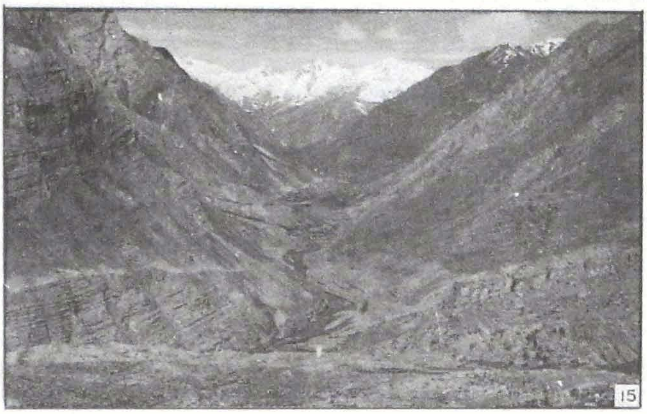
Though there are several palaeo-lake beds, only two still retain water. The Yang Tso is located in the Spiti Valley along the course of the Yang *Nala*. Further down below, the stream ensuing out of it leaps into a water fall. It shows evidence of considerable shrinkage in the form of a vast dried lake bed (Fig.1.17). Another small subcircular lake is located at Nako village. Excellent lacustrine clay bed is exposed at Ganfa (Fig.1.18).

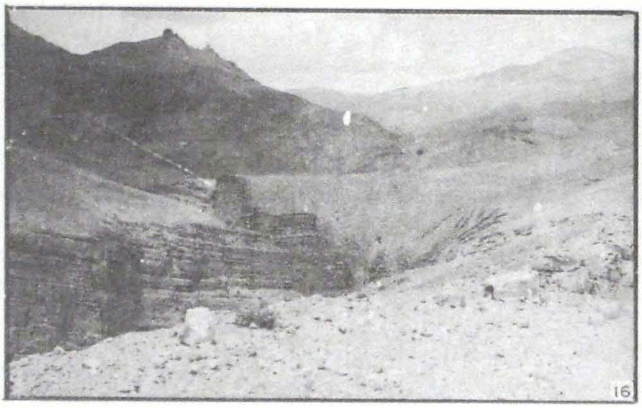
1.5 GEOTHERMAL RESOURCES

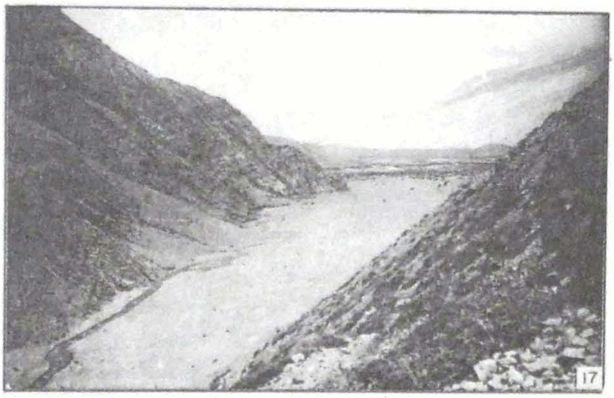
Numerous hot springs are known in the Spiti and Kinnaur areas. Those in the Kinnaur part are located along the Satluj Valley and in the Spiti along the Pare Chu. In folklore many of these springs are considered to be of therapeutic value. Shankar and Prakash (1977), Das (1982), Prakash and Bajaj (1983) and Jangi and Bajaj (1984) have examined various hot springs of the area.

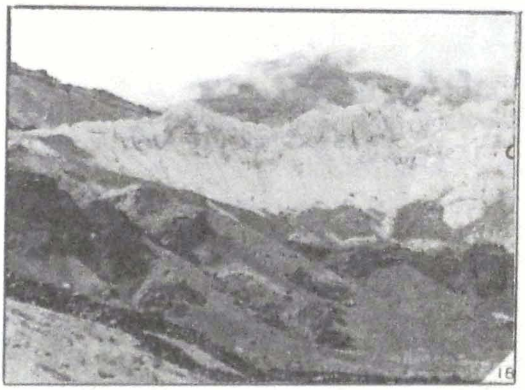
Various attributes of these springs are summarised in table 1.1.

Figs. 1.15 – 1.18









Explanation of Figs. 1.15 - 1.18

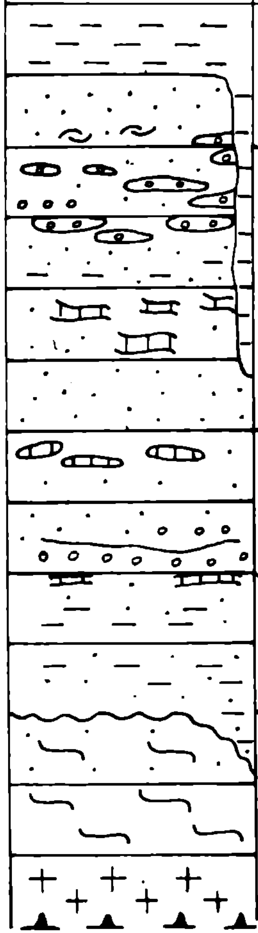
Fig. 15. U-shaped Parahio Valley, upstream of Kaga *Nala* confluence. **Fig. 16.** Filled up fossil Valley of the Puri Lungpa - a tributary of the Spiti River. **Fig. 17.** Dried up lake bed of the shrinking Yang Tso, along the course of the Yang *Nala*. **Fig. 18.** Lacustrine clay deposits, Loc. Ganfa.

Table 1.1

SPECIFIC CHARACTERISTICS OF HOT SPRINGS IN KINNAUR-SPITI AREA
(Compiled after Shanker and Prakash, 1977; Das, 1982; Prakash and Bajaj, 1983; Jangi and Bajaj, 1984)

	Hot Spring	River Valley	Height from River bed	Rock Formation	Temp. in $^{\circ}C$	pH	Discharge lit/mts.	Salts at Orifice	TDS in spring water and type of water	Sp. Conductivity mhos	Base temp. in celcius (Na-K-Ca thermometry)
1.	Baru ,emerges through over burden	Panchhot *Khad* (Satluj Valley)	350m	Gneiss, schist (Jeori-Wangtu Gneissic Complex)	$40^{\circ}C$	7.8	25		TDSI 300m/lit	1996	83.5°
2.	Tapri (a)	Satluj .near Tapri	2m	Gneiss, schist (Jeori-Wangtu Gneissic Complex)	32°	8	10	Sul*Phu*rous	TDS 255	325	91°
	(b)	Satluj 2 km upstream of Tapri			40°	8.1	10-20		TDS 268	310	
3.	Karcham (a)	Satluj downstream of confluence with Baspa	1m	Quartzite ,Schist (Jutogh Group)	48°	7.6	50		TDS 1280	1783	181°
	(b)		30m		40°	7.9	25		TDS 1203 NaCl type	1741	183°
4.	Thopan. along NW-SE joints	a, b Satluj (right bank) near c, d Thopan Dogri	at road level 10m above a & b	Gneiss (Kharo Gneiss)	42°	8	100 (cumula-tive for four springs)	Sul*Phu*rous	TDS 362	456	59°
5.	Baren	Right bank of Satluj near Baren Dogri	—	Gneiss (Kharo Gneiss)	28°	8	5	Sul*Phu*rous	TDS 1576 $Ca\text{-}HCO_3$ type	2123	178°
6.	Skiba, through Quaternary sediments	Left bank of Satluj	5m	Rakcham granite	50°	7.5	75		TDS 671	530	83.7°
7.	Chusa (Sumdo) scattered over 3.8km, emerges through overburden near Kaurik Fault.	Right bank of Pare*Chu*	83	Schist (Morang Formation)	$29\text{-}59^{\circ}$	7.1 to 7.4	1000 (cumu-lative for 33 springs)	Sul*Phu*rous	3955-4280	4990 5205	84.4°

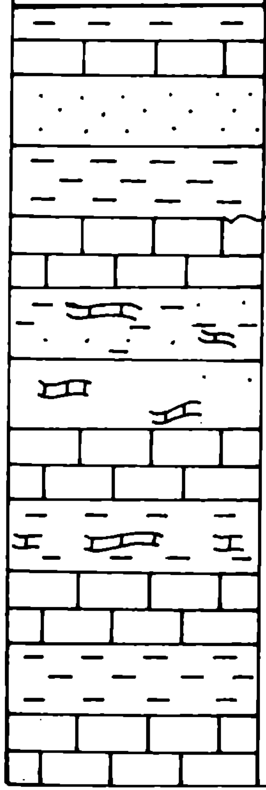
Table 1.2a



DOMINANT LITHOLOGY	PRESENT WORK: GROUP	PRESENT WORK: FORMATION	HAYDEN (1904, 1908): SYSTEM/SERIES	SRIKANTIA (1974, 1981): GROUP/FORMATION		NANDA & SINGH (1977): FORMATION/MEMBER	
	KULING	GUNGRI (LP)	PRODUCTUS SHALE (P)	KULING Fm (P)	GUNGRI M.	RALAKUNG Fm (P)	
		GECHANG (EP)	CALC SANDSTONE (P)		GECHANG M.		
	KANAWAR	GANMACHIDAM (LC-EP)	PERMIAN CONGLOMERATE (P)	KANAWAR GR. (C)	GANMACHIDAM Fm	TANZE (C)	MEMBER C
		PO (EC)	PO (LC)		PO Fm		
		LIPAK (LD-EC)	LIPAK (D-C)		LIPAK Fm		MEMBERS A-B
		MUTH (LS-LD)	MUTH (LS?)	MUTH Fm (M-LD)		KENLUNG Fm (D)	
	SANUGBA	TAKCHE (LO-LS)	SILURIAN (S)	TAKCHE Fm (LS-ED)		THAPLE Fm (S)	
		THANGO (O)		HAIMANTA GR. (PЄ-ES)	THANGO Fm		
	HAIMANTA	KUNZAM LA (E-MЄ)	HAIMANTA (Є)		KUNZAM LA Fm	KARSHA Fm (O)	
		BATAL (Ptz_3 - Є)			BATAL Fm	PHE Fm (Є)	
		SHIASU					
	VAIKRITA (E-M Ptz)	MORANG		SALKHALA GR.		SURU CRYSTALLINE (PЄ)	
		KHARO		ROHTANG GNEISSIC COMPLEX			
	TECTONIC BASE						

E-EARLY, M-MIDDLE, L-LATE

Table 1.2b



DOMINANT LITHOLOGY	PRESENT WORK: GROUP	PRESENT WORK: FORMATION	HAYDEN (1904, 1908): SYSTEM/SERIES		SRIKANTIA (1974, 1981): GROUP/FORMATION		NANDA & SINGH (1977): FORMATION/MEMBER
	LAGUDARSI	CHIKKIM (EK–LK)	CHIKKIM (K)		KIBBER GROUP (J–K)	CHIKKIM Fm	DRAS Fm (K)
		GIUMAL (EK)	GIUMAL Sst (K)			GIUMAL Fm	
		SPITI (LJ–EK)	SPITI SHALE (LJ)			SPITI Fm	
	LILANG	KIOTO (LT–EJ)	MEGALODON – KIOTO Lst (LT–EJ)		LILANG GROUP (T–LJ)	SIMOKHOMBDA Fm	ZANGLA Fm (T)
		NUNULUKA (LT)	QUARTZITE	LT		ALAROR Fm	
		ALAROR (LT)	MONOTIS SHALE				
		HANGRANG (LT)	CORAL Lst				
		SANGLUNG (LT)	GREY TO JUVAVITES BEDS			NIMOLOKSA Fm	
		CHOMULE (M–LT)	HALOBIA BED				
			DAONELLA Lst	MT		HANSE Fm	
		KAGA (MT)	DAONELLA SHALE				
		MIKIN (E–MT)	OTOCERAS BEDS–U. MUSCHELKALK	EMT		TAMBA KURKUR Fm	

DISCONFORMITY

E–EARLY, M–MIDDLE, L–LATE

1.6 PRESENT WORK

The present publication gives the geological account of Spiti and Kinnaur based on surveys carried out by the authors. In this venture, R.N. Srivastava and S.K. Gadhoke were associated in the Spiti Valley during 1982-83 and 1983-84 respectively. Both of them carried out section measurements, while the mapping was carried out by O.N. Bhargava (Bhargava and Srivastava, 1983; Bhargava *et al*, 1984, 1985, 1987, 1991; Bhargava and Gadhoke 1985, 1988). U.K. Bassi, S. Chopra, B.M. Dutta, Late A.K. Chattopadhyaya, A. Banerji, I. Singh and Des Raj (Year-wise details are furnished in mappers' index) were associated in Kinnaur and parts of Spiti and Ladakh (see inset in Sheet No.2).

Despite construction of roads along the main valleys, the tributary valleys and the divides in between these still remain inaccessible or extremely difficult to negotiate. With such physiographic constraints, the mappable stratigraphic sub-divisions adopted in this work are such which provide colour and/or lithologic contrasts. Of these, the latter is excellently manifested in the physiographic expressions of the area. Both these help in identifying different lithounits of inaccessible areas from distant vantage points (*e.g.* triangulation points) and also in the aerial photographs. The Spiti Valley is sparsely populated, hence there are very few localities which can be utilised for naming the formations. It is quite often that no geographical name exists in the vicinity of good stratigraphic succession of a particular formation. Also some of the well known localities (*e.g.* Thango, Lagudarsi Pass, Charana Pass) are not marked on the topographic maps. These limitations have resulted in naming of a few formations after the localities which do not afford their best sections. Takche, Gechang, Kioto and Chikkim Formations are such examples. For lithostratigraphic groupings, the transgressive and regressive cycles, with due emphasis on unconformities, have been taken into consideration. However, formations which show local overlaps or questionable breaks (*e.g.* base of Gungri Formation), have been tentatively classified under the same group.

At the time the present authors commenced mapping, at least three lithostratigraphic classifications existed (Table-1.2a & b). Nanda and Singh (1976) used the names Phe, Karsha, Thaple and Kenlung for Cambrian, Ordovician, Silurian and well-known Muth Quartzite respectively. No stratigraphic thickness of the newly proposed formations as required by the Code of the Stratigraphic Nomenclature was furnished by these authors. The Phe Formation, representing undifferentiated Batal Formation and non-calcareous part of the Kunzam *La* Formation, is ill-defined. The name Karsha in type area represents carbonate sequence of the Kunzam *La* Formation of Middle Cambrian age and is not mapable in Spiti-Kinnaur. Moreover, Karsha and 'Silurian Limestone' have been interchangeably used. The Thaple Formation of Nanda and Singh (1976) represents green, grey, red and purple slate with partings of calcareous sandstone followed by conglomerate, red and purple, highly calcareous sandstone overlain by conglomerate. This, presumably, represents a part of the Thango Formation of Srikantia (1974, 1981), though no reference is made by Nanda and Singh (1976) of the enormous thickness of quartzite sequence found at this level. The Thaple Formation is overlain by the Kenlung Formation (≡Muth Formation) and no mention has been made by Nanda and Singh (1976) of any sequence equivalent to the Takche Formation, which is developed between the Thango and Muth formations. The name Kenlung and Tanze for well-known Muth and Lipak-Po formations respectively are obviously superfluous. Due to these ambiguities, the nomenclature proposed by Nanda and Singh (1976) has not been adopted in the present work. Goel and Nair (1977, 1982), in localised section, used Shian Quartzite, Pin Limestone and Thanam Limestone for the Ordovician sequence. The mappability of these units, as required by the Code of Stratigraphic Nomenclature, was not established. Moreover, limestone is only locally developed in the 'Pin Limestone', as defined by Goel and Nair (1977, 1982). Of late, Ranga Rao *et al*, (1987) added a few more new names like Losar Conglomerate for the Ganmachidam Formation of Srikantia (1981). This conglomerate is neither exposed at Losar nor was there any need for a new name. For the Palaeozoic sequence, the lithostratigraphic nomenclature proposed by Srikantia (1974, 1981), the mappability of which has been established over the entire Spiti-Zanskar and Kinnaur basins have, therefore, been adopted.

The subdivisions of the Lilang Group, as proposed by Srikantia (1981), however, could not be adopted as various formations proposed by him comprise mainly the carbonates and, more or less, have identical lithology. No mention is made of sequences which are predominantly argillaceous or arenaceous (*e.g.* Kaga, A and C Members of

Sanglung, Alaror and Nunuluka of the present classification). Besides being poorly defined, the thickness of each formation seems unrealistic and difficult to match with the units actually mapped in the entire Spiti Valley (Bhargava,1987). The basal most Tamba Khur Khur Formation of Srikantia (1981), for example. is 500 m thick. With this thickness the Tamba Khur Khur Formation alone shall swallow the entire Mikin, Kaga, Chomule Formations, and a part of the Sanglung Formation (whole of Member A and a part of the Member B). However, the youngest fossil in the Tamba Khur Khur Formation is *Hedenstroemia*, implying that it represents only a part of the Mikin Formation. Thickness-wise, the Hanse Formation (350m) seems to represent part of the Member B and whole of the Member A of the Sanglung Formation but, as per fossil contents, it includes part of the Kaga Formation and whole of the Chomule Formation. Likewise, as per thickness, the Nimoloksa (300m) possibly includes the Hangrang Formation and a part of the presently defined Alaror Formation, but the fossil contents indicate in it the presence only of the Members A and B of the Sanglung Formation.. The Alaror Formation (100m) of Srikantia (1981), according to thickness, includes perhaps part of the present Alaror Formation and whole of the Nunuluka Formation, whereas, as per fossil contents it includes the Member C (Sanglung Formation), and Hangrang, Alaror and Nunuluka Formations. The Simokhambda Formation of Srikantia (1981) is same as the well-known Kioto. Thus, none of the formational names suggested by Srikantia (1981) can be adopted. However, due to dearth of locality names, the term Alaror has been retained after redefinition. The classification of the Lilang Group, suggested by Srikantia (1981), was informal as he did not map various formations even in a small stretch. The formations, as proposed by Bhargava (1987), thus, have been adopted in the present volume. The present volume is mainly devoted to the Eocambrian-Cretaceous sequence. Only a passing reference is made to certain crystalline formations which marginally crop out in the Kinnaur part. However, the Vaikrita Group, which forms the basement for the Tethyan succession, has been dealt with in some detail.

2. STRATIGRAPHY

Table-1.2a and b and insets in Plates 1 (Sheets 2 and 4) give a generalised order of superposition of the rocks of the area. The ages assigned to various formations here, due to lack of precise fossil control, are broad based. Of all the lithostratigraphic units described here, only the Nugalsari and Kilba Formations have been informally used.

2.1 EARLY PROTEROZOIC

2.1.1 Jeori-Wangtu Group

The Jeori-Wangtu Group, which is a successor of the Jeori-Wangtu Gneissic Complex (Bhargava, 1982), is equivalent to the Bandal Granitoid Complex. These complexes yielded Rb-Sr isochron ages of 2025 ± 86 Ma (Kwatra *et al*, 1986), 1840 ± 70 Ma (Frank *et al*, 1977) and 1220 ± 40 Ma (Bhanot *et al*, 1982). It is regarded as a basement complex (Bhargava, 1982), which has been reworked from time to time during the Precambrian.

The rocks of this group are excellently exposed between Jakhri-Jeori-Wangtu-Karcham and are mainly represented by gneiss. This group is divisible into two formations, viz. Nugalsari and Kilba (Bassi, 1988a) .

2.1.1.A *Nugalsari Formation*

It comprises migmatised greyish pelitic gneiss, minor schist, quartzite and lenses of marble. The gneiss is composed of quartz, K-felspar, biotite, sphene and opaques with local zones of bladed kyanite and radiating clusters of sillimanite. Tremolite and wollastonite are common in the marble. This formation shows an intercalated contact with the overlying Kilba formation.

2.1.1.B *Kilba Formation*

This formation is more extensively developed. It is made up of porphyroblastic gneiss. The porphyroblasts are of felspar and quartz which vary in shape from rounded eggs, augen to rectangular. Lenticular bands of metaconglomerate, reported from Jeori area (Bhargava, 1982), also possibly form part of this formation. Near Choling, the gneiss encloses epidote-zoisite-hornblende rock. Thin bands of quartzite and schist form common xenoliths. The schist xenoliths contain staurolite and kyanite.

The vein quartz in the rocks of the Wangtu Group, as observed at Wangtu, locally contains fluorite. Amphibolite occurs as concordant bodies along the foliation plane and also as xenoliths in the Kilba Formation. Some of the xenoliths show folded foliation plane (Fig.2.1).

The Jeori-Wangtu Group has been regarded to form basement for the overlying Rampur Group (Bhargava and Ameta, 1987). The western contact of this group with the Rampur Group is in the form of a reverse fault (e.g. at Jakhri), whereas, along the eastern and NE contacts, the Rampur Group stratigraphically succeeds it along a decoupled contact.

The presence of staurolite, kyanite and sillimanite indicates acquisition of upper to lower amphibolite facies of metamorphism by the rocks of the Jeori-Wangtu Group.

2.1.2 Rampur Group

This group encircles the Jeori-Wangtu Group and is exposed in the Rampur-Larji Window (Bhargava *et al*, 1972; Sharma, 1977).

It is divisible into three formations, viz. (a) Bhallan (b) Green Bed and (c) Manikaran Formations (Sharma, 1977). Of these, only the Manikaran Formation is exposed in the Kinnaur area, near Karcham. The quartzite of the Manikaran Formation, in most of the area, is strongly cross-bedded and shows variations in colour from white, pale white to pale green and light pink. It bears epigenetic remobilised uraninite mineralisation, which has been dated at 1200 Ma and 700 Ma by Pb-U method (Narayan Das *et al*, 1979). The volcanics interstratified with the Rampur Group, on being dated by Sm-Nd method, have yielded a whole rock isochron age of 2510 ± 9 (Bhat, 1990). The Jeori-Wangtu Group, which forms the basement of the Rampur Group, would thus be still older. The formations of the Rampur Group are characterised by chlorite, biotite and rare garnet indicating green schist facies metamorphism.

2.2 PRECAMBRIAN CRYSTALLINE SEQUENCES OF UNCERTAIN AGES

Under these are included the crystalline rocks which enclose Precambrian granitoids. The crystalline rocks are certainly older than the granitoids, but their exact age still remains to be ascertained.

2.2.1 Kulu Group

It rests over the Rampur Group along the Kulu Thrust and, in turn is, followed by the Jutogh Group along the Jutogh Thrust. These rocks were earlier referred to as the Chail and Jutogh (Jangi and Gaur, 1975; Gaur and Ameta, 1979; Tewari *et al*, 1978), Salkhala (Srikantia and Bhargava, 1974; Bhargava, 1982; Bhargava and Ameta, 1987). However, during a regional mapping reappraisal, these were found to be different from all the aforementioned rock groups and thus were classified under the Kulu Group (Bassi, 1989b).

The Kulu Group is divisible into (a) Khamrada (b) Gahr and (c) Khokan Formations (Sharma, V.P., 1977). In the Kinnaur area, only the first two formations are exposed. The Gahr Formation at Baragaon has yielded a Rb-Sr isochron age of 1430 ± 150 Ma (Bhanot *et al*, 1978).

2.2.2 Jutogh Group

It succeeds the Kulu Group along the Jutogh Thrust.

The rocks of the Jutogh Group include chlorite, biotite in basal part and garnet, staurolite, kyanite in upper part, indicating metamorphic facies variation from green schist to amphibolite. In the present area, however, mainly biotite, garnet with occasional staurolite are developed.

2.2.3 Vaikrita Group

The name Vaikrita was originally suggested by Griesbach (1891) for the schists overlying the gneiss and underlying the Haimanta Group. This term fell in disuse after Hayden (1904) stated that the 'Vaikrita' along strike merges with the Haimanta, of which it is a more metamorphosed equivalent. The term Vaikrita was later used by Sharma, K.K., (1977) in the Kinnaur area. It was during a revision mapping programme that an independent entity of the Vaikrita, separate from the Jutogh and the Haimanta could be established (Bassi, 1989b). The term Vaikrita is used here in the sense of Griesbach (1891) and is being accorded a group status. In the redefined Vaikrita Group are included felspathic gneiss, schist, quartzite and migmatitic rock resting above the Jutogh Group along a thrust. It is well exposed between upstream of Shongtong (Satluj Valley) and Giumdo (Lower Spiti Valley) and along the Pare *Chu* gorge.

This succession incorporates "metamorphosed Haimanta" of Hayden (1904), Mehbar and Mangling Gneisses of Tewari *et al*, (1978) and 'Vaikrita' of K.K. Sharma (1977). Granitoids of early Palaeozoic and Cretaceous ages occur within the Vaikrita Group.

The Lower contact of the Vaikrita Group with the Jutogh/Kulu Group is defined by the Vaikrita Thrust, whereas, its upper contact with the Haimanta Group is interpreted here as an unconformity. The Vaikrita Group in Spiti-Kinnaur has been divided into Kharo, Morang and Shiasu Formations.

2.2.3.A *Kharo Formation*

It comprises schist, quartzite, local marble, gneiss and migmatitic rocks with best exposures between Shongtong and Kharo along the NH-22.

The sillimanite, kyanite bearing biotite schist, interstratified with dark grey quartzite, occurs in the basal part and is exposed near Shongtong. This sequence is intruded by both basic and granitic rocks.

The gneissic rocks are inter-layered with argillo-arenaceous metasediments towards the base. In the Thopan-Kharo-Khadra section, as well as in the Batsering section (Baspa Valley), the gneiss develops migmatitic character. Local concentration of amphiboles around quartzitic lenses is common in this sequence. Marble and calc-silicate bands of limited thickness are exposed near Rarang and Kharo.

In its tectonic position and lithologic composition, the Kharo Formation is correlatable with the Rohtang Gneissic Complex (Srikantia and Bhargava, 1982) and Kulti Formation of Prashra *et al*, (1988) of the Manali-Lahaul area.

2.2.3.B *Morang Formation*

This name is suggested for a sequence of schist and quartzite, which is exposed between Akpa and Spilo along NH-22, with best exposures at Morang. It is also exposed in the Spiti Valley between Khab and Giumdo (barring Leo and Ganfa-Shalkar stretch) and along the Pare Valley. Its further extension in the tributaries of the Satluj is limited due to wrapping by the overlying sequences along the antiformal flanks. These rocks were earlier referred to as the Maldi Formation (Bassi and Chopra, 1983). The term 'Maldi' is considered a misnomer, as this village is not only remotely located but is also not situated on this formation. Since 'Maldi Formation' has not found much usage, it is being dropped in favour of a better defined Morang Formation.

Along its lower contact is the Rakcham Granitoid occurring in between the Kharo and Morang Formations. Its upper contact with the Shiasu Formation is gradational. At Thangi, it is unconformably succeeded by the Haimanta Group of rocks.

The Morang Formation comprises sillimanite, kyanite, staurolite, garnet, biotite, sericite schist, and grey quartzite and schistose quartzite with local calcsilicate, carbonaceous and pebbly rocks and frequent basic sills. Garnetiferous schist is particularly observed in Morang-Spilo, Morang-Thangi, Jangi-Kanum, Titan Khad, Khab-Kah Dogri, Namgiya-Tashigang- Shipki and Maling-Chango sections. Staurolite schist is exposed near Morang Fort, Tirung, Khab and east of Chango. A quartz-calcite-staurolite vein is exposed along the tract to Shipki *La*, four kilometres from Namgiya. Kyanite schist is developed at Morang Jhoola, Jangi, Duba Khad and sporadically between Khab and Kah Dogri. The kyanite blades, as observed two kilometres north of Dabling along NH-22, have been affected by the F_2 folding. Sillimanite has restricted development. It is exposed at (i) 500m south of Khab along the road cutting as radiating clusters constituting about 40% of the grey coloured schist (ii) 1.5km SE of Nako associated with calc-silicate and hornblende rich rock. Tourmaline is profusely developed in schist near Khokpa and Dabling.

The calc-silicate lenses occur in Nako and Morang *Nala* sections, Khab Dogri and east of Maling. Carbonaceous schist lenses crop out at Khokpa, Kanum and Maling. Small lenticular pebbly rock occurs within the schist north of Thangi, near PWD Rest House at Pooh, Dabling, Khab, three kilometres south of Khab Dogri and three kilometres north of Shalkar. The clasts are flattened and are of vein quartz, quartzite, schist, chlorite schist and gneiss.

2.2.3.C *Shiasu Formation*

An arenaceous sequence, exposed between Telingkyu and Dabling in the Satluj Valley and between Shiasu and Giabong in the Ropa Valley is designated as the Shiasu Formation. This formation occurs in the core of an overturned synform and has limited exposures. Towards NW as well SE, it gets overlapped by the rocks of the Haimanta Group due to an unconformity.

The Shiasu Formation comprises grey and greenish, fine grained quartzite with thin biotite schist interbands. The quartzite, specially along the left bank of the Titan Khad, shows extensive cross-bedding. The cross-beds are about five to eight centimetres thick and show low angle torrential and asymptotic types of cross-beddings. Near Hojis Lungba-Satluj confluence, the cross-beds have a thickness of 50cm. The ripple marks preserved in the quartzite are oscillation, current and interference types (Fig.2.2).

The rocks of the Vaikrita Group, especially those of the Morang and Shiasu Formations, show common occurrence of light coloured hornblende garbenschiefer, which has varied mode of occurrence (Fig.2. 3 & 2.4). At Tirung, these occur as two to five centimetres thick slabs within the kyanite schist. Normally the hornblende garbenschiefer occurs as 15 cm to five metres discontinuous lenses along the foliation plane (Fig.2.3), more or less at the same stratigraphic level. At a few places (*e.g.* near Shiasu), hornblende garbenschiefer occurs along the cross beds.

The Vaikrita Group of rocks enclosing biotite, garnet, staurolite, kyanite and sillimanite show lower to upper amphibolite facies metamorphism. The grade of metamorphism in the Vaikrita Group of rocks, unlike that of the Kulu and Jutogh Groups, falls towards the physical top, which is also the stratigraphic top. The metamorphic minerals in the Vaikrita Group are at least of two generations implying two phases of metamorphism. A brief description of these minerals and their relationship with the rock fabric is given below :

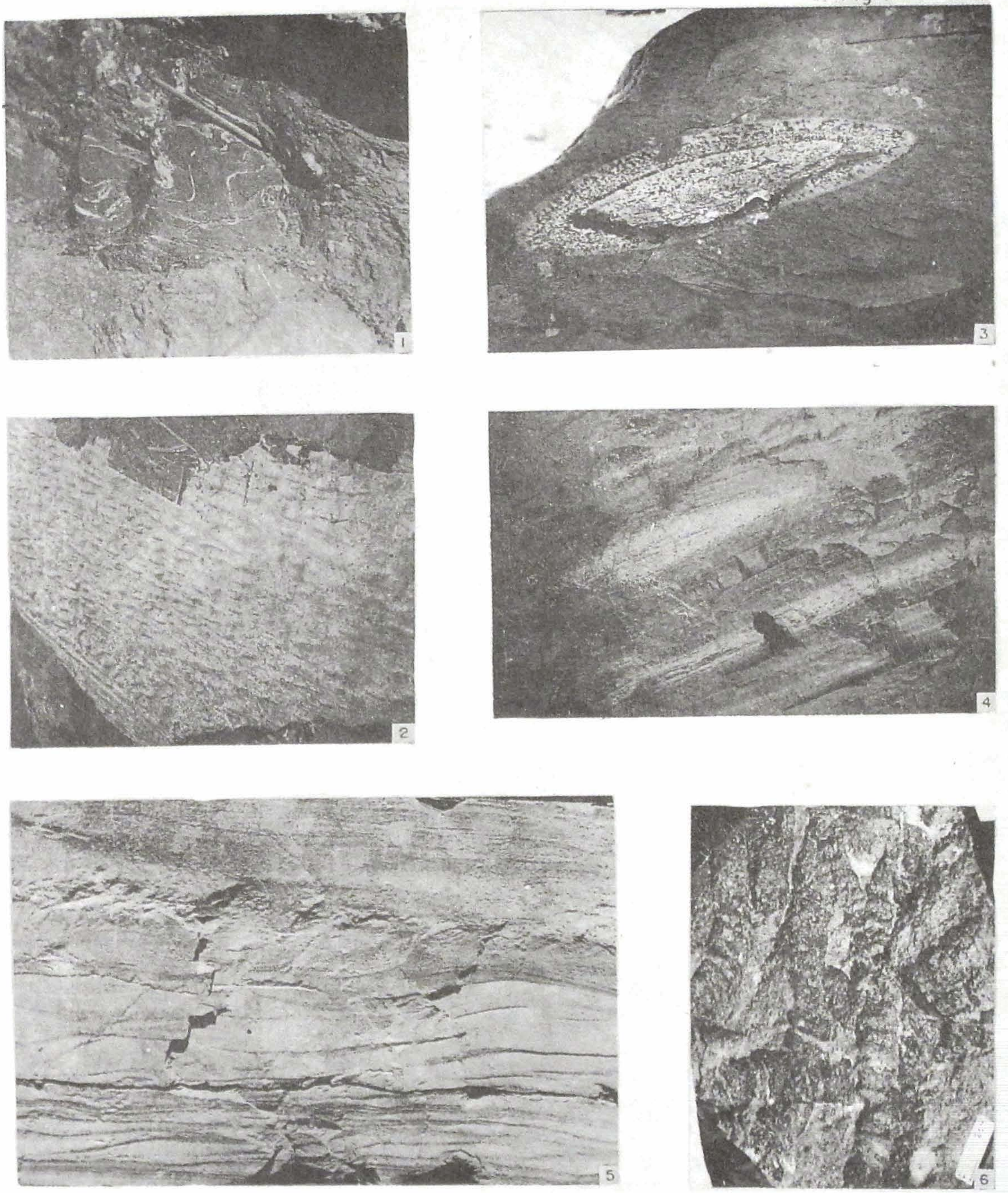
a) **Quartz** : It occurs as (i) granulated and aligned parallel to the S_1 foliation plane (ii) as porphyroblasts oblique to the S_1 plane.

b) **Biotite** : It is found parallel to S_1 as well as S_2 planes. Some biotite occurs as porphyroblasts cutting across the S_1 foliation and are possibly parallel to S_2 plane. The biotite of the later generation does not show much alteration.

c) **Garnet** : It is found as (a) extensively granulated and aligned parallel to foliation, (b) snow-ball showing continuous Si and Se planes with respect to S_1 foliation and (c) idioblastic, inclusion free and helicitic grain as rims over snow-ball garnet and also as independent grains across the S_1 plane. The first two types show extensive alteration, while the last one is only marginally altered.

d) **Staurolite** : It is found as anhedral grains showing inclusion of quartz, biotite and garnet along the cleavage plane. Its relationship with the foliation

Figs. 2.1 – 2.6



Explanation of Figs. 2.1 - 2.6

Fig. 1. Raft of amphibolite showing folded foliation plane, near Urni. **Fig. 2.** Ripple marks in the Shiasu Formation, Dabling. **Fig. 3-4.** Hornblende garbenschiefer in the Vaikrita Group 3. eye-shaped at Dabling. 4. interstratified, lenticular at Jangi. **Fig. 5.** Ripple bedding and low angle truncation in the Batal Formation, Patseo section (Lahaul). **Fig. 6.** *Plagiogmus* sp. in basal part of the Kunzam *La* Formation. Loc. Parahio Valley, opp. Moppo. (Bar scale is 10 cm).

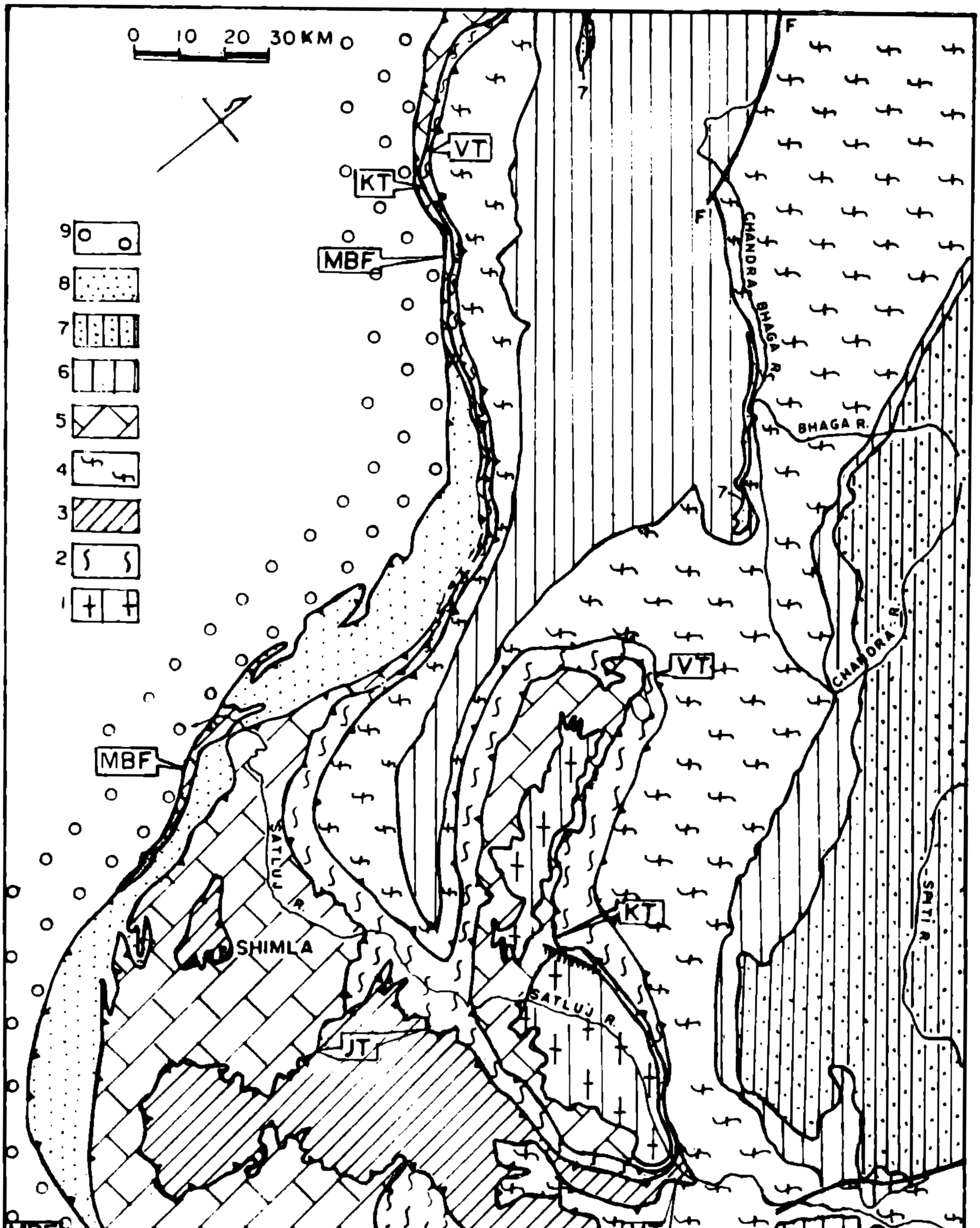


Fig. 2.7. Generalised sketch geological map of the Himachal Himalaya (modified after Bhargava *et al*, 1991a). Expl: 1. Jeori-Wangtu-Bandal Gneissic Complex (Early Proterozoic); 2. Kulu Group; 3. Jutogh Group; 4. Vaikrita Group (2-4 of uncertain Proterozoic age); 5. Parautochthonous Precambrian-early Cambrian Lesser Himalayan Sequences; 6. Batal (≡ Manjir-Katarigali) Formation (Eocambrian); 7. Tethyan (Palaeozoic-Mesozoic); 8. Subathu-Kasauli Formations (Palaeogene) and 9. Siwalik Group (Neogene).

is not clear. It occurs parallel to S_2, which at places due to transposition, has become parallel to S_1 plane. It also shows helicitic structure.

e) **Kyanite** : Its relationship with the S_1 plane is also not clear. It has two habits (i) parallel to and also folded along S_2 foliation and (ii) in clusters, commonly bluish coloured associated with quartz veins and having haphazard relationship with the foliation.

f) **Sillimanite:** It occurs as clustered prismatic grains (Fig.3.1) often warped along the biotite associated with garnet.

The mineral-foliation relationship indicates following metamorphic episodes.

a) First (M_1) metamorphism : Chlorite, granulated and snow-ball garnet, biotite defining S_1 plane were formed. It varied from early to Syn-F_1 folds (D_1 deformation).

b) Second (M_2) metamorphism : Idioblastic inclusion-free porphyroblasts of garnet and quartz, biotite parallel to S_2 and possibly staurolite and kyanite, which are certainly post-S_1 plane, were formed. This could be pre - F_2 in a static phase between F_1 and F_2 or early F_2 as suggested by Naha and Ray (1971) in case of the Jutogh Group of rocks.

c) Third (M_3) metamorphism : Porphyroblasts of biotite seem to be related to the development of S_3 planes. Along with this phase possibly also occurred the retrogressive metamorphism. It left biotite phorphyroblasts unaffected.

2.3 EOCAMBRIAN - PALAEOZOIC

2.3.1 Haimanta Group

The term Haimanta, originally suggested by Greisbach (1891), was adopted by Srikantia (1981) in his lithostratigraphic groupings. He classified the Batal, Kunzam *La* and Thango Formations under the Haimanta Group. As the Thango Formation has been found to be separated from the Kunzam *La* Formation along a regional unconformity, it has been separated from the Haimanta Group. The presently defined Haimanta Group thus includes only the Batal and Kunzam *La* Formations. In the present narration, only those fossils which have been detected during the present survey or those which have been utilised in palaeoenvironmental or stratigraphic interpretations have been mentioned. For a complete checklist of fossils, already known, a reference may be made to Pascoe (1968).

2.3.1.A *Batal Formation*

It derives its name from a place at the foot of the Kunzam Pass in the Chandra Valley. Its basal contact with the Vaikrita rocks has been variously considered as gradational (Srikantia, 1981) and tectonic (Gaetani *et al,* 1985). The Batal Formation along a low dipping contact overlaps the steeper contact of the Morang and the Shiasu Formations one kilometre upstream of Spilo and near Pooh. This relationship clearly brings out a regional and angular unconformity between the Batal Formation and the underlying Vaikrita Group (also see structure). Tectonic contacts do exist between the Batal and Vaikrita rocks. These are both due to original basinal structures (see basin evolution) and also to post-depositional deformation of the sequences (*e.g.* in Batal type area). The upper contact of the Batal Formation with the Kunzam *La* Formation is intercalated.

The Batal Formation is identifiable from a distance by its darker shade and well developed bedding with reference to the underlying lighter coloured Vaikrita rocks and the overlying Kunzam *La* rocks.

This formation is developed throughout the Spiti Valley. Towards SE, the Batal Formation, has been cut off by the Kaurik Fault Complex near Leo in the lower Spiti Valley. East of the Satluj, in Kinnaur, it is exposed as a crescent-shaped outcrop between Shipki in the north to the Jadhganga Valley in the southeast. It maintains more or less a uniform thickness except in the Baspa Valley where its basal part has been digested by the Rakcham Granitoid.

The rocks belonging to the Batal Formation were earlier referred to in Kinnaur as the Hilap Formation (Bassi *et al*, 1983), which in fact also included the Kunzam *La* Formation. In Lahaul, rocks earlier mapped as the Batal Formation between Tandi and Jispa (Srikantia and Bhargava, 1979) are possibly the equivalent of the Morang Formation.. Possibly only small thickness of the Batal Formation exists below the Tandi Group; towards northwest the Batal Formation is exposed beyond Darcha (Fig.2.7).

The Batal Formation comprises a thick sequence of carbonaceous slate/phyllite, meta-siltstone and slate, interstratified with white to greyish white locally boudinaged quartzite, local grit/conglomerate, calcareous bands and basic volcanic rocks. Pyrite is sporadically disseminated in the dark grey slates. The base of the Batal Formation is mostly defined by a carbonaceous bed. Its upper contact has been delineated where greenish-grey slate/shale, siltstone predominate.

The basal part is dominantly pelitic while the upper part has psammitic component. The rocks, towards the upper part, gradually become less carbonaceous and are lighter coloured. The carbonaceous slate/phyllite are, at many places, interstratified with siltstone and chert bands.

The conglomerates in the Batal Formation, in the Spiti Valley, are developed mainly in the basal and middle parts, whereas, in the Tidong, Baspa, Hojis and Gyamthing sections, these occur persistently in the upper part as discontinuous lenses. The clasts in grit/conglomerate are mostly rounded and flat and made up of quartzite, vein quartz, slate and schist, embedded in an argillaceous matrix (chloritic). Locally the clasts are as large as 70cm (e.g. 1.5km north of Giabong). The clasts of phyllite and schist show foliation oblique to the matrix. A schist clast at Murmur Dogri shows tight folding. The matrix-clast ratio is around 3:1. The calcareous rocks in the Batal Formation are exposed near Murmur Dogri (Hojis Valley).

The basal part of the Batal Formation in the Parahio, Wangar, Raura, Tidong and Baspa Valleys is intruded by the early-middle Palaeozoic Rakcham Granitoid which contains xenoliths of the country rock.

Large roof pendants of the rocks of the Batal Formation occur in the Tidong and Baspa Valleys. The country rocks near granite contact show quartz veins, recrystallised biotite and tourmaline. The carbonaceous rocks have developed hornfelsic texture with carbonaceous matter segregated around subrounded quartz grains.

The Batal rocks show a few metres thick fining upward cycles; where the cycles are thick, the sand-shale alternations are conspicuous. Major sand beds are only a centimetre thick; within the cycle, ripple layers (Fig.2.5) are arranged in decimetre-scale and show low angle truncation (Fig.2.5). Lenticular bedding is found in shale-rich part, which also shows layered rhythmite of silty-fine sand and silty shale. Besides these, several one to six centimetres thick graded layers, stacked one over another, are present. These internally show prolific sub-parallel lamination and sporadic rippled lamination. Low angled cross-bedding, which is quite common in decimetre-thick unit, shows an inclination between 5^0 and 10^0 along the discordant surfaces. The fine grained sandstone units are 20-40cm thick and are separated by one to two centimetres thick rippled drapes. Towards the stratigraphic top, the cycles become thicker and show coarser sediments as compared to lower units.

Petrographic studies of rocks across the Vaikrita-Haimanta contact by Bassi (1988a) revealed existence of three metamorphic episodes in the Vaikrita rocks and only one in the Batal rocks. It is, however, not clear whether the retrogressive metamorphism of the Vaikrita Group was a prograde event in the rocks of the Batal Formation.

The cyclicity observed at Batal bridge is shown in Fig.2.8A and Appendix-I.

Age : By virtue of its position below the low early Cambrian trace fossil horizon of the Kunzam *La* Formation (Bhargava *et al*, 1982), the Batal Formation can be assigned a Vendian age.

2.3.1.B *Kunzam La Formation*

This name was suggested by Srikantia (1974, 1981) after the Kunzam *La*. Nanda and Singh (1976), during their traverse to Zanskar, included the Batal and a part of the presently defined Kunzam *La* Formation in their Phe Formation; the upper part of the Kunzam *La* Formation was referred by these authors under the Karsha Formation. These terms are not properly defined and cannot be adopted. The type section suggested by Srikantia (1981), however, is structurally complicated, hence is not ideal for stratigraphic work. Better sections are available near Moppo (Parahio Valley) and Tariya (Pin Valley). The Kunzam *La* rocks, together with the Batal in the Jadhganga Valley, were mapped as Nelang Formation (Puri, 1982). Further east, these rocks form upper-most part of the Martoli sequence. The upper-most part of the Kunzam *La* Formation is also described as the Suti Formation (Bassi and Chopra, 1978).

The Kunzam *La* Formation could be easily differentiated both in the field and also in aerial photos due to its greenish-grey colour and softer topography with respect to the dark-grey Batal Formation and red coloured Thango Formation. Its upper part weathers to a brown colour.

This formation comprises greenish-grey siltstone, shale/slate, sandstone, dolarenite in the upper part and locally pebble beds. In the Kinnaur area, it contains an acid volcanic suite of rocks (Magnetite tuffs) at Mangsu *La* in the Lungsho *Khad*. Its lower contact with the Batal Formation is intercalated while its upper contact is marked by the appearance of maroon coloured arenaceous rocks.

In the type area, the succession of the Kunzam *La* Formation, as described by Srikantia (1974, 1981), is divisible into following six members:

f) Pinkish brown quartzarenite, shale, slate and dolomite (400m).
e) Dolomite, quartzite with current and interference ripples (750m).
d) Slate, flaggy quartzarenite with dolomite lenses, load casts, ripple marks (750m).
c) Flaggy quartzarenite with slate partings (950m).
b) Shale, slate, siltstone and quartzarenite interbeds (500m).
a) Grey quartzarenite, quartzite and slate (750m).

The Kunzam *La* Formation, according to lithologic assemblage, is divisible into five units in the type section (Fig.2.8b, Appendix-II).

The carbonate beds of unit 'e' in the Kunzam *La* section have sharp and erosional contact with the underlying clastic rocks. The upper contact with the clastics is also sharp. Within this unit, each terrigenous cycle begins with a silty unit and terminates into a sandy one. No cyclicity could be ascertained in the remaining units and various lithologies occur randomly.

In the Parahio section, Kumar *et al*, (1984) classified the Kunzam *La* Formation into two members, viz. Debsa Khad and Parahio. However, on the basis of vertical facies zoning, four units are identifiable (Fig.2.8c, Appendix-II).

Trace fossils *Phycodes*, *Plagiogmus* (Fig.2.6) and *Rusophycus* were reported from the Kunzam *La* Formation, exposed on the right bank of the Parahio River (Bhargava *et al*, 1986). On the basis of strike and structural attitude, the fossils from the right bank were interpreted to represent a horizon lower than that of the Moppo level (Bhargava *et al*, 1982). According to this correlation, *Plagiogmus* occupies stratigraphically a level lower, as compared to *Diplichnites* etc. (Bhargava *et al*, 1982).

The Kunzam *La* Formation in the Kinnaur sub-basin is also represented by a lithology similar to that encountered in the Spiti area. In the Pin, Baspa (Logurgur *Thach*) and Tidong Valleys (Brati *Thach*), there occur lenticular pebble and gritty beds. The pebbles are subrounded, well-sorted and made up of quartzite. Some of these are as big as 20cm across.

The clasts are set in an arenaceous matrix. Ill-preserved current crescents are observed in the sandstone exposed on the left bank of the Arsomang *Gad*, about 250m upstream of its confluence with the Baspa River. In SE Kinnaur (Chorgad Valley), *Phycodes pedum* (Fig.2.9) and *Lingulella* occur over the acid volcanic suite of rocks.

The clastic sequence of the Kunzam *La* Formation shows more or less identical distribution throughout Spiti-Zanskar. The carbonate rocks, forming the upper part of the formation show prominent variation. Between Patseo and Padam, the carbonate rocks predominate and show algal mat and column (Fig.2.10) mainly made up of *Epiphyton*. SW of Patseo, the thickness of carbonate rocks is considerably reduced. In the Losar section it is negligible, whereas, in the Pin-Parahio it has a limited development. It is only between Charang and Nakurche and Hojis and Titan *Khads* in the Kinnaur area that the dolomite is again developed. The present variation in thickness of the Kunzam *La* Formation is possibly due to erosion in pre-Thango time. It is because of the pre-Thango erosion that, in the areas where the thickness of the Kunzam *La* Formation is least, only the lower part of this formation is preserved. In the NW Zanskar, the Kunzam *La* Formation is overlapped by the Phe Volcanics of the Permian age.

At Phalong Danda, pegmatite/granitoid and in the Zanskar, the Gumboranjan Granite (Srikantia *et al*, 1978a) are intrusive in the Kunzam *La* Formation. In the Racho *Khad* section (Tidong Valley), these rocks are intruded by quartz-specularite veins.

The rocks of the Kunzam *La* Formation are traversed by malachite stained quartz vein right from the Baralacha Pass to the Jadhganga Valley.

Age : The trace fossils in the basal part of the Kunzam *La* Formation indicate an early Cambrian age (Bhargava *et al*, 1982), whereas, the trilobite fauna recorded in its upper part suggests middle Cambrian age. Middle Cambrian age is also supported by a lone conodont (Bhatt and Kumar, 1980) reported from the Parahio Valley. The Kunzam *La* Formation is, thus, considered to range in age from early Cambrian to middle Cambrian.

2.3.2 Sanugba Group

This term was suggested by Bhargava *et al*, (1991b) after the Sanugba stream, a tributary of the Ratang *Nala*.. Since a probable break is envisaged between the Takche and Muth Formations in the present work, the latter is being delinked from the Sanugba Group and included in the Kanawar Group.

2.3.2.A *Thango Formation*

This name was proposed by Srikantia (1974) after well-known Thango locality (not marked on the toposheet) in the Parahio River section. It was originally included by Srikantia (1974) under the Haimanta Group. However, due to a major plane of unconformity now identified between it and the underlying Kunzam *La* Formation, the Thango Formation has been separated from the Haimanta Group.

The Thango Formation has also been referred as Shian Quartzite (Goel and Nair, 1977, 1982) without (a) properly defining the type section, (b) providing measured lithostratigraphic details and (c) proving its mapability. Similarly, the Thaple Formation of Nanda and Singh (1976) lacks these very details. Since these terms have not taken roots, whereas, 'Thango' has been frequently used in the literature, we have opted for the latter. In Kinnaur, it was earlier referred to as Tiwri and Yamrang *La* Formations (Bassi *et al*, 1983).

The Thango Formation is one of the most characteristic formations of the Spiti area. Due to its deep crimson/maroon colour and rugged topography, it is recognisable from a distance (Fig.2.15) and easily picked in aerial photos due to distinct tone. In the Tariya section (Pin Valley), it has lost its characteristic red colour. At Phalong Danda (Lahaul) also, the Thango Formation has been decolourised due to intrusion of granitoid. Decolourisation effect is observed also in the area north of Hango. This decolourisation has been attributed by Hayden (1904) to metamorphism.

The Thango Formation rests over the Kunzam *La* Formation along a sharp contact. In the Spiti, Pin (Fig.2.11) and Chorgad Valleys, an angular discordance exists between the two. The upper contact of the Thango Formation with the Takche Formation is gradational and partly intercalated. Its contact with the latter has been delineated at the appearance of first carbonate bed and/or brownish coloured calcareous sandstone.

The Thango Formation is essentially an arenaceous sequence which, in most of the sections, begins with a conglomerate bed (Fig.2.12-13). The conglomeratic sequence in Kinnaur, except between the Charang *Gad* (Tidong Valley) and Arsomang (Baspa Valley) where it is absent, is unusually thick (25-40m). In sections where two prominent conglomeratic horizons are developed, the lower one shows clasts mainly of grey-green sandstone, siltstone, shale, dolomite and vein quartz of the Batal-Kunzam *La* affinity. The upper conglomerate, in addition to above mentioned clasts, also contains clasts of red sandstone, siltstone and shale of Thango parentage. In the Gyamthing *Gad* section, the conglomerate contains clasts derived from quartz-specularite veins. In the sections where only one conglomerate is present, it is invariably the upper one. East of Shushin *Thach*, the conglomerates in the Thango Formation are lenticular and do not form the base. In the Zanskar area, the clasts are mostly from the dolomite of the Kunzam *La* Formation (Karsha Formation of Nanda and Singh, 1976). The clasts in the conglomerate are in the size range of boulder (5%), cobble (5-10%) and pebble (80-90%), but the medium size pebbles predominate. The clasts are moderately to well-sorted, rounded to well-rounded, having a sphericity of 0.3 to 0.4. These are embedded in an arenaceous matrix in the ratio of 60/40 : 40/60. In general, the clasts dominate in the upper part of the conglomerate sequence. The size of the clasts in the conglomerate in most cases decreases towards the stratigraphic top. However, in a few sections (*e.g.*, Pin Valley) in the basal conglomerate, the clasts size first increases and then decreases. In the Chorgad section, three upward-fining cycles are recorded in the basal conglomeratic horizon.

The sequence in between the conglomerate is haematitic, which is conspicuous in the Pin, Parahio

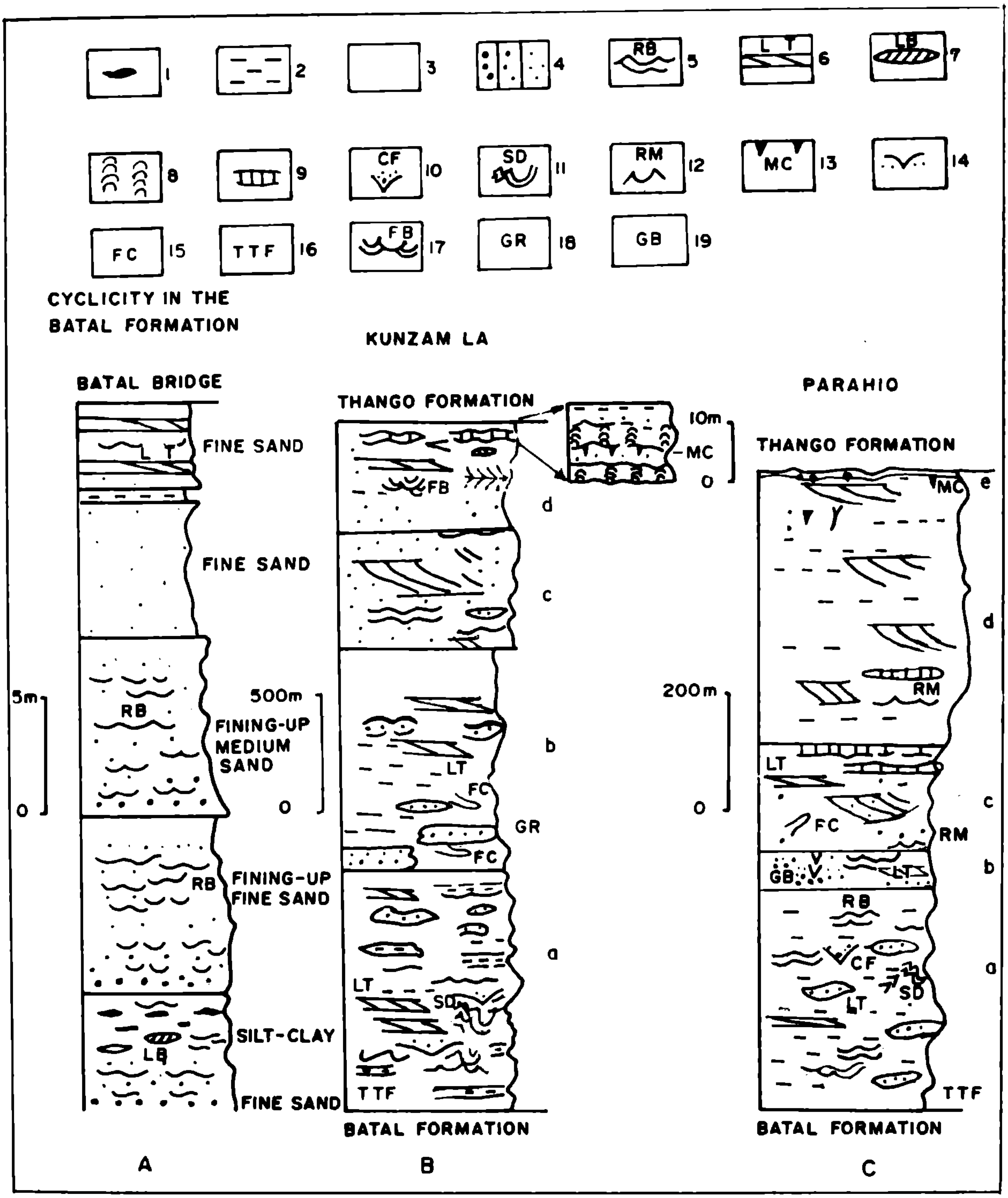


Fig. 2.8. Lithologs of the Batal (A) (in part) and Kunzam *La* Formation (B, C). Expl: 1. Clay, 2. Shale, 3. Siltstone, 4. Sandstone , coarse, medium, fine, 5. Ripple bedding, 6. Low angle truncation, 7. Lenticular bedding, 8. Stromatolitic columns, 9. Carbonate beds, 10. Channel fills, 11. Syndepositional deformation, 12. Ripple marks, 13. Mudcracks, 14. Sand partings with mud drapes. G.B. Graded bedding, F.C Flute casts, TTF Trilobite trace fossils, FB Festoon bedding, G.R. Graded rhythmites, a-e are subdivisions of the Kunzam *La* Formation.

Ratang, Gyundi and Shitikar sections (left bank of Spiti).

The sequence above the conglomerate is largely made up of fine grained sandstone with a few silty and shaly partings. The shale intercalations in the Kinnaur part are more pronounced and contain excellently preserved trace fossils (Fig.2.14). The upper part of the sequence in Spiti also shows layers of red shale which are rich in trace fossils.

The sub-facies of various sections are depicted in Fig.2.17, the details of which are provided in Appendix-III.

The sequence and subfacies in the Parahio Valley are more or less identical to those exposed in the Pin Valley except that there are two conglomerate bands, separated by a 8-10m thick sandstone bed in the former.

In the Takche section, there is very limited development of conglomerate. The absence of conglomerate is possibly due to a strike fault which has also caused shearing. The generalised sequence of facies in ascending stratigraphic order is (a) several tens of metres-thick fine, medium and coarse grained sandstone (Fig.2.18) showing common herringbone cross-bedding (Fig.2.19), rare low-angled cross-bedding, planar cross-bedding (Fig.2.20) and tidal bundles. This also shows a few centimetres thick ripple layers with thin mud drapes and ripple marks with bifurcating crests (Fig.2.16); (b) sandstone sequence with lenticular units of low angle cross-bedding showing channel and discordance surfaces (Fig.2.21) and rare high angled (25^0) planar and festoon cross-bedding. A few centimetres thick rippled layers with mud drapes and bifurcating linguoid round-crested ripples and mudcracks are also present. Thicker sandy units show hummocky cross-stratification.

In the Hango section, along the Hango-Kirasang *Jhoola* track, a few calcareous lenses of bioturbated mudstone enclosing totally recrystallised crinoids are present. The bioturbated parts are filled with darker material along with some quartz grains. At the Dipgyamba *Gad* confluence (Tidong Valley) and the Gyamthing Valley also there is a crinoidal calcareous lens.

In the Gyamthing section, the Thango Formation is intruded by chalcopyrite-quartz veins, and in the Arsomang, Mangla and Gyamthing sections, by the quartz-barite-galena veins. Very fine scales of gypsum are associated with the upper red shale in the area SE of Charang and Arsomang Glacier snout.

Numerous small sills of gabbro-norite affinity are observed within this formation in the Tidong and Gyamthing Valleys. A dolerite sill is observed in the Tariya area.

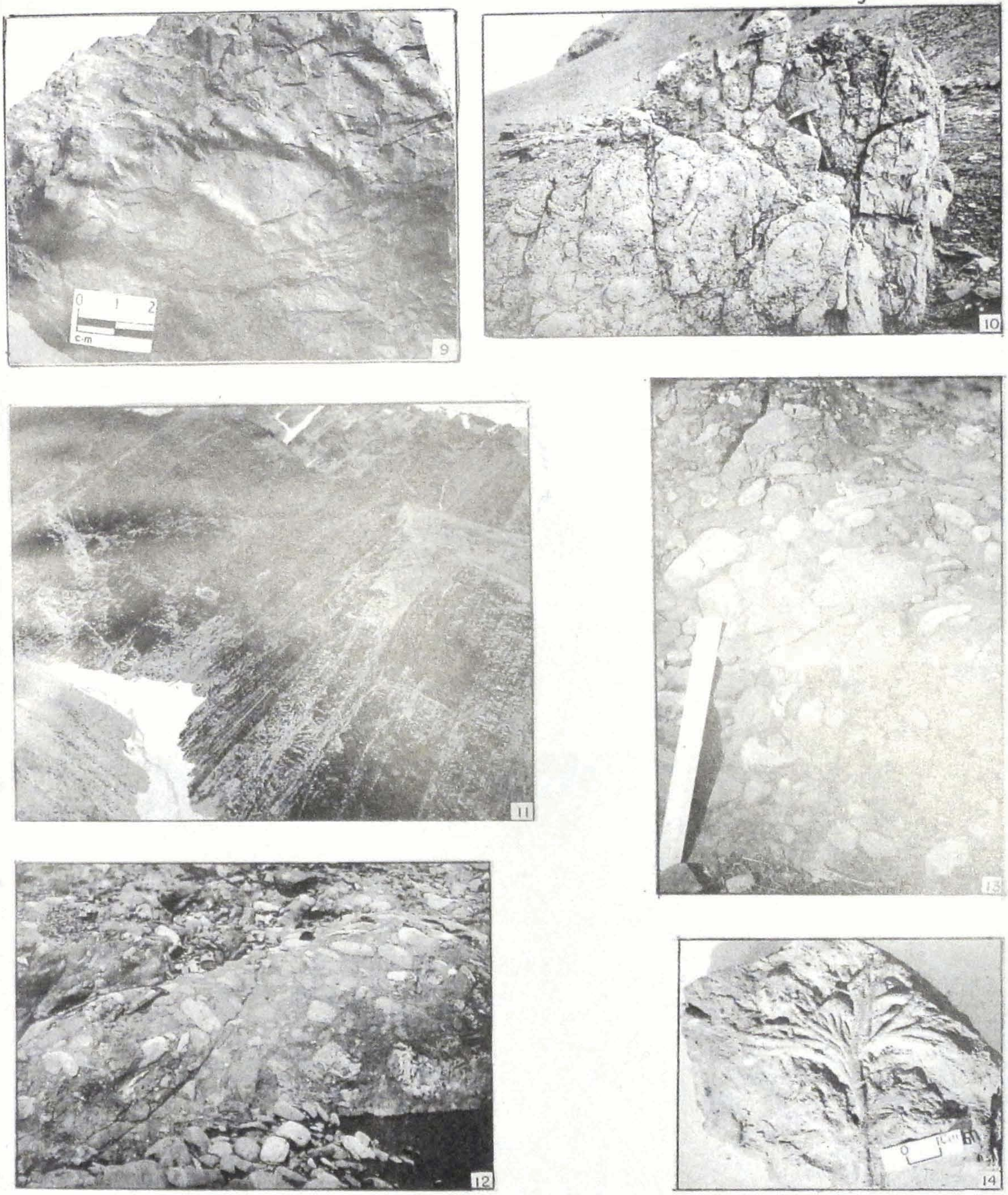
The Thango Formation in the Kinnaur Basin is fossiliferous, showing ubiquitous presence of gastropod *Raphistoma* sp. At the Loechhutongsa *Khad* confluence with the Tidong, a dip slope of the Thango Formation is crowded with casts of pentamerids.

The Thango Formation shows a gradual reduction in thickness towards the SE in the Spiti Valley. In the southeasternmost part, it is cut off along the Kaurik Fault Complex (KFC). Towards east in Kinnaur, it maintains a uniform thickness. Further east in the Jadhganga Valley, it was found to link up with the conglomerate mapped in this section as the Ralam conglomerate of 'Precambrian age'. In the Zanskar area also, it maintains the uniformity of sequence showing conglomerate (2-20m) in the basal and red shale in the upper parts. Its thickness decreases towards NW, least being at Tanze Yogma. In the north-western part of Zanskar, the conglomerate is practically absent.

The following body and trace fossils, mainly from the Kinnaur area (Bhargava *et al*, 1984a), have been recovered from the Thango Formation. Body fossils : *Raphistoma*, *pentamerids*, *Trochonema*, Trace fossils : *Phycodes* sp., *P. circinatum*, (Fig.2.14) *P. palmatum*, *Skolithos*, *Planolites*, *Sinusites*, *Arenicolites*, *Teichichnus*, *Rusophycus*, *Rouaultia*, *Monomorphichnus*. *Isopodichnus*, *Bifungites*, *Spirophycus*, giant burrows and other indeterminate fossils.

Age : The paucity of index fossils makes it difficult to fix the age of this formation. *Phycodes circinatum*, one of the rare trace fossils which is considered as an index fossil for early Ordovician, occurs 650m above the base of the Thango Formation. The lower age limit of the Thango Formation, thus, may be latest Cambrian or earliest Ordovician. The upper age limit of early Silurian for this formation was determined on the basis of *Pentamerids* present in the Thango Formation. However,

Figs. 2.9 – 2.14



Explanation of Figs. 2.9 - 2.14

Fig. 9. *Phycodes pedum* in the basal part of the Kunzam *La* Formation. Loc. Chorgad Valley. **Fig. 10.** Algal bioherm, Kunzam *La* Formation, rolled boulder at Patseo. **Fig. 11.** Angular discordance between the underlying Kunzam *La* Formation and the overlying Thango Formation. Loc. Right bank of Pin River, Siabong. **Fig. 12-13.** Conglomerate of the Thango Formation, 12. It has more of matrix. About 1.5 km downstream of Gechang in the Parahio Valley, 13,. Clast supported, near Thidim. **Fig. 14.** *Phycodes circinatum*, Thango Formation. Loc. One kilometre downstream of Manchap.

Figs. 2.15 – 2.16

15

16

Explanation of Figs. 2.15 -2.16

Fig. 15. Conspicuously red-crimson Thango Formation resting over the Kunzam *La* Formation at Thango type locality. Right bank of Parahio River, downstream of Thango. **Fig. 16.** Bifurcating, smooth topped ripple marks in sandstone of the Thango Formation. Loc. Thango.

Ordovician, as upper age limit of the Thango Formation, is more probable.

2.3.2.B *Takche Formation*

This lithostratigraphic name was suggested by Srikantia (1974, 1981). Goel and Nair (1977) used the term 'Pin Limestone' without defining it properly or proving its mappability. Khanna *et al*, (1983) proposed the term 'Pin Dolomite' for the rocks bound by the Muth Quartzite towards the top and the 'Shian Quartzite' towards the base. The rocks in the Pin Limestone/Pin Dolomite are neither exclusively limestone nor dolomite. Besides, in well-developed sections, these together constitute only about 30% of the sequence. Neither of the term is thus suitable.

At the Takche type locality, however, the section is not well-developed. Best section of this formation is exposed at the Manchap *Thach*. Since the Manchap section requires at least six days of arduous trekking to reach, the present authors prefer to retain the term Takche. The name Manchap Formation (Bassi *et al*, 1983), however, may be retained as a junior synonym after the most important reference section. The Pin and Parahio Valleys also show good sections of the Takche Formation.

The Takche Formation, being rich in carbonate, is easily recognisable from a distance by its earthy brown appearance, sandwiched between the purple Thango Formation below and the white coloured Muth Formation above.

With the intercalations of a few calcareous sandstone/ arenaceous dolomite and brown shale, the underlying Thango Formation imperceptibly passes upward into the Takche Formation. However, in the Guimdo section (eastern-most Spiti Valley), the Takche Formation rests unconformably over the Precambrian schist of the Morang Formation. In the upper part, the Takche Formation includes matrix-rich sandstone interbeds over which the matrix-poor/free white clean sandstone of the Muth Formation appears abruptly. The contact of Takche and Muth Formations, thus, is only apparently conformable. This contact, which is marked at the first appearance of white sandstone bed in the Takche section, is gently undulatory. However, in view of strong deformation suffered by the rocks, it is difficult to decide whether this undulation represents an original depositional surface or structural deformation.

In the Spiti Valley, the Takche Formation has a sizeable arenaceous component towards its NW end (*i.e.*, the type locality). The carbonate content gradually increases towards SE, being maximum in the Pin Valley. In eastern Kinnaur, it is being essentially a carbonate sequence showing sudden variation in thickness due to its biohermal nature. The sequence comprises several cycles commencing mostly with carbonate and ending with clastics. The details of the sequences in various sections are illustrated in Figs.2.25-2.26 and Appendix-IV.

The Takche Formation has protean characters and includes small reefal buildups (Bhargava and Bassi, 1986). The corals reported in the Takche area are strepteplasmids. *Chonophyllum*, small colonies of *Favosites*, *Halysites*, and *Plasmoporella* (Fig.2.22) (Bhargava and Bassi, 1986) and *Heliolites*. *Orthis* and *Atrypa* are frequent in the middle and upper parts of the sequence. *Apidium indicum*, thought to be an ostracod (Reed, in Pascoe, 1968), has been interpreted by Kato *et al*, (1987) to be an algae. It occurs in the middle part of the sequence at Takche. The identification of *Chonophyllum* and *Plasmoporella* by Bhargava and Bassi (1986) are still tentative.

The Gechang section yielded strepteplasmid and *Tryplasma* from basal part and *Chonophyllum* from the upper. Small colonies of *Thamnopora*, *Favosites*, *Heliolites* (Fig. 2.23), *Halysites* (Fig.2.24), *Stromatoporoid* (Fig.2.27-28) and ?*Protaraea* occur in the carbonate beds (Bhargava and Bassi, 1986).

The fossils recorded by Bhargava and Bassi (1986) from Muth-Shian section are : *Stromatopora concentrica* Goldfuss, *Halysites catenularia* var. *kanaurensis* Reed, *H. wallichi* Reed, *Favosites spitiensis*, Reed, ? *Propora*, ? *Parachaetetes*, *Orthis*, *Chonetes*, ?*Atrypa*, a few *Tentaculites*, *Pleurotomaria* and rare orthoceratids. The identification of *Calymene* and *Cheirurus* as based on fragmentary remains are tentative.

The fossils collected from Leo are Rugose coral ?*Chonophyllum* and strepteplasmids. Both of these are mildly to strongly recrystrallised and ferruginised. These are common in the upper part of the sequence. Tabulate corals *Halysites catenularia* var. *kanaurensis* Reed and *H. wallichi* Reed are most common. A few colonies of these corals are almost 30cm wide. These are associated with spheroidal colonies of *Favosites*. ?*Protaraea kanaurensis* (Reed) is present in the basal part.

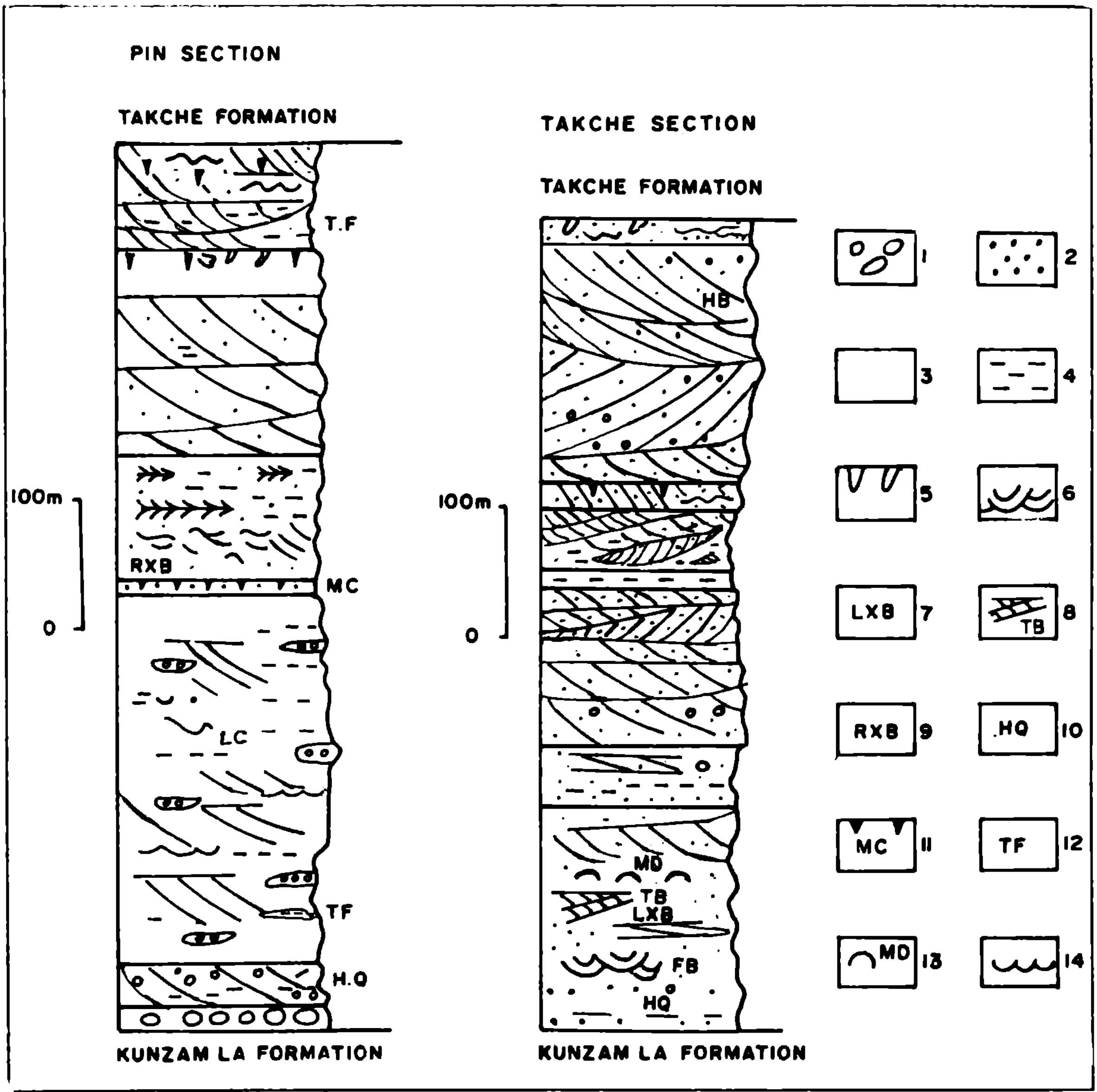
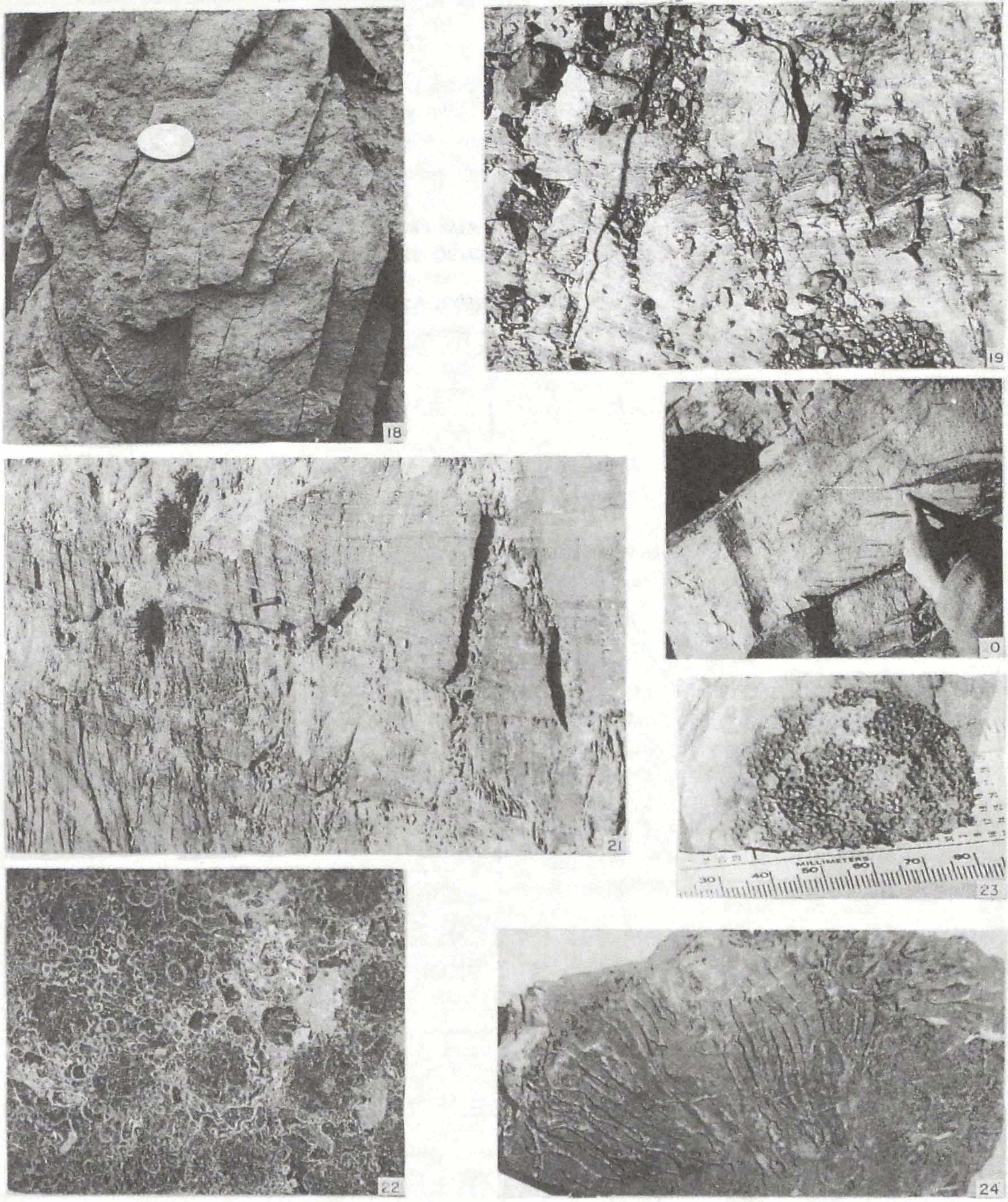


Fig. 2.17. Lithologs of the Thango Formation. Expl: 1. Conglomerate with pebble to boulder size clasts, 2. Sandstone, 3. Siltstone, 4. Shale, 5. Burrows, 6. Festoon cross-bedding, 7. Low angled cross-bedding, 8. Tidal bundles, 9. Ripple cross-bedding, 10. Haematitic quartzite, 11. Mudcracks, 12. Trace fossils, 13. Mud drape, and 14. Ripple marks.

Stromatoporoids are highly recrystallised and difficult to identify. These are mainly laminar, low domal (Fig.2.27), extended domal and rarely dendritic types (classification after Kershaw and Riding, 1978). The form, previously identified as clathrodictid (Bhargava and Bassi, 1986), is possibly *Ecclimadictyon* (Fig.2.28) which ranges in age from late Ordovician to Silurian.

The bryozoan *Hallopora* (Fig.2.29) is a common genus in the Takche Formation. In addition to it, bifoliated forms, fenestellids, *?Fistulipora* and coral *Coenites* have been reported (Bhargava and Bassi, 1986). Algae are represented by nodular colonies of *?Parachaetetes*, which also occur as binder. Amongst brachiopods are *Chonetes* and *Orthis*. Crinoids, though rare in the Leo section, are of larger dimensions as compared to those in other areas. Molluscs are represented by orthoceratids and gastropods. Echinoderm spine and other frag-

Figs. 2.18 – 2.24



Explanation of Figs. 2.18 - 2.24

Fig. 18. Coarse grained sandstone of the Thango Formation. Loc. Takche. **Fig. 19.** Tabular cross-bedding, Thango Formation. Loc. Takche. **Fig. 20.** Herringbone cross-bedding, Thango Formation. Loc. Takche. **Fig. 21.** Low angle discordance, erosional channel and cross-bedding in the Thango Formation. Loc. Takche. **Fig. 22.** Slide print of *Plasmoporella* (Proporid?), Takche Formation. Loc. Manchap. **Fig. 23.** Small circular colony of *Heliolites*, Takche Formation. Loc. Gechang. **Fig. 24.** *Halysites* colony, Takche Formation. Loc. Gechang. (Bar scale is 3mm).

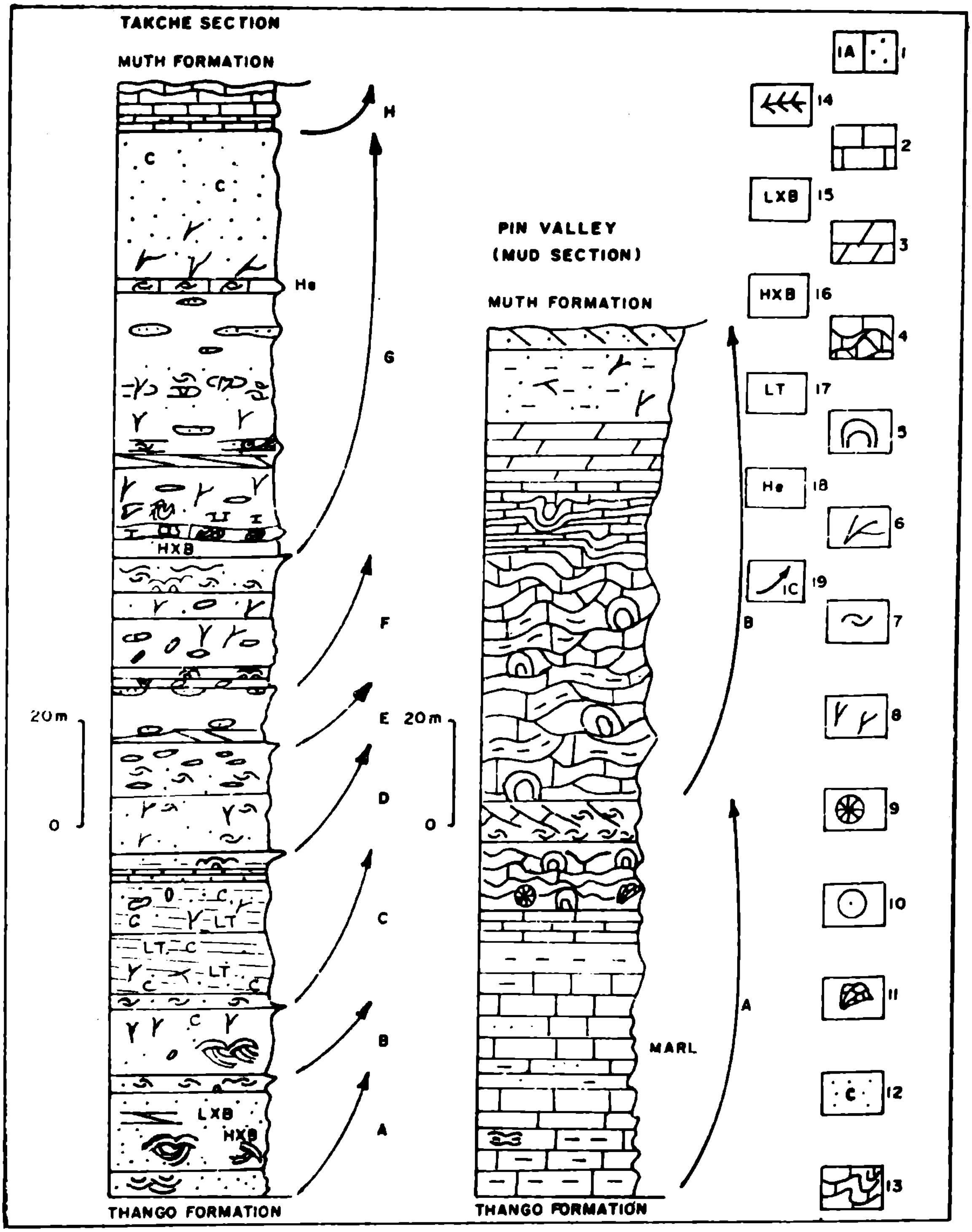


Fig. 2.25. Lithologs of the Takche Formation. Expl: 1. Sandstone, 1a. Siltstone, 2. Limestone, 3. Dolomitic limestone/dolomite, 4. Nodular bedding in the carbonates, 5. Stromatoporoid, 6. *?Psilophyton*, 7. Shells-brachiopod/lamellibranchs, 8. Bioturbations, 9. Solitary Corals, 10. Echinoids, 11. Colonial Corals, 12. Calcareous sandstone, 13. Syndepositional slumps in carbonates, 14. Herringbone cross-bedding, 15. LXB - Low angle cross-bedding, 16. HXB - Hummocky cross-bedding, 17. L.T. - Low angle truncation, 18 He - Heliolitids, and 19. A, B - cycles, I.C. - Incomplete cycles.

ments are sporadically found. A few carapaces of ostracodes were encountered in thin sections.

From the Manchap section, Bhargava and Bassi (1986, 1987) have reported stromatoporoid (Fig.2.30), *strepteplasmids*, *Tryplasma*, *Ptychophyllum*, *Halysites*, *Favosites*, *Plasmoporella*, *Radiastraea* (Fig.2.31-32), calcified lithistid sponge (Fig.2.33), *Coenites*, *Hallopora* and other bifoliated bryozoa, and algae *Vermiporella* and *Girvanella*. The codiacean algae (Fig.2.34) of Bhargava and Bassi (1987) is possibly same as *Apidium indicum* identified by Kato *et al*, (1987). The identification of *Psilophyton* (Bhargava and Bassi, 1986) was based on external resemblance though no vascular structure could be seen. Kumar and Kashkari (1987) seem to interpret all *Psilophyton* like forms in the Takche Formation as trace fossils *Chondrites*. Though *Chondrites* does occur in the Takche Formation (Bhargava, *et al*, 1984a; Bhargava and Bassi, 1986), the forms referred to as *Psilophyton* are certainly distinct from *Chondrites*.

The Takche Formation contains trace fossils *Arenicolites, Arthrophycus, Chondrites, Planolites, Skolithos and Rusophycus* (Bhargava *et al*, 1984a Bhargava and Bassi, 1988). *Palaeodictyon*, described by Kumar and Kashkari (1987), most probably is a cast of a *Favosites* colony (Fig.2.35).

Khanna *et al*, (1983), have reported acritarchs and chitinozoa from a sequence equitable with the Takche Formation. Mehrotra *et al*, (1982), in addition to the acritarch assemblage recorded by Khanna *et al*, (1983), have reported *Angochitina capillata*, *Bursachitina* sp., *Eremochitina* sp., *Desmochitina* sp. from the Takche Formation of the Pin Valley.

The Takche Formation, as mentioned earlier, becomes more calcareous towards SE in the Pin-Parahio and Tidong Valleys. Its further extension in Kumaon has been described as the Yong Limestone (Khanna *et al*, 1985) and also as Variegated Formation which show massive stromatoporoid colonies. Towards NW of Spiti, the arenaceous content in the Takche Formation increases and it becomes difficult to distinguish it from the underlying Thango Formation. However, in the Sarchu area, though the Takche Formation has a limited thickness, it shows a distinct carbonate facies. Thickness-wise, the maximum development of this formation is at the Takche type area, which is maintained upto the Ratang *Nala* (Sanugba confluence), thereafter the thickness decreases towards SE. Similarly, the thickness decreases towards NW also. The Takche Formation is intruded by small transgressive sills of doleritic affinity in the Tariya and Manchap areas.

Age : The Takche Formation was assigned an Upper Silurian to Lower Devonian age by Srikantia (1981).Based on the occurrence of Pentamerus in the underlying Thango Formation, Bhargava and Bassi (1986) suggested an early to middle Silurian age to the reefal part of the Takche Formation. Kato *et al*, (1987), on the other hand, advocated an Ordovician age to their 'Pin Limestone' (≡Takche Formation) on the basis of algae *Coelosphaeridium* and *Apidium indicum*, the former being so far known from Caradocian only.

A review of fossils described from the presently defined Takche Formation, which includes beds regarded in age to as Ordovician and Silurian sequences by Pascoe (1968), reveals (Table-2.1) contradictory ages. For example, bryozoa *Ptilodictya*, brachiopod *Hindella*, trilobite *Calymene*, ostracode *Leperditia* and *Beyrichia*, which as per Moore (1956-1964) do not occur below the Silurian, coexist with trilobite *Illaenus*, *Asaphus* and ostracoda *Leperditella*, which are confined to Ordovician. Still more puzzling is the occurrence in the overlying unit 3, of coral *Lyopora* and *Mesotrypa* and in unit 4 of *Streptelasma* and cephalopod *Gonioceras* exclusively of Ordovician age along with chain coral *Halysites catenularia*, brachiopods *Strophonella* and *Camerotoechia* of Silurian age.

Of the fossils described in earlier literature, the identification of *Halysites catenularia* and *Pentamerus* indicating Silurian age has been doubted by Talent *et al*, (1988). The identifications of Silurian fossils *Chonophyllum*, *Coenites*, *Protaraea* and *Tryplasma*, reported by Bhargava and Bassi (1986), were from unoriented sections and thus, are provisional. Even after eliminating these forms of doubtful identification, there are several taxa which are characteristic of Ordovician and Silurian respectively (Table-2.1a - c).

Obviously, either the age ranges of these fossils as given by Moore (1956-1964) have undergone modification and a mix-up of fauna of different levels has occurred or identifications of some of the fossils are not correct.

Before any firm conclusion regarding the age

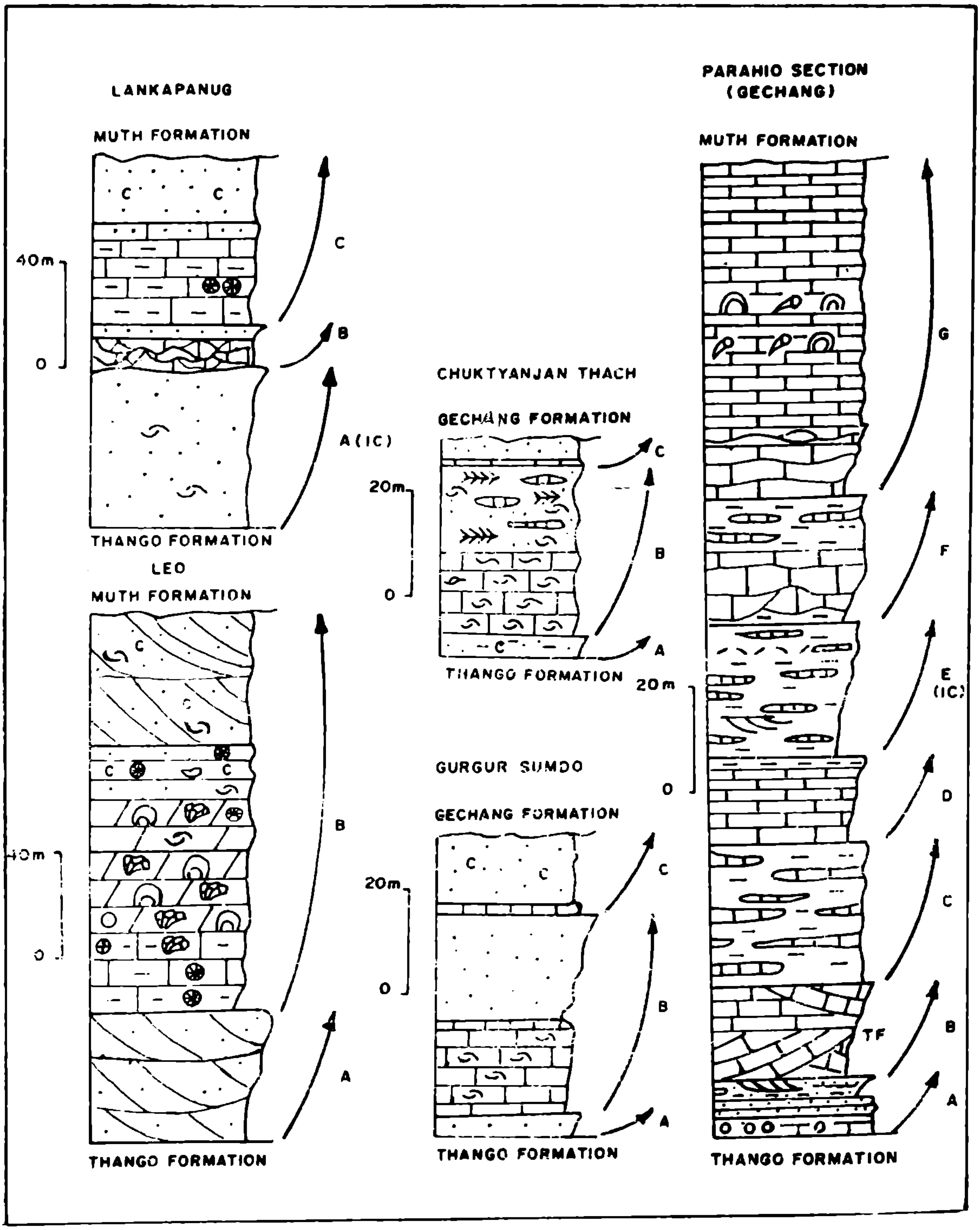
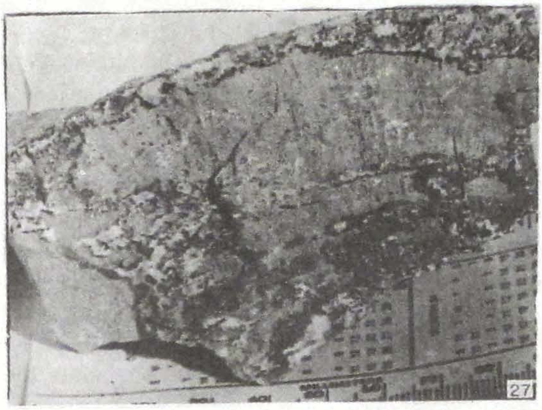


Fig. 2.26. Lithologs of the Takche Formation. Index same as for Fig. 2.25

Figs. 2.27 – 2.29



Explanation of Figs. 2.27 - 2.29

Fig. 27. Stromatoporoid in the Takche Formation. Loc. Gechang. **Fig. 28.** *Ecclimadictyon* sp. encrusting a coral, Takche Formation. Loc. Manchap. **Fig. 29.** *Hallopora* sp. Takche Formation. Loc. Manchap. (Bar scale is 2 mm).

of the Takche Formation is deduced, it is necessary to critically re-examine all old fossils and also the collection made by the present authors during 1984. Till such an exercise is accomplished, late Ordovician to middle or even late Silurian age seems most plausible, especially due to occurrence of corals *Heliolites* and *?Radiastraea*, in the upper part of the Takche Formation, latter being of middle Silurian age. Such an age broadly tallies with that of the Nowshera Reef of Pakistan (Stauffer, 1968), indicating a widespread favourable reef building palaeoenvironment over the Indian Plate during Silurian.

2.3.3 Kanawar Group

The term Kanawar was suggested by Hayden (1908). The original Kanawar 'System' included only the Lipak and Po 'Series'. Srikantia (1974, 1981), redesignated it as the Kanawar Group and enlarged its scope by including under it the Lipak, Po and Ganmachidam (≡ Permian Conglomerate of Hayden, 1904) Formations. In the present work, the three fold classification, as proposed by Srikantia (1974), has been further enlarged to encompass also the Muth Formation as it forms a conformable sequence with the Lipak Formation and is separated from the Takche Formation by an unconformity.

2.3.3.A *Muth Formation*

The name 'Muth Series' was suggested by Stoliczka (1865) after a village in the Pin Valley, which is spelt in the modern topographical sheet as 'Mud'. This has also been referred in the literature as Muth Quartzite (Hayden, 1904) and also Muth System (Hayden, 1908). Srikantia (1981) redesignated it as the Muth Formation. The strike extension of this well known formation in Lahaul and Zanskar was described as the Kenlung Formation by Nanda and Singh (1976). The Muth Formation is the most conspicuous sequence of the Tethyan Himalaya, having more or less similar characters right from Kashmir-Zanskar to Kumaon. This formation, due to its white colour, can be recognised even from a great distance (Fig. 2.36) and easily picked on aerial photographs.

The Muth Formation comprises white to white mottled quartzarenite with rare light grey shades and local thin dolomitic sandstone and conglomerate interbeds. The lower contact of the Muth Formation with the Takche Formation, as stated earlier, is undulatory and abrupt. It has been marked at the first appearance of white/mottled quartzarenite bed. In the Spiti Valley near Guimdo, it overlaps the Takche Formation and rests over the Precambrian Morang Formation. Along the upper contact, it is variously overlapped by the Lipak, Gechang and Gungri Formations. Its contact with the overlying Lipak Formation in fully developed sections is intercalated and has been delineated at the first appearance of dolomite/limestone or matrix-rich sandstone in the upper part of ts sequence. The contact between the Muth Formation and the Gechang and Gungri Formations is sharp everywhere. At Jongchen it shows an undulatory erosional top below the Gungri Formation.

The quartzarenite in the basal part of the Muth Formation is largely mottled and friable. It is succeeded by an alternating sequence of siliceous white quartzarenite and friable quartzarenite.

Planolites, Palaeophycus tubularis, Arenicolites, Skolithos and arthropod trackways (Bhargava and Bassi, 1988) are known from the Muth Formation. Ameta and Gaur (1980) reported poorly preserved orthoceratids and corals from a rolled boulder of the 'Muth Quartzite' in the type area. From the Khimokul *La* section, Bassi (1988b) reported mould of *Orthis aff. rustica*..

The sequence of the Muth Formation at Takche (Spiti Valley), Mud (Pin Valley), Hango-Tumtum Thanga and Khimokul *La* (Tidong Valley) sections are presented in Figs. 2.38-39 and Appendix-V. The entire sequence of the Muth Formation is composed of fine to medium grained white sandstone.

The Muth Formation has more or less uniform thickness in the main Spiti Valley. On the left flank of the Ropa Valley it shows conspicuous thickness variations, ranging from 2m to 50m in short stretches of barely 250m. It is altogether absent south of the Hangrang Pass. Beyond Kirasang *Gad*, it shows a thickness varying between 90m and 200m. In the Kinnaur basin, it is uniformly developed with thickness varying between 80m and 120m.

NW of Spiti towards Zanskar, the thickness of the Muth Formation decreases. In this stretch the passage beds developed between the Muth and the Lipak Formations, conspicuous in Kashmir (Wazura Formation of Srikantia and Bhargava, 1983) and also partly in Spiti, are lacking, and as a result, the contact between the Muth and Lipak Formations is sharp. A dolerite dyke is observed in the Muth

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

Table 2.1a. The fauna of units e and f of Hayden (1904) of 'Ordovician Sequence', near Shian, Pin Valley (in Pascoe, 1968) and their age ranges after Moore (1956-64).

UNIT	FOSSILS
i	*Streptelasma corniculum* Hall
	Favosites sp
	Phylloporina sp.
	Rhinidictya sp
	Ptilopora sp
	Stictopora elongulata Hall
	Aloctoporella sp.
	Orthis (Dalmanella) testudinaria Dalman
	O. (Dinorthis) porcata var. *peregrina* Reed
	Leptaena rhomboidalis Wilckens
	Strophomena wisconsinensis Whitfield
	Sowerbyella sericea Sowerby
	Hindella shianensis Reed
	Lophospira bicincta Hall
	Hormotoma cf. trentonensis Ulrich and Schofield
	Bellerophon sp
	Gonioceras anceps Hall
	Illaenus sp.
h	
g	*Lyopora* sp.
	Orthis (Plectorthis) stracheyi Reed
	O. (Dalmanella) testudinaria Dalman
	Parastrophia indica Reed
	Mesotrypa sp.
	Conradella obliqua Ulrich and Schofield
	Pasceolus shianensis Reed
	Apidium indicum Reed

Table 2.1b Fauna of units g and i of Ordovician Sequence' of Hayden (1904) near Shian, Pin Valley, (in Pascoe, 1968) and their age ranges after Moore (1956-64).

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

Table 2.1c Fauna of stages 1, 2 and 3 of Silurian Sequence of Hayden (1904), exposed near Shian, Pin Valley (in Pascoe, 1968) and their stratigraphic ranges after Moore (1956-64).

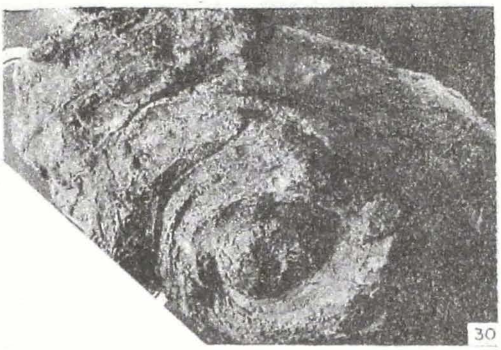
Formation north of Tariya.

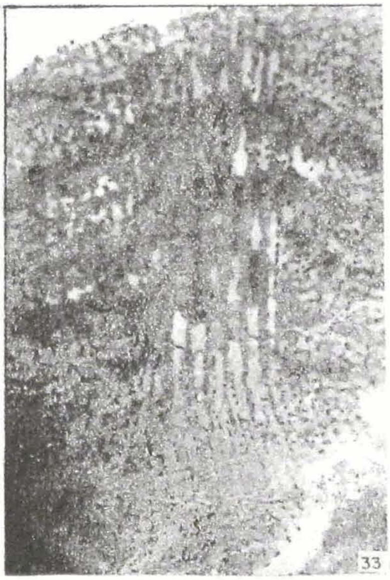
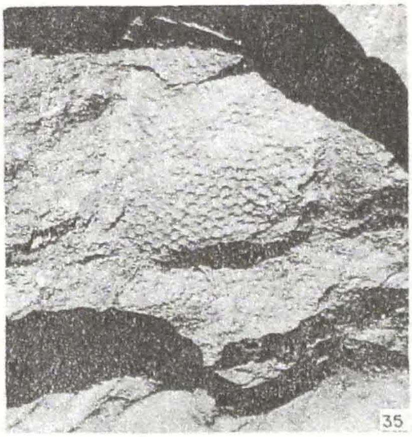
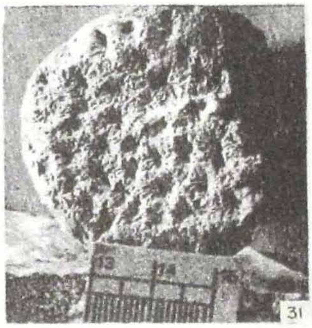
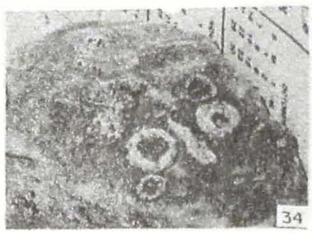
Age : The erstwhile Muth Series/Quartzite included parts of the Takche and probably also the presently redefined Lipak Formation. This Muth 'Series' was assigned an Upper Silurian age by Stoliczka (1865) and Hayden (1904), Carboniferous by Oldham (1888) and Greisbach (1889), whereas, Srikantia (1981) considered Muth Formation to range in age from middle to upper Devonian. Goel *et al*, (1987) reported brachiopods belonging to genus *Pentamerifera* (restricted to Silurian only) and some primitive corals of Silurian age from the lower part of the Muth Quartzite of the Kiogad Valley (Garhwal) and suggested a Silurian age for this level. From the Takche section, Ranga Rao *et al*, (1987) reported 'Upper Silurian' and 'possible Lower Devonian elements' from the quartzite-slate alternation and dolomite of the 'Muth Sequence' (classified in the present work under the Lipak Formation). Ranga Rao *et al*, (1987) further state that 'a very small thickness of sediment separates' the Silurian horizon 'from the overlying Lipak Formation' of Carboniferous age, which they explain by non-deposition/diastem during the greater part of Devonian. From a similar sequence occupying identical stratigraphic position in the Pin Valley, these authors report long ranging but post-Silurian elements. Ranga Rao *et al*, (1987), therefore, consider the upper contact of the Muth Formation as time-transgressive, representing Devonian age in the Pin Valley and possibly Silurian in the Takche section. The Muth Formation has a conformable contact with the overlying Lipak Formation, which ranges in age from latest Devonian to early Carboniferous. Even during bed by bed measurement of section, no sedimentologic and/or lithologic break between the two formations could be deciphered. It is, thus, difficult to accept the age interpretation given by Ranga Rao *et al*, (1987) for the Muth Formation. We shall prefer to wait till another palaeontological group re-investigates the Takche section. In view of conformable contact between the Muth and the Lipak, the upper age limit of the Muth Formation has to be within the Devonian. If the sharp and undulatory contact between the Takche and the Muth Formations, as suggested in this work, represents a hiatus, it is likely that a part of the Silurian/Devonian are absent in the Spiti-Kinnaur basin. Thus, the Muth Formation is likely to represent a major span of the Devonian. The Silurian fossils, reported from the basal 'Muth' by various workers, possibly are from the Takche Formation as the Muth Formation has no carbonate beds in its basal part.

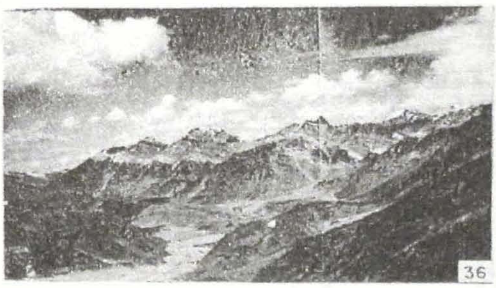
2.3.3.B *Lipak Formation*

This name was proposed by Hayden (1904) after a valley of this name in Kinnaur. The strike extension of this formation in Lahaul and Zanskar has been designated as the Lower Member and also

Figs. 2.30 – 2.37





Explanation of Figs. 2.30 - 2.37

Fig. 30. Low domal stromatoporoid (or Algae?) showing concentric structure in transverse view. Takche Formation, Loc. Manchap. **Fig. 31.** Nodular colony of *Radiastraea*, Takche Formation, Loc. Manchap. **Fig. 32.** Slide print of a transverse section of *Radiastraea* of Fig. 31. **Fig. 33.** Calcified lithistid sponge, Takche Formation. Loc. Manchap. **Fig. 34.** Codiacian algae (?), Takche Formation. Loc. Gechang. **Fig. 35.** Cast of a colony of *Favosites*, Takche Formation. Loc. Takche. **Fig. 36.** A view of the Chandra Valley from Balamola Pass showing dark hued Thango-Takche Formation, overlying somewhat lighter coloured Kunzam *La* Formation. White band is the Muth Formation and dark thin band is the Gungri Formation, in between these two occur Lipak, Po, Ganmachidam and Gechang. Over the Gungri Formation is the Lilang Group. **Fig. 37.** Hard ground in the coral reef part of the Lipak Formation. Loc. Takche. (Bar scale is 1cm for Figs. 2.30, 2.31, 2.33, 2.34, 2.35 and 1mm for Fig. 2.32.

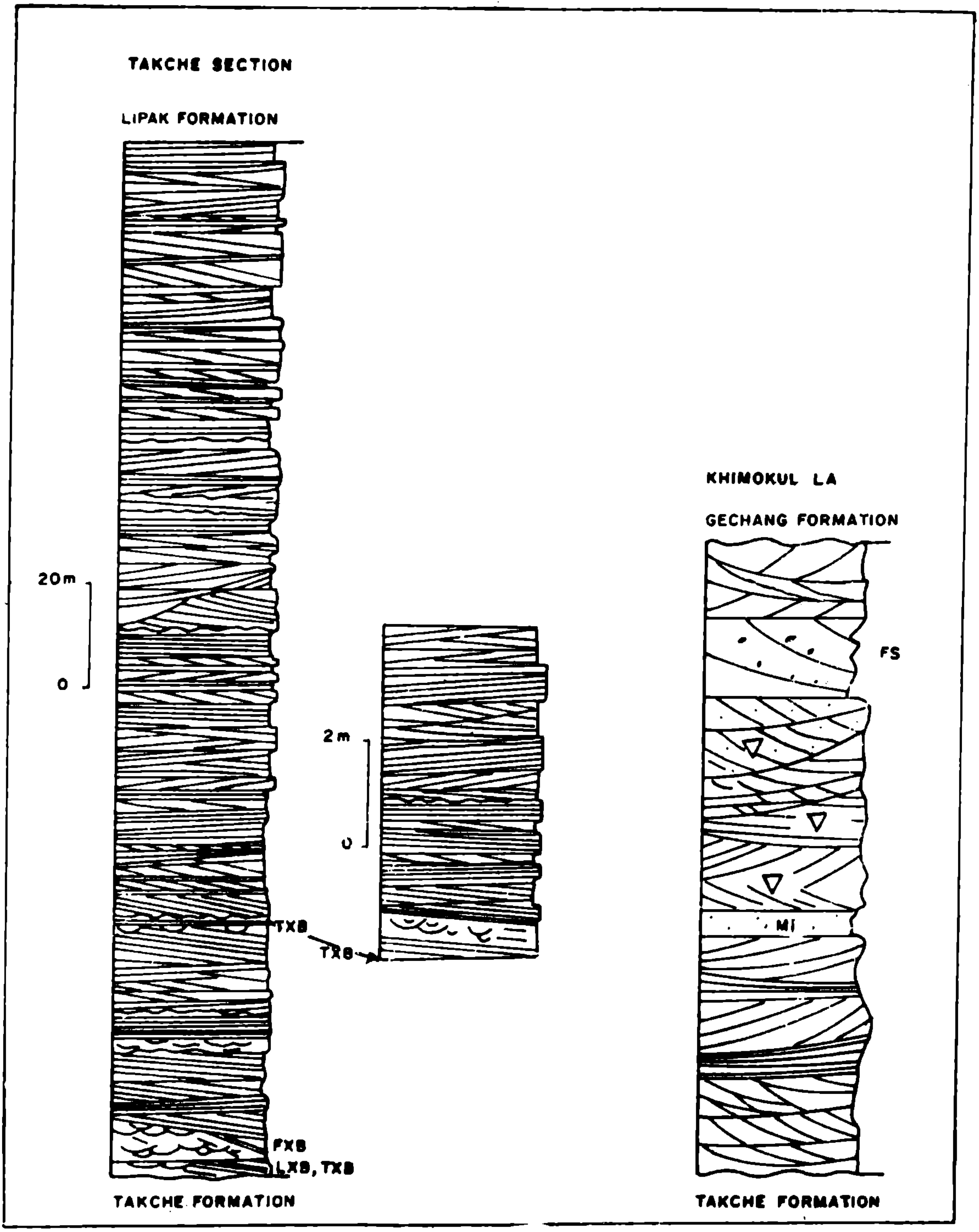


Fig. 2.38. Lithologs of the Muth Formation. Expl: 1. Brachiopod-impressions, 2. Sub-parallel bedding, 3. Low angle cross-bedding and truncation, 4. Herringbone cross-bedding, 5. Ripple mark, 6. Carbonate band, 7. Shale, 8. Bioturbations, 9. Erosional surface, 10. Low angle cross-bedding, 11. Festoon cross-bedding, 12. Tabular cross-bedding, 13. Burrow, 14. Calcareous sandstone, 15. Micaceous sandstone and 16. Bioturbated haematitic quartzarenite.

as Members A and B of the Tanze Formation (Nanda and Singh, 1976; Nanda *et al*, 1978).

The Lipak Formation, due to its dark carbonate rich lithology, in contrast to the underlying white Muth Formation and the overlying shale dominated Po Formation, is easily identified from a distance in fully developed sections.

The Lipak Formation shows extensive facies variation. It comprises dirty white to grey, locally cross-bedded sandstone in basal part, grey to ash grey shale interbedded with limestone and sandstone in middle part and limestone, local shale and lenticular gypsum bed in upper part. Gypsum is present near Losar, Hurling-Shalkar, Chango, Yulang and Yangthang. Hardgrounds (Fig.2.37) and coral-algal input is also present. By and large, the sequence of the Lipak Formation is made up of multiple cycles commencing with carbonate and ending in clastics represented by shale, siltstone or sandstone.

The Lipak Formation, to the east of the Kaurik Fault Complex in Leo-Yangthang sector, has been thermally metamorphosed into pyroxene-hornfels facies. It has a mineral assemblage of calcite+ diposide+ wollastonite+ epidote + sphene. The gypsum has been transformed into anhydrite. The carbonate rocks show flowage causing 'chocolate slab' boudins. Thermal metamorphism, leading to the formation of marble + wollastonite, has also been recorded in the area NE of the More Plain Fault, south of Rupshu in the Phirse Valley and east of the Syarma Fault Complex near Phiphuk in the Lingti Valley.

In complete sections, the Lipak Formation has a conformable contact with the underlying Muth Formation and also with the overlying Po Formation. The lower contact in such sections is marked by the first appearance of dolomite/ limestone band. Disappearance of carbonate rocks and predominance of shale-sandstone sequence has been taken as the beginning of the Po Formation. In sections where the Lipak Formation rests above the Morang Formation and is succeeded by the Gechang Formation, its both the lower and upper contacts are sharp and abrupt.

The lithologic details of the Lipak Formation in various sections are illustrated in Figs.2.40-41 and details furnished in Appendix-VI.

The rocks of the Lipak Formation are mostly fossiliferous. At Takche, Lipak *Gad* and Yulang sections they are unusually rich in fossils.

The Lipak Formation has an uneven distribution throughout Spiti. In the NW (Losar section) and SE (Lipak, Yulang and Hurling sections), it has maximum thickness. In these parts, it rests over the Muth Formation and is followed by the Po Formation.

In central part of Spiti, the thickness of the Lipak Formation is highly variable. In these parts, it is overlain by the Kuling Group. In the Lingti Valley, near Phiphuk, it rests over the Morang Formation and is unusually thick. South of the Pin Valley, upto north of Hango, the Lipak Formation is absent. In Sanand *Nala*, where Hayden (1904) categorically mentioned the absence of the Lipak Formation, it is represented by a 60m thick sequence enclosing *Syringothyris* (Kumar and Dutta, 1984). North of Hango, it is insignificantly present, but three kilometres beyond, its thickness increases to 600m.

Together with the Thango, Takche and Muth Formations, it forms an inverted sequence in the Yulang Valley in between the Kaurik and Na Faults. In the south-easternmost part of the Spiti area, (*i.e.* Yangthang, Chango and Shalkar), only upper part of the Lipak Formation is developed and like Phiphuk section, it rests over the Morang Formation .

In the Kinnaur area, this formation or its equivalent is not developed, but further SE in the Kumaon area, similar rocks are referred to as the 'Kali Series' by Valdiya and Gupta (1972) and Mamgain and Misra (1989). Towards NW and in the Lahaul area, it has a considerable thickness. In Zanskar, it displays a transgressive nature about two kilometres NW of Tanze, where it overlaps the Muth Formation as well as the Thango Formation and rests over the Kunzam *La* Formation. In turn, it is overlapped by the Phe Volcanics in the Thidsi *Nala* section. Only for a short distance does the Lipak Formation reappear near Marlung.

Rocks of doleritic affinity occur in the Lipak Formation as sills at Tariya, Shalkar and WNW of Yulang Dogri.

Age : The basal part of the Lipak Formation was regarded by Hayden (1904) and Pascoe (1968) to be of Devonian age. *Tentaculites* (Fig.2.43), which is not known beyond Devonian, occurs in the basal part of the Lipak Formation of the Yulang section (Bassi, 1990) and confirms such an age interpretation. *Syringothyris cuspidata* in the lower part and *Phillipsia cf cliffordi* in the upper part of the Lipak Formation indicate an early Carboniferous age. The *Tentaculites* level resting conformably below the *Syringothyris* yielding beds in the Yulang section, therefore, represents a latest Devonian age. In the Takche section, about 80m above the Muth-Lipak Formations' contact, the present authors have recorded *Lithostrotion* (Figs.2.42, 3.30), thamnoporid (Fig.3.25) and hexagonarid (Fig.3.31). Of these, the first generally is not known in pre-Carboniferous sediments, whereas, the latter two do not occur in post-Devonian. However, anomalously at Takche, *Lithostrotion* was found at a stratigraphic level lower than those of the thamnoporid and hexagonarid. No tectonic discontinuity or overturning could be noticed to explain relative anomalous position of these fossils. The entire sequence is upward younging and conformable. It is, therefore, suggested that this part of the Lipak sequence containing these fossils represents inter-mixing of Devonian and Carboniferous elements. The stratigraphic boundary between Devonion and Carboniferous is possibly located either in this part or in slightly a higher part of the sequence, while the basal part of the Lipak represents a late Devonian age. In view of its fauna being identical to that of the *Syringothyris* Limestone, following Savage (1982), Tournaisian may be assigned as the upper age limit of the Lipak Formation. The age of the Lipak Formation is, thus, interpreted to range broadly from late Devonian to early Carboniferous.

2.3.3.C *Po Formation*

This formation was named by Hayden (1904) after the village of the same name (spelt as Poh in the modern toposheet). The Po Formation is mainly developed in NW and SE corners of the Spiti Valley. In NE part, it is exposed in the Sumkhel Valley and west of the Syarma Fault in the Lingti Valley. It is entirely absent in eastern Kinnaur. As a rule, though the Lipak Formation is developed independent of the Po Formation, the latter is always found only in those sections where the former is developed.

Due to alternation of light coloured quartzite and dark shale, the Po Formation forms stepped topography and is recognisable in the field and also in aerial photos (Fig.2.44). It has conformable contacts with the underlying Lipak and the overlying Ganmachidam Formations. It comprises alternation of dark grey, pale green shale, siltstone and white and grey sandstone, with shale predominating in the middle part of the sequence. Pebbles appear in uppermost part of the sequence.

The shale-sandstone succession forms one cycle (Fig.2.45). In the Losar section, the cycle begins with dark grey shale with silty streaks. The burrows in this zone are millimetre thick. This is succeeded by dark grey silty shale with millimetre fine silt to silty fine interlayers with intense bioturbation. In the upper part, 1-3 cm thick fine sand layers become common. These show abundant sole marks in the form of burrows. The lower part of these shows sand layers parallel to undulatory laminations while the top part shows rippled beds. Surface trails are also observed. The third unit is represented by grey siltstone alternating with fine sand layers which are intensely bioturbated. A few centimetres thick fine sand layers are intercalated in this unit. Some of the thicker sand beds represent amalgamated layers showing internal erosional surfaces. The next succeeding unit is grey siltstone alternating with rippled fine sand. This unit overall shows low degree of bioturbation, though a few intensely bioturbated layers do exist. This shaly-silty sequence is topped along a sharp contact by 5m to 10m thick low angled festoon cross-bedded clean quartzarenite with a thin horizon of rippled bed. This shale-quartzarenite cycle is repeated five to eight times (Fig.2.44). Each succeeding cycle is thinner and is coarser grained as compared to the underlying cycle, till it is overlain by the Ganmachidam Formation.

The shale is thinly laminated to fissile, specially in the upper part. In the Mardang *Nala* section, shale in upper part of the Po Formation contains cherty nodules, one to eight centimetres size, enclosing pyrite and also pyritised nautiloid, orthoceratid, *Fenestella* (Fig.2.46), *Pleurotomaria* and crinoid. The dark shale at most of the places is pyritous.

Near Tabo, on foot track to Angla, the Po Formation contains plant fossils. Plant remains are also known near Losar (Ranga Rao *et al*, 1987) and at Shalkar and Thibda (Bassi, 1988a) (Fig.2.47). The plant bed at Tabo is followed by a bed full of *Skolithos* filled with ferruginous material. On the basis of the presence of plants in the basal part, Hayden (1904)

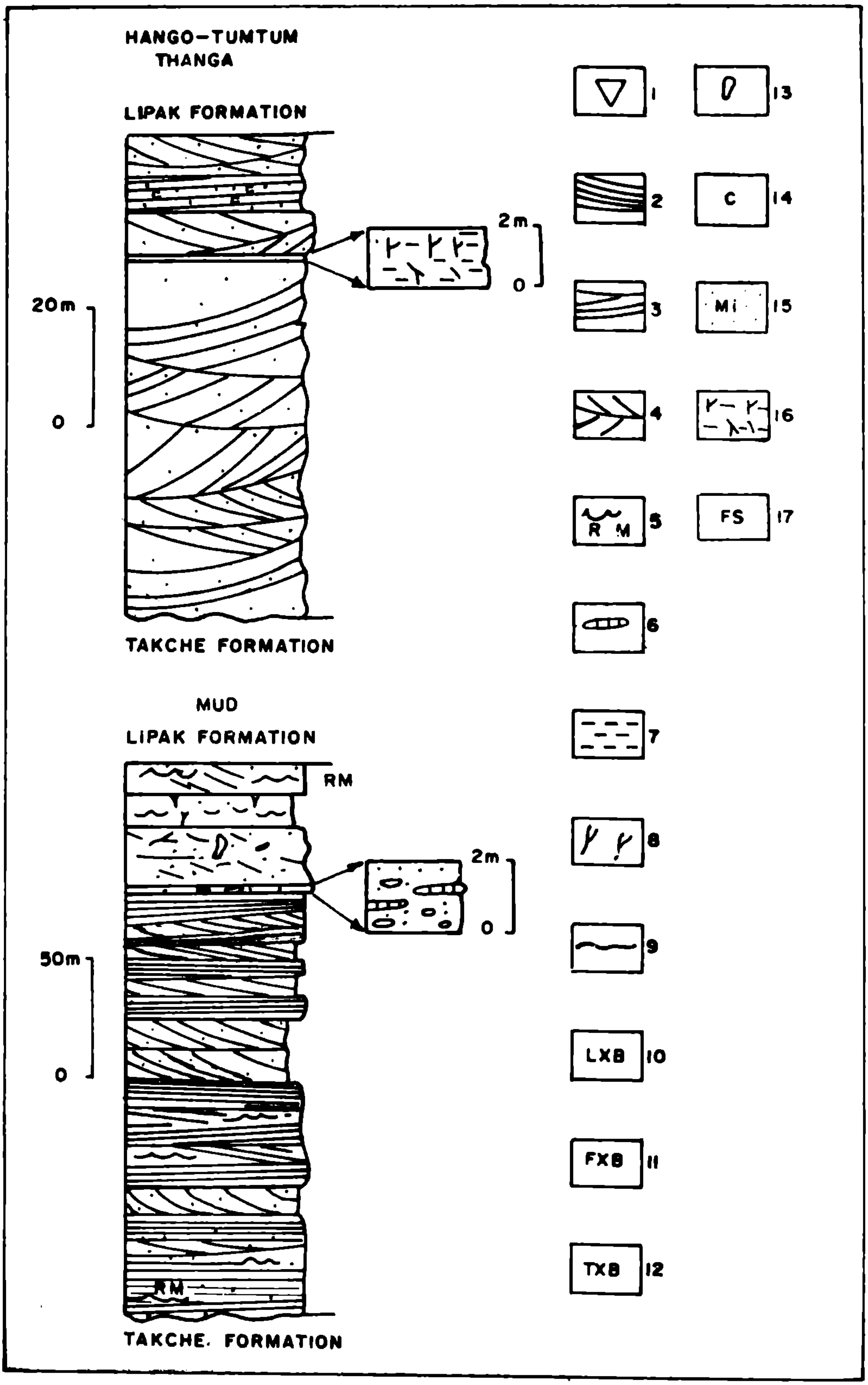


Fig. 2.39. Lithologs of the Muth Formation. Index same as for Fig.2.38

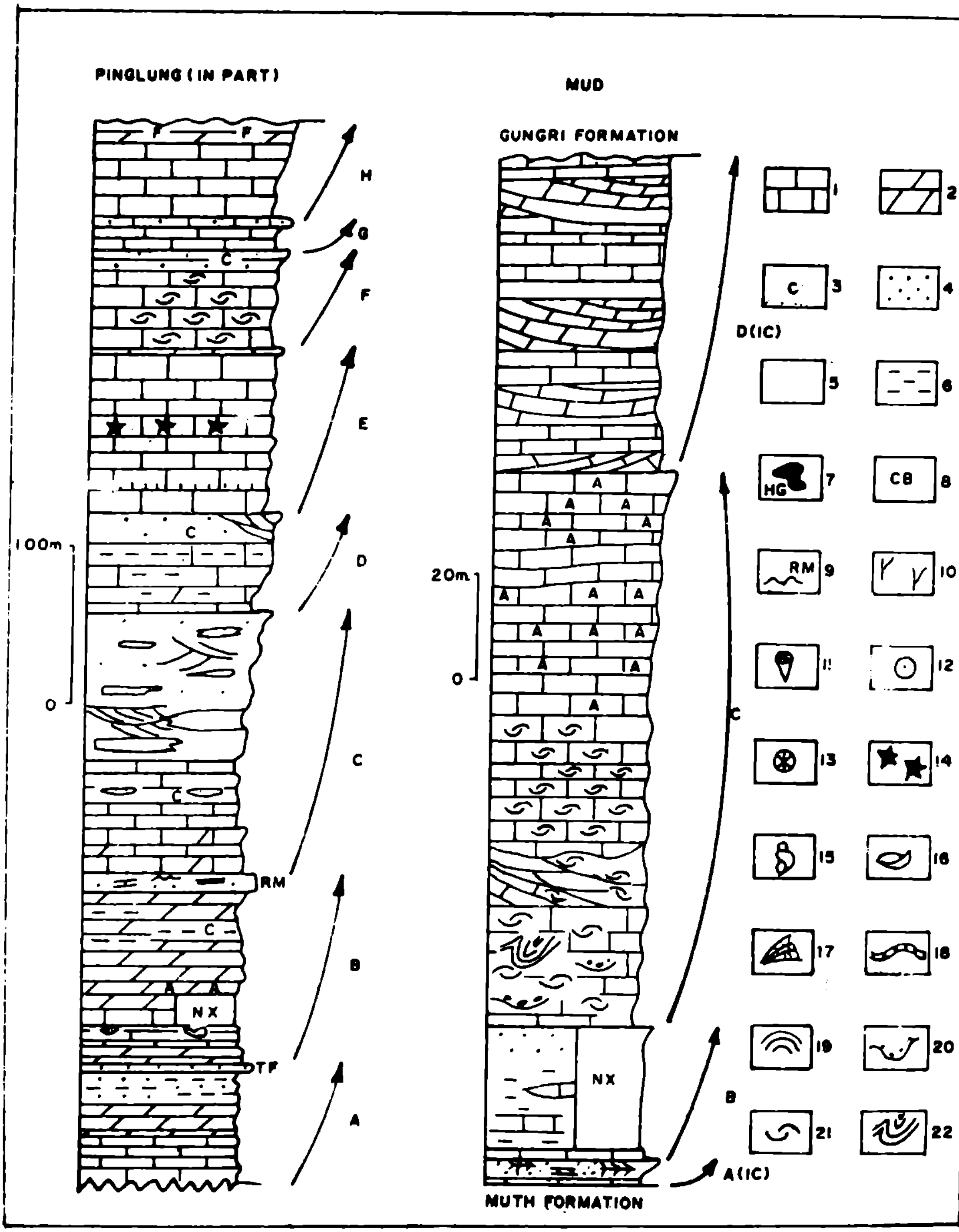


Fig. 2.40. Lithologs of the Lipak Formation. Expl: 1. Limestone, 2. Dolomite, 3. Calcareous component, 4. Sandstone, 5. Siltstone, 6. Shale, 7. Hardground (HG), 8. Cross-bedding, 9. Ripple mark, 10. Bioturbation, 11 and 13. Solitary corals, 12. Oolite, 14. Crinoid, 15. Gastropods, 16. Brachiopods, 17. Branching/colonial corals, 18. Algal bedding, 19. Stromatolitic structures, 20. Channel and lag, 21. Shell hash/coquina, 22. Syn-depositional slumps, 23. Trace fossils, 24. Bird's eye structures, 25. No exposure, 26. Silty limestone, 27. Argillaceous limestone, 28. Incomplete cycle, 29. *Hexagonaria*, 30. *Lithostrotion* and 31. Thamnoporid. (23 to 31 given in Fig.2.41).

subdivided the Po Formation into the lower 'Tabo Plant Stage' and upper 'Fenestella Stage' Lithologically, however, there is no distinction between the two.

The Po Formation, in its upper part, shows sporadic presence of pebbles at several levels. Gradually the frequency of the clasts increases and this formation grades into the overlying Ganmachidam Formation. Such a sequence is well developed in the Pomorang and Kurig sections.

The Po Formation, northeast of the More Plain Fault, is thermally metamorphosed and shows development of biotite.

There is no measurable section exposing the entire sequence of the Po Formation. A few partial sections are presented in Fig 2.50 and Appendix-VII.

The trace fossils *Asteriacites* (Fig.2.48), *Aulichnites* (Fig.2.49), *?Cochlichnus* (Fig.2.51), *Gyrochorte*, *Phycodes*, *Planolites*, *Rusophycus*, *Rhizocorallium*, and *Skolithos* have been recorded from the Po Formation. The body fossils known from the Po Formation are listed by Pascoe (1968). The plant fossil *Lepidosagillaria* (Fig.2.47) has been recovered from the Mardang *Nala*. Dhar *et al*, (1983) reported lepidendroid from Losar section. Jain *et al*, (1972) recorded several ostracode taxa from a dark grey limestone alleged to form part of the Po Formation of the Takche section. Neither the Po Formation contains any limestone nor is this formation exposed in the Takche section. Thus, the report by Jain *et al*, (1972) has not been considered by the present authors.

The Po Formation in NW and SE corners of the Spiti Valley has uniform thickness, whereas, its thickness decreases towards the central part, first gradually and then rapidly. For example, the thickness of 600m in the Na-Shalkar section, is reduced to a thin shale band at Liwa *Thach* (Lipak *Gad*) within a distance of about three kilometres. Towards east in Kinnaur, the Po Formation is not developed. The *Fenestella* Beds reported from the Kali River section by Mamgain and Misra (1989) may be the possible equivalents of this Formation in the Kumaon basin.

From Losar towards NW in Zanskar area, there is not only gradual reduction in thickness, but also prominent local variations in thickness. The Po Formation is developed only upto Thidsi in the Zanskar area.

The lower-middle part of the Po Formation, in the SE part of the Spiti Valley, is intruded by dolerite and olivine-dolerite transgressive sills varying in thickness from 1m to 25m with 0.5 km to 5 km lateral extent in the Thibda-Sumra-Shalkar-Po-Pomorang and Yidsizi-Kun-Kurmo areas. In the vicinity of these sills, shale of the Po Formation shows baking effect and specks of arsenopyrite.

Age : Though based on plant remains, Gothan and Sahni (1937) assigned a middle Carboniferous age to the Po Formation and the overall invertebrate fossil assemblage suggests a lower to lower middle Carboniferous age (Waterhouse, 1985).

2.3.3.D *Ganmachidam Formation*

The 'Permian conglomerate' of Hayden (1904) was renamed after the Ganmachidam Hill by Srikantia (1974, 1981). Better sections, however, are exposed at hill north of Poh and Pomorang. The Ganmachidam Formation is developed only in those sections where the Po Formation is present. In sections where the Po Formation is absent, the Ganmachidam Formation is also absent.

By and large the Ganmachidam Formation forms rugged topography. In aerial photo and also from a distance it is difficult to distinguish the Ganmachidam Formation from the underlying and overlying formations.

The Ganmachidam Formation is not wholly conglomeratic as its original name 'Permian Conglomerate' seems to suggest. It comprises pebble conglomerate (Fig.2.52), mudstone, pebbly siltstone, pebbly sandstone, conglomerate, sandstone and pale grey to brown shale alternations. All these lithounits being lenticular, the characters of this formation vary even in a small area. The conglomerate, too, has protean characters. Overall the sequence comprises cycles commencing with sandstone and ending in gritty/conglomeratic unit. Eight such cycles are recognisable in the Ganmachidam Hill. Like those of the Po Formation, each successive cycle within the Ganmachidam Formation is thinner and coarser grained as compared to the preceeding cycle.

Though Hayden (1904) described a perfect gradational and conformable sequence between the

Po and Ganmachidam Formation (*i.e.* the Permian conglomerate), the contact between these two was regarded as unconformable by Pascoe (1968) and Ranga Rao *et al*, (1987). Srikantia (1974, 1981), however, considered it as a terminal phase of the Po cycle of sedimentation having a normal stratigraphic contact. Ranga Rao *et al*, (1987) considered the Ganmachidam Formation (their Losar diamictites) to rest conformably over the Po Formation, but along a sharp contact. The observations in various sections during the present mapping reveal that in most of the sections (e.g. Ganmachidam, Mandaungsar, Po, Angla, upper reaches of the Yulang *Gad* and Kurig) the litho-units in the upper part of the Po Formation show presence of pebbles whose frequency gradually increases towards the stratigraphic top, providing almost a passage to the Ganmachidam Formation. This feature is best documented in the Kurig, Pomorang and upper reaches of the Yulang Valley. However, in the Sumkhel and Pare Valleys, the Ganmachidam Formation shows a sharp and abrupt contact with the Po Formation. Its upper contact with the Gechang Formation is sharp.

The clasts in the conglomerate of the Ganmachidam Formation vary in size from granule to cobble (rare) with 4-16mm pebbles being most common. The matrix:clast ratio varies from 30:70 to 40:60. The clasts are moderately sorted and mostly subangular to subrounded, though the rounded ones are not uncommon. The roundness is around six and sphericity between four and six (Power's Scale, 1953). In general, granule forms 35%, pebble 63% and cobble about 1-1.5%. The clasts are of grey sandstone (21-51%), white sandstone (13.8-22.50%), brown sandstone (0.75=1.9%), grey limestone (7.6-19.6%), black shale (4.5-9%), granite (0.75-2.9%), and vein quartz (1.5-2%). 32-62mm clasts are mostly composed of white sandstone and sporadically of green sandstone, shale and limestone. 16-32mm size clasts are of white, purple, grey green sandstone, clasts smaller than 16mm are represented by all the rock types enumerated above. The sandstones are of two types, gritty sandstone and lithic wackes. The sequence of this formation, as exposed in various sections, is illustrated in Fig.2.60 with details in Appendix-VIII.

The Ganmachidam Formation, exccept for ill-preserved fossils is, by and large, unfossiliferous.

The Ganmachidam Formation, as stated earlier, is present only in the sections where the Po Formation is also present. In the Spiti area accordingly, it has best exposures in NW and SE corners and also in the Lingti-Sumkhel-Pare Valleys in NE. In eastern Kinnaur and Kumaon areas, it is totally absent. Towards NW, in Zanskar, the Ganmachidam Formation extends up to Thidsi.

Age : This formation was assigned a Lower Permian age by Hayden (1904) and Ranga Rao *et al*, (1987), whereas, Srikantia (1981) considered it to be of Upper Carboniferous age. The upper age limit of the underlying Po Formation is certainly late lower Carboniferous, if not younger, whereas, the basal part of the overlying Gechang Formation has yielded *Eurydesma cordatum* (Srikantia *et al*, 1978b), *E. manendragarhensis* and *E. hasdoensis* (Bhargava *et al*, 1985a) of Asselian age. The unfossiliferous Ganmachidam Formation, thus, is likely to represent mainly middle to late Carboniferous age possibly extending into early Permian also.

2.3.4 Kuling Group

The term Kuling was originally proposed by Stoliczka (1865) and later revived by Hayden (1908) as Kuling System. It was redesignated as the Kuling Formation by Srikantia (1981). In view of different and distinct lithologic units within the Kuling 'Formation' and their proved mappability, it is proposed to raise it to a group level. This group is divisible into the Gechang and Gungri Formations.

2.3.4.A *Gechang Formation*

This name was proposed by Srikantia (1974, 1981) after a village in the Parahio Valley for a sequence described as 'Calcareous Sandstone' by Hayden (1904). The Gechang section, however, is least representative of this Formation. Its best sections are exposed in the Lingti Valley, around Lalung village, along the left bank of the Spiti River between Poh and Tabo, Khimokul *La* and in the Ratang Valley. The Gechang Formation, together with the Ganmachidam Formation, form steep slope and is indistinguishable from the latter from a distance and in aerial photos. It comprises light brown to grey, pale grey, mostly coarse grained to calcareous cross-bedded sandstone with local 5-20 cm thick conglomerate at the base as lag (Fig.2.53) and locally shale towards top (*e.g.* Poh and Pomorang, 10m thick). Slightly above the base, it invariably encloses coquina bands which, when coarse (Fig.2.54), form a sort of basal lag. Commencing from lag at base it shows coarsening-up sequence and then in some sections followed by fining-up sequence.

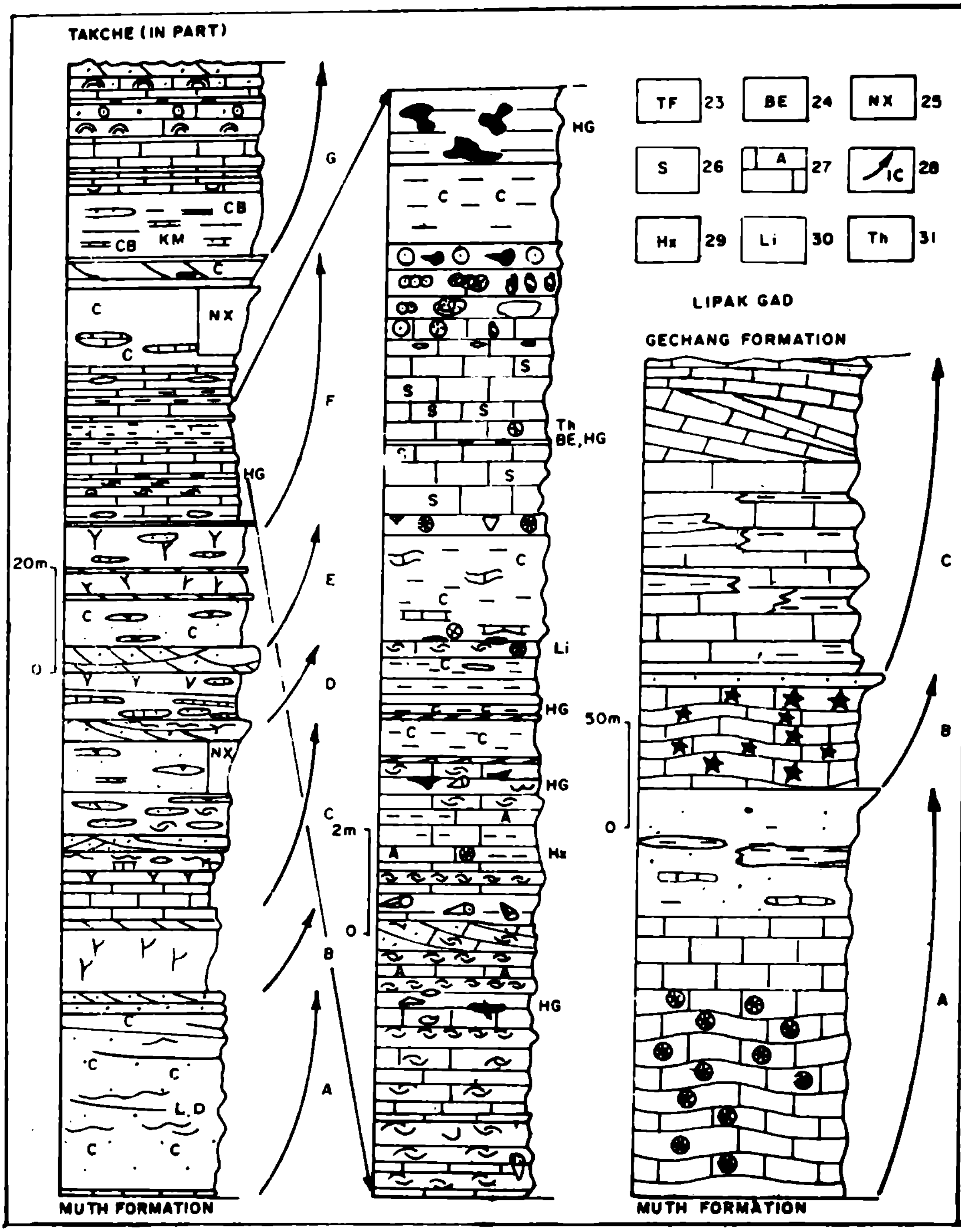
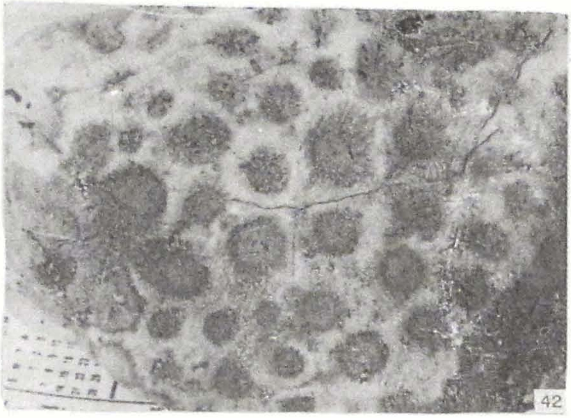
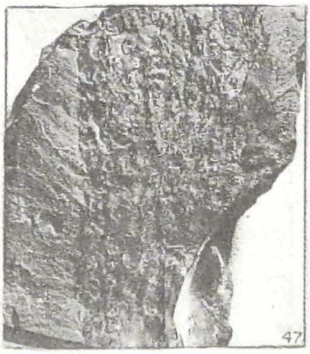


Fig. 2.41. Lithologs of the Lipak Formation. Index same as for Fig.2.40.

Figs.2.42 – 2.49





Explanation of Figs. 2.42 - 2.49

Fig. 42. Coral Lithostrotion colony, Lipak Formation. Takche section. **Fig. 43.** Slide print of a wackestone showing *Tentaculites*. Loc. Yulang Valley. **Fig. 44.** Hill opposite Losar showing sandstone-shale alternation of Po Formation in lower part succeeded by the Ganmachidam, Gechang, Kuling (dark) and Lilang Group (light coloured in upper part), the precipitous part is constituted of the Kioto Formation. **Fig. 45.** A prograding cycle ends with a sandstone and is followed by another cycle with clay-shale bed which coarsens up terminating into siltstone-sandstone bed at the Ganmachidam Hill. **Fig. 46.** *Fenestella* in shale of the Po Formation. **Fig. 47.** *Lepidosaggilaria* sp. Po Formation. Loc. Thibda. **Fig. 48.** *Asteriacites* (resting trace of starfish), Po Formation. Loc. base of Ganmachidam Hill. **Fig. 49.** *Aulichnites* with *Planolites* and *Skolithos*, Po Formation. Loc. Ganmachidam Hill (Bar scale is 1 cm).

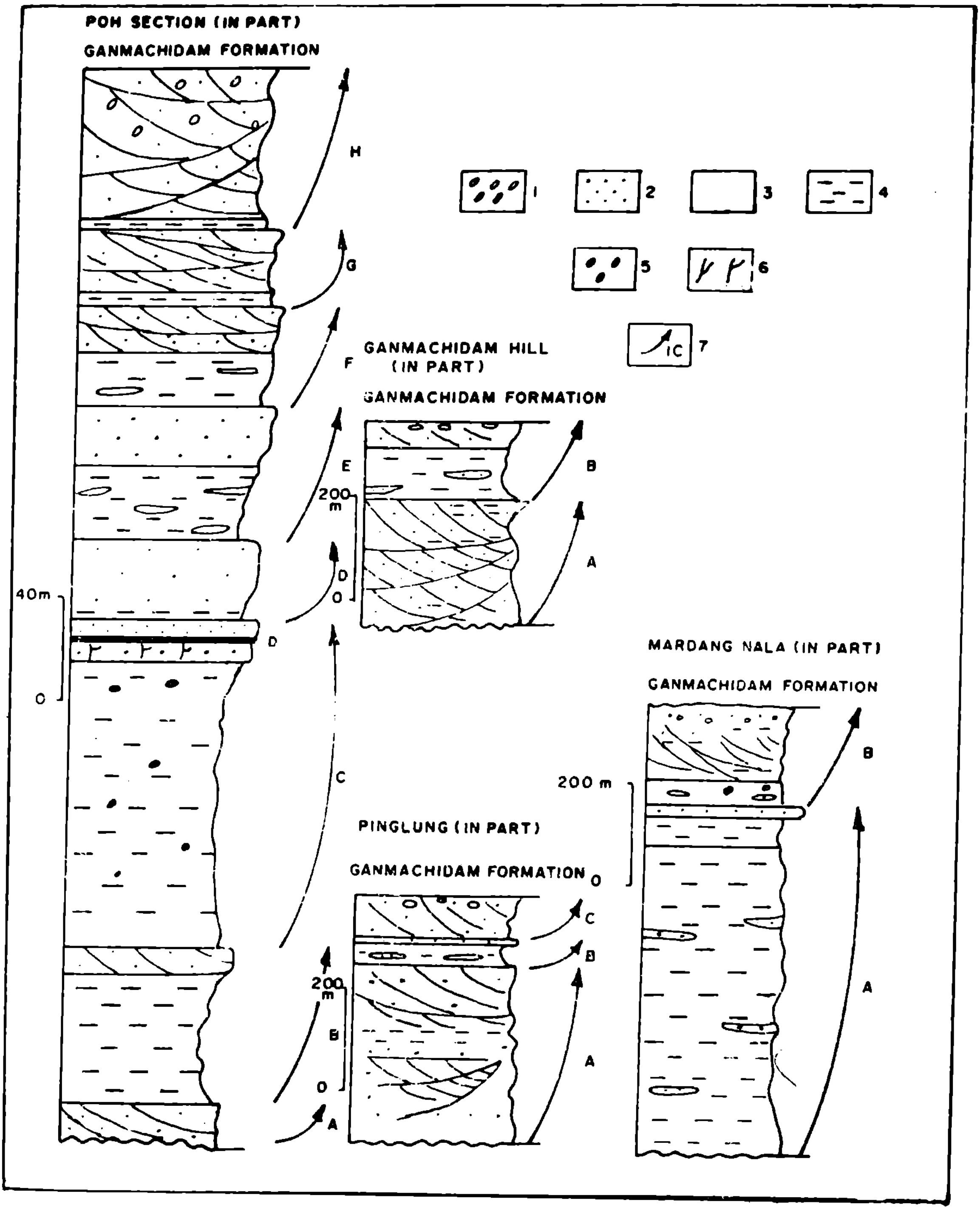


Fig. 2.50. Lithologs of the Po Formation. Expl: 1. Pebbles - grit - conglomerate, 2. Sandstone, 3. Siltstone, 4. Shale, 5. Nodules enclosing fossils, 6. Bioturbation in Dolomitic Sandstone, A-B etc. Sedimentary cycles, I.C. Incomplete cycle.

The lower contact of the Gechang Formation with the Ganmachidam Formation, specially where it is conglomeratic at base, looks apparently gradational.

However, the conglomerates of the Gechang Formation are mostly clast supported and their matrices are cleaner in contrast to the Ganmachidam whose conglomerates are mostly muddy and matrix supported. In sections where the Ganmachidam Formation is absent (in such sections Po Formation is also absent), the contact of the Gechang Formation with the underlying Lipak, Muth or Takche Formations is abrupt and unconformable. Its upper contact with the overlying Gungri Formation is also sharp, abrupt and most possibly unconformable (Gaetani *et al*, 1990; Bhargava *et al*, 1991b). The uppermost beds of the Gechang Formation are crowded with vertical burrows (Fig.2.62). Details of its succession in various sections are given in Fig.2.61 and Appendix-IX.

In addition to the fossils check-listed by Pascoe (1968), Srikantia *et al*, (1978b) recorded *Eurydesma cordatum* and *Deltopecten*. Bhargava *et al* (1985a) reported *Eurydesma manendragarhensis* and *E. hasdoensis* and Chopra *et al*, (1980) discovered coral *Waagenophyllum*. *Eurydesma cordatum* (Fig.2.55-56) has been found at Liwa *Thach* 12m above the base of the Gechang Formation. *Neospirifer* (Fig.2.57) was recovered from the upper part of this formation exposed in the Khimokul *La* section.

The thickness of the Gechang Formation varies from five metres in Kidul to about 150m in the Ratang *Nala*. In some sections of Spiti and Kinnaur, the Gechang Formation is totally absent. In Zanskar, according to Srikantia *et al*, (1978a), wherever the Phe Volcanics are developed, the Gechang Formation is absent. Gaetani *et al*, (1990), however, report the Chumik Formation (≡Gechang Formation) in the Zanskar area which is associated with the volcanics.

Age : With *Eurydesma* (Fig.2.55-56) in basal part and *Waagenophyllum* near top, the Gechang Formation is interpreted to range in age from Asselian to Sakmarian, possibly extending to early Artinskian also.

2.3.4.B *Gungri Formation*

Named after the Gungri village near Pin-Parahio confluence (Srikantia, 1974, 1981), this sequence was originally described as the Productus Shale (Hayden, 1904). It forms a subdued gentle topography and due to black colour is easily identified in field from a distance and also in the aerial photos (Fig.2.36).

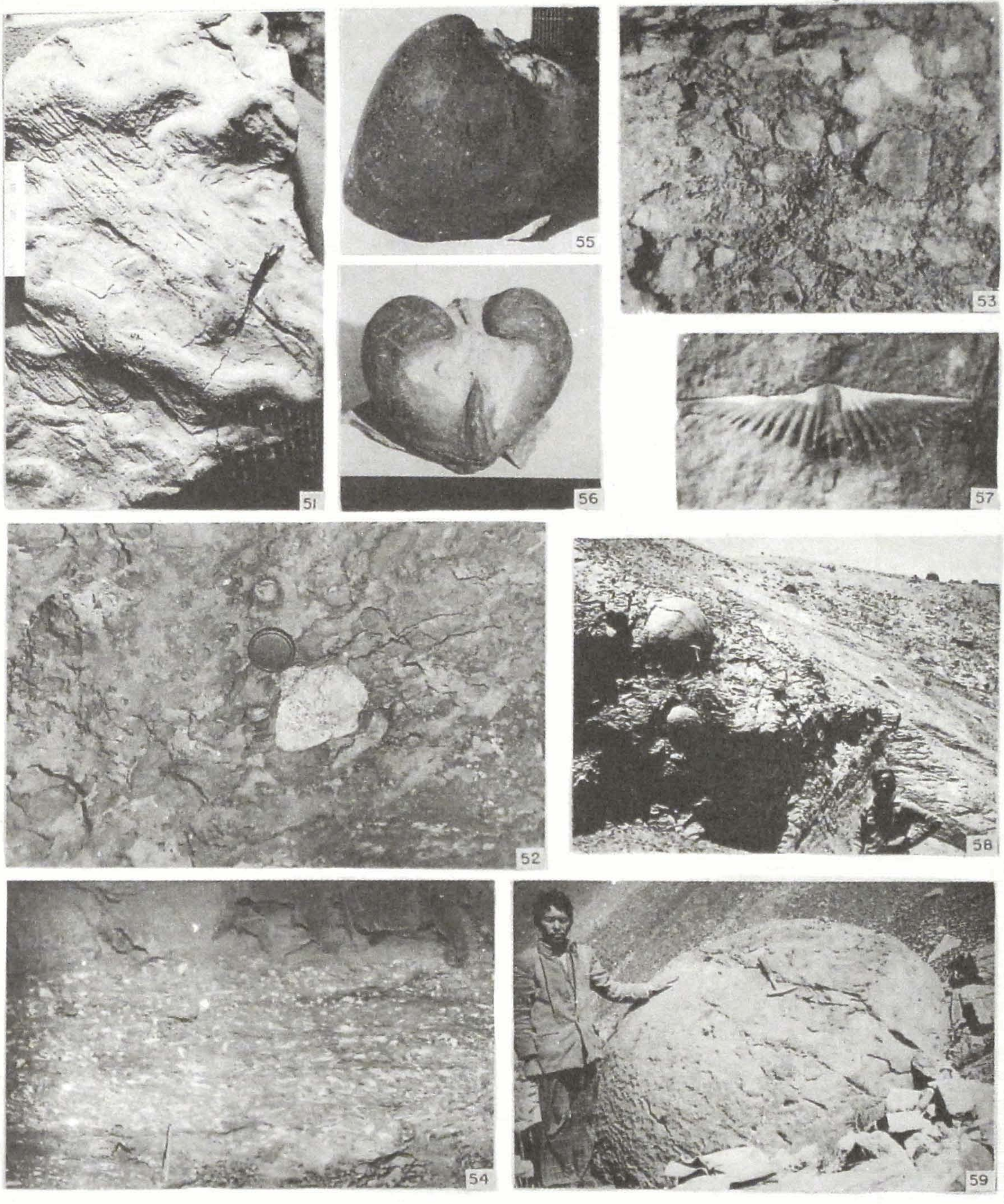
The Gungri Formation mainly comprises black, calcareous, silty shale and shale, phosphatic, cherty and calcareous nodules with 0.5cm to more than 100cm diameter (Fig.2.58-59), thin siltstone and coquina limestone lenses. Some of the nodules enclose fossils. The cherty nodules are largely phosphatic. The silty shale mostly occurs in the basal part, whereas, the upper part is made up of shale. The transition zone from silty-shale to shale is characterised by *Zoophycos* (Fig.2.67) in several sections (Bhargava *et al*, 1985b). The sequence includes millimetre to centimetres thick shaly siltstone and calcareous siltstone intercalations. Overall, the Gungri sequence shows two to three cycles coarsening upward.

As stated earlier, the lower contact of the Gungri Formation with the Gechang Formation is sharp. In the Kinnaur area, at Jongchen, the Gungri Formation rests over the eroded surface of the Muth Formation, the former filling up the eroded portions. The upper contact of the Gungri Formation with the Mikin Formation (Lilang Group) looks apparently conformable. However, at the base of the Lilang Group occurs a 0.5-1.5cm thick ferruginous bed (silty shale) with more or less sharp boundaries with both the underlying and the overlying rocks (Fig.2.63). This band was interpreted by Bhatt *et al*, (1977) to represent a sub-aerial break. On the other hand, Bhargava (1987) considered it to signify a sub-marine hiatus. This question may be kept open at this stage.

The lithostratigraphic details of this formation in various sections are given in Fig.2.65-66 and Appendix-X.

The Gungri Formation is the most persistent stratigraphic horizon in the Spiti and Kinnaur areas. In most of the sections of Spiti, this formation maintains a thickness between 35-50m. However, it is 25m near the Hangrang Pass. In the Kinnaur area, where it generally rests unconformably over the Muth Formation, great variation in its thickness is noticed. The thicknesses are markedly less towards north. Near Jongchen (Gyamthing Valley), it is barely five metres. Towards east in the Kumaon area also, the Gungri Formation is extensively developed. It is observed throughout the Zanskar area where it rests over the Phe Volcanics and is mostly very thin

Figs. 2.51 – 2.59



Explanation of Figs. 2.51 - 2.59

Fig. 51. ? *Cochlichnus*, Po Formation. Loc. Na Dogri. **Fig. 52.** Pebble conglomerate enclosing a granite pebble, Ganmachidam Formation. Loc. 100m east of Staging Hut, Chango. **Fig. 53.** Conglomerate forming basal part of the Gechang Formation at Gungri. **Fig. 54.** Coquina lag at the base of the Gechang Formation. Loc. Lalung. **Fig. 55-56.** *Eurydesma cordatum*, Gechang Formation. Loc. Liwa Thach, 55. side view, 56. top view. **Fig. 57.** *Neospirifer* sp. Gechang Formation. Loc. Khimokul La section. **Fig. 58-59.** Nodules in the Gungri Formation. 58. At downstream of Atargoo, 59 at Jongchen. (Bar scale in 2cm).

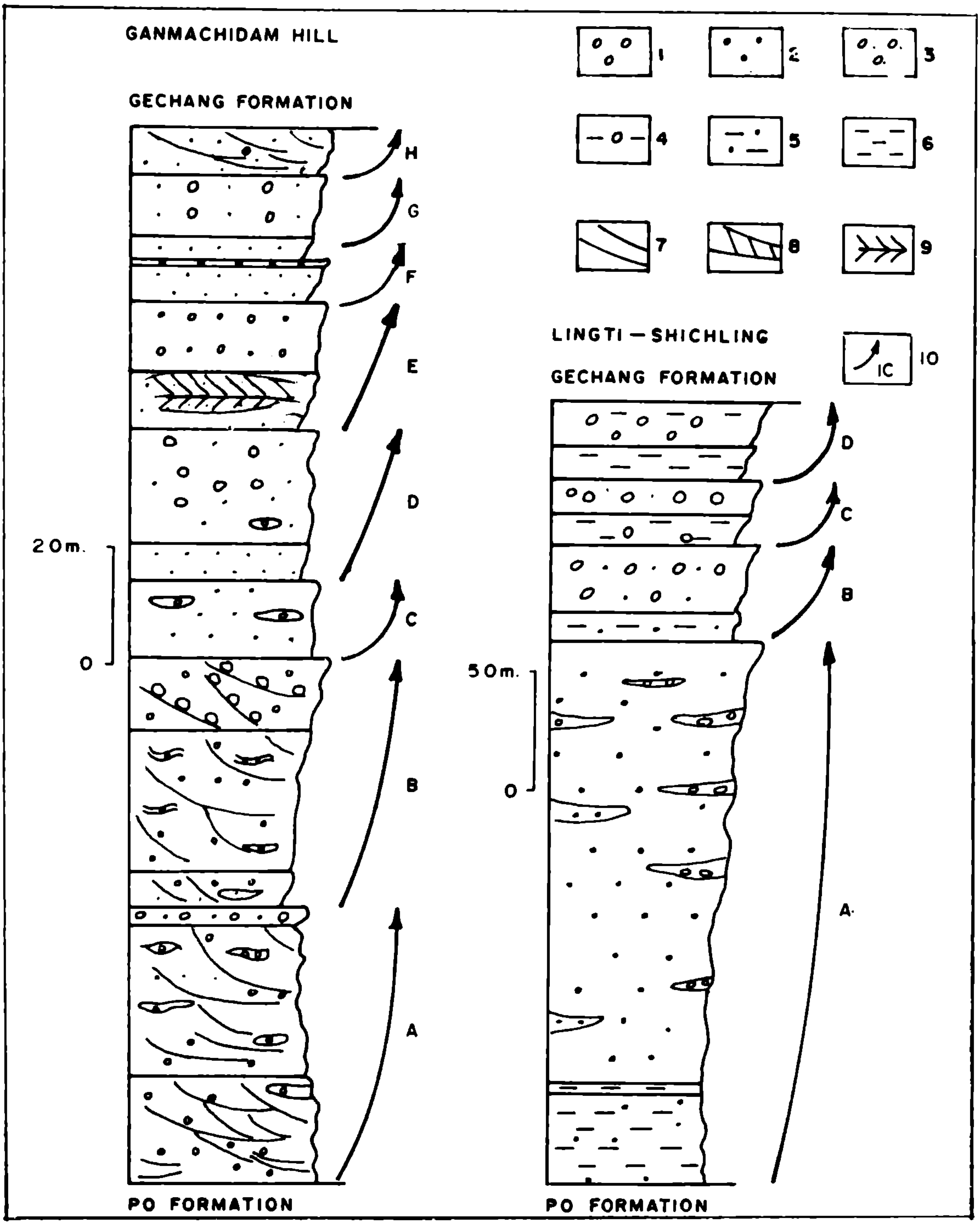


Fig. 2.60. Litholog of the Ganmachidam Formation. Expl: 1. Conglomerate, 2. Grit, 3. Gritty sandstone, 4. Shale with a few pebbles, 5. Gritty shale, 6. Shale, 7. Cross-bedding (unclassified), 8. Torrential cross-bedding and 9. Herringbone cross-bedding. A - H Sedimentary cycles.

and contains thin calcarenite bands. The limestone beds reported by Ganesan *et al*,(1981) in the Kuling Formation are considered as the tectonic slices of the Lilang Group (personal communication S.V. Srikantia). Similarly, the Triassic of Frank *et al*, (1977) in the Indus Suture Zone, according to S.V. Srikantia, is mostly Gungri rocks tectonically involved within a schuppen zone.

Age : The fossil assemblage of the Gungri Formation suggests an age ranging from Djulfian to a part of Dorashmian. The uppermost Dorashmian elements have not been reported so far.

The age analysis of the Gechang and the Gungri Formation indicates absence of Kungurian to Midian, thereby suggesting a break between the Gechang and the Gungri Formations (Gaetani *et al*, 1990; Bhargava *et al*, 1991b).

2.4 MESOZOIC

2.4.1 Lilang Group

A thick and mainly a carbonate rich sequence was named by Stoliczka (1865) as the Lilang System after the village of the same name (spelt as Lalung in the modern toposheet) in the Lingti Valley. It was subdivided into nineteen biostratigraphic subdivisions by Diener (1912, 1915). The term Zangla suggested by Nanda and Singh (1976) for the Lilang sequence is superfluous. Srikantia (1974, 1981) redesignated it as the Lilang Group and subdivided it broadly into five formations of unproven mappability. The names suggested by Srikantia (1974, 1981), save Alaror, could not be adopted for the reasons stated in the introduction. During the present mapping, it has been possible to divide the Lilang Group into nine units (Bhargava, 1987), all of which are mapable in large part of the area on 1:50,000 or 1:100,000 scale. These do not coincide with the subdivisions suggested by Srikantia (1974, 1981). The formations adopted here have been mapped all over the Spiti Valley (Bhargava, 1987), but not differentiated in the Kinnaur area, where mapping had preceded that of Spiti. Description of these formations is as follows:

2.4.1.A *Mikin Formation*

This is the oldest diagnostic lithounit of the Lilang Group, named after a village in the Parahio Valley, where its excellent section is exposed. It is ubiquitously well-developed specially near Guling, north of Lalung village, on the right bank of the Lingti, north of Poh, Tabo, in the Pinglung Valley and north of Mandaungsar.

It forms a steep topography over the gentle slopes of the Gungri Formation and can be recognised from a distance (Fig.2.64 and 2.73). However, due to distortion caused by steep topography, this formation is not always decipherable in aerial photos. The Mikin Formation represents the biostratigraphic zones of *Otoceras*, *Ophiceras*, *Meekoceras Zones*, *Hedenstroemia* Beds, Basal Muschelkalk, Nodular Limestone, Lower Muschelkalk and Upper Muschelkalk.

Below the Gungri-Mikin contact occurs 1 to 15cm thick ferruginous bed having sharp contacts with both the underlying and overlying rocks(Fig. 2.63).

The Mikin Formation is made up of thick to medium bedded, grey to dark grey dolomite, which is cherty at places. Dark grey to ash grey, cherty shales having limited strike continuity are sporadically present in the sequence. The sequence shows sedimentary cycles commencing with pure carbonate and ending in a carbonate-shale unit. A network of ferruginous veins along and across the bedding, imparting a nodular character, is the most diagnostic feature of this formation (Fig.2.68). Nodular and wavy bedding, sporadically minor subaqueous slumps and ophiceratids shells (Fig.2.69) are prominent features of this formation. It has disconformable and conformable contacts with the underlying Gungri Formation and the overlying Kaga Formation respectively.

The lithological details of the Mikin Formation in the Lalung section are furnished in Fig. 2.76a and Appendix-XI.The Mikin Formation is uniformly developed in Spiti and Kinnaur. Its extension in Zanskar has not yet been established, though rocks having similar stratigraphic position and microfacies are known from Kumaon

The following conodonts, foraminifers and ostracodes have been recorded from this Formation:

Conodonts[^] : *Anchignathodus cf. typicalis Sweet*[1], *Celsigondolella watznaueri* **Kozur**[2] *Cratognathodus kochi* **Huckriede**[2], *Cypriodolella mulleri*[2], *C.scolosculpture*[2], *Diplododella sp.*[1], *D. magnidentata*[2], *Ellisonia triassica* **Muller**[1,2], *Ellisonia gradata* Sweet[1], *E. nevadensis* **Muller**[1], *E. teicherti* **Sweet1**[2] *Enantiognathus ziegleri*[2], *Gladygondolella tethydis*[2], *Hadrodontia sp.*[2], *Hibbardella of subsymmetria Muller*[1], *Hindeodella (Metaprionoides)* *spengleri*[2], *H. (M). petraevirdis*[2], *H. (M). multihamata, H.(M). suevica*[2], *H. (M). pecteniformis*[2], *Lonchodina sp.*[1], *L. hungarica*[2], *L. aequiarcuata* **Muller**[1], *L. posterognathus*[2], *L. mulleri*[2], *Neogondolella planata*[3], *N. carinata*[1,3], *N. navicula*[2,3], *N. mombergensis*[3], *N. constricta*[2], *N. steinbergensis*[2], *N. bifurcata*[2], *N bulgarica*[2], *N. jubata*[2], *N. shoshoensis*[2], *N. prekummeli*[4], *Neohindeolella nevadensis*[2], *Neospathodus dieneri*[1,3], *N. novaehollandites*[3], *N. labiatus*[2,3], *N. spitiensis*[3], *N. waageni*[2,3], *N. Ozarkodina tortillis*[2], *Paragondolella sp.*[2], *P. timorensis*[3], *N. kummelli* Sweet[1], *N. kristagalli* Huckriede[2], *N. descritus*[2], *N. kockel*[2], *N. pakistanensis*[2], *N. homeri*[2], *N. triangularis*[2], *N. jhelumi*[2], *N. srivastavai*[2], *N. germanicus*[2], *N. spathi*[2], *excelsa*[2], *Platyvillosus costatus*[2], *Prioniodella prioniodellides* Tatge[1], *Prioniodella sp.*[2], *P. ctenoides*[2], *P. aff. prona*[2], *P. excavata*[2], *P. magnidenta*[2], *P. mulleri*[2], *P. spengleri*[2], *Roundya A*[2], *Roundya B*[2], *Roundya C*[2], *Roundya D*[2], *Roundya mebneri*[2], *Spathognathodus Sp.*[2], *Xaniognathus curvatus Sweet*[1], *X. deflectens* Sweet[1].

Foraminfera[B] : *Ammobaculites inconspicua* Cushman and Waters[1], *A. radstadensis* Kristman-Tollamn[2], *Ammodiscoides sp.*[3], *Ammodiscus erugatus* Crespin[1], *A. parapriscus* Ho[2], *Ammodiscus sp.*[1,3], *Ammovertella sp.*[3], *A. labyrintha sp.* Ireland[1],

A..prodigalis Ireland[1], *A. undulata* Galloway and Harltan[1], *Bathysiphon sp.*[3], *Bolivina lathetica* Tappan*l*, *Citharinella chapmani* Marie[1], *Dentalina bucculenta* Schwager[1], *D. cassiana* Gumbel[1], *D. collisa* Schwager[1], *D. kornyephora* Gumbel[1], *Earlandinita sp.*[1], *Frondicularia sp.*[1], *Glomospira sp.*[3], *Glomospirella sp.*[3], *Lituotuba sp.*[1,3], *Lituotubella glomospiroides* Rauser-Cernousova, *Meandrospira sp.*[2], *Nodosaria cushmani* Paalzow[1], *N. decoris* Crespini[1], *N. bambusa* Chapman[1], *N. crassula* Crespin[1], *Schizaminna sp.*[1], *Uzbekistania sp.*[3].

Ostracodes[C] : *Bairdia sp.*[1,2], *B. mesotriassica* Goel *et al*[1,2], *B. mocki*[1], *Hungarella sp.*[2], *Hungarella ussuriensis* Gramm[1], *Paraberounella oertillii* Kozur[1], *Patellacythere spitiensis* Goel *et.al*,[1].

Age: The fossil assemblage suggests an age ranging from Scythian to Anisian for the Mikin Formation.

2.4.1.B *Kaga Formation*

This formation is named after the stream Kaga, a tributary of the Parahio River, where it shows excellent lithologic and faunal development. Good sections are also exposed along the right bank of the Lingti river, north of Lalung and Angla villages. In between the precipitous slopes constituted of the Mikin and Chomule Formations, the Kaga Formation forms gentle topography (Figs.2.64, 2.70, 2.73). On account of earthy colour on weathered surface and softer topography, it is recognisable from a distance and also on aerial photos. It has an intercalated and gradational contact with the Mikin and Chomule Formations respectively.

The Kaga Formation is constituted of light to dark grey, green calcareous shale and sporadic thin lenticular beds of grey limestone and dolomite. The shale and carbonate alternation constitutes a cycle. There are several cycles of shale-carbonate alternations. This formation is rich in cephalopod fauna. In the Kaga section, the cephalopods (Bhargava *et al*, 1984d) occur as 'organic dropstone' crowded along limestone-shale interface in the basal beds (Fig.2.71). The lithologic composition of the Kaga Formation in the Lalung section is depicted in Fig. 2.76b with details given in Appendix-XII.

The Kaga Formation is well developed throughout the Spiti Valley. In eastern Kinnaur too, it is consistently developed and well exposed in the Tidong and Gyamthing Valleys and on the Dunthi Peak in the Baspa valley. Its mapping so far has not been extended in the Lahaul-Zanskar area.

Age : The Kaga Formation corresponds to the *Daonella* Shale biostratigraphic horizon, which is regarded to be of Ladinian age (Diener, 1912).

2.4.1.C *Chomule Formation*

Named after a locality along the left slope of the Spiti Valley, near Tabo, this formation shows good development throughout the valley, specially along the left bank of the Lingti, opposite Lalung village and the left bank of the Pin-Parahio, opposite Guling village. It corresponds to the biostratigraphic subdivisions of the *Daonella* Limestone and *Halobia* Beds (Diener, 1912). Throughout the area this formation forms precipitous slopes (Fig.2.64, 2.67, 2.74) and is easily identifiable from a distance (Fig.2.77). It has a conformable contact with the Sanglung Formation.

[A] (1 . Bhatt and Joshi, 1978b; 2. Bhargava and Gadhoke, 1988; 3. Goel, 1977; 4. Bhatt *et al*, 1981b) . [B] and [C] (1. Goel *et al*, 1981; 2. Bhargava and Gadhoke, 1988; 3. Bhatt and Joshi, 1978b).

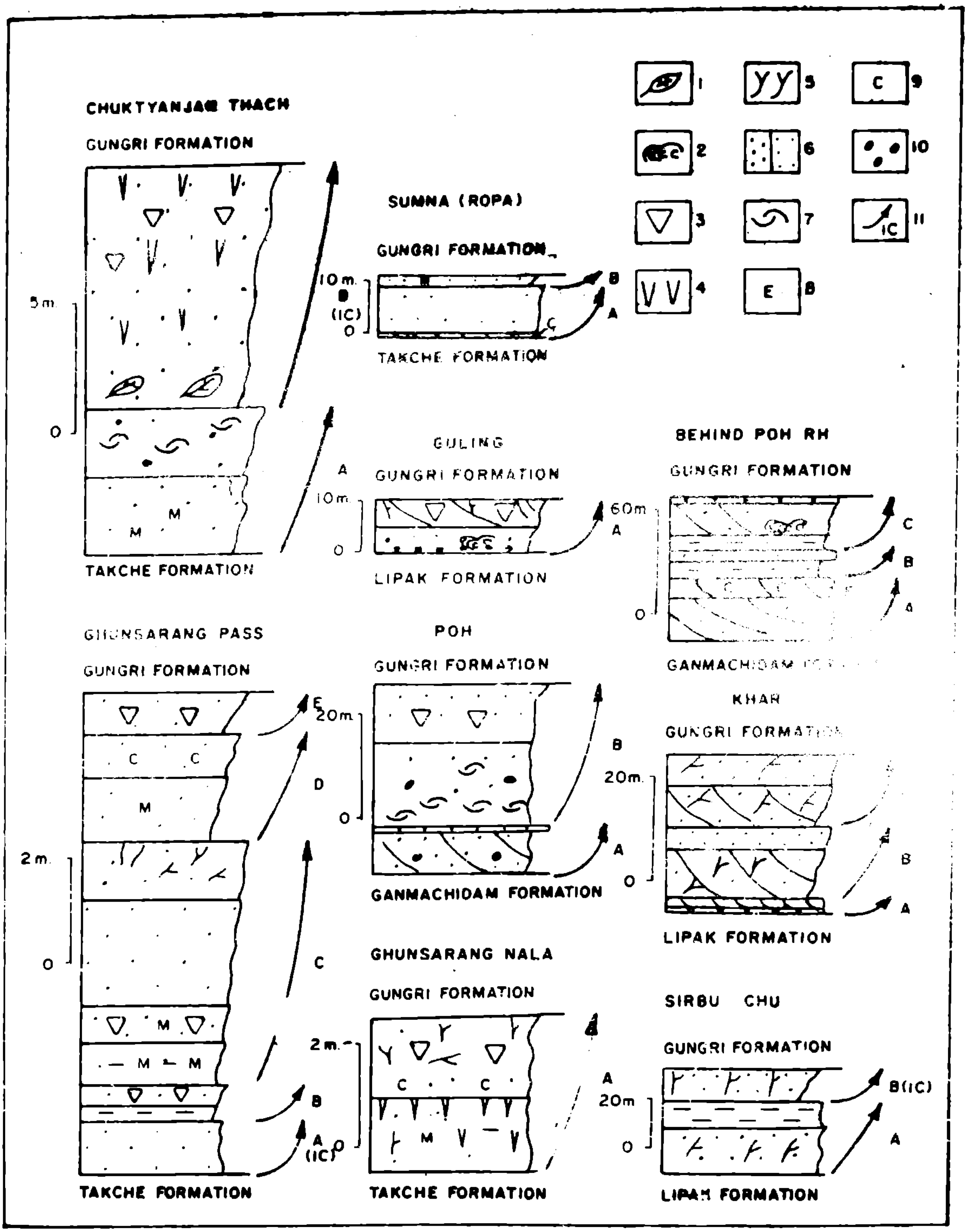


Fig 2.61. Litholog of the Gechang Formation. Expl: 1. Plant fossil, 2. *Zoophycos*, 3. Brachiopod, 4. Skolithos, 5 Bioturabtions/burrows, 6. Sandstone/M-micaceous, C-calcareous, E.Eurydesma. I.C. Incomplete cycle. Arrows indicate sedimentary cycles.

Figs. 2.62 – 2.64

Explanation of Figs. 2.62 - 64

Fig. 62. Vertical burrows along the upper surface of the Gechang Formation. Loc. Gungri. **Fig. 63.** A ferruginous band along the Gungri-Mikin contact. Loc. Lingti (Atargoo) section. **Fig. 64.** A view of a part of the Lilang Group opposite Lalung village. Lower most steep faced beds are of the Mikin Formation, followed by the gentle sloped Kaga Formation. The steep slope above it is of the Chomule Formation followed by the A - C Members of the Sanglung Formation. (Bar scale is 4 cm).

The Chomule Formation comprises evenly bedded (Fig.2.72), light grey dolomite in the basal part and dark grey dolomite in the upper with local subordinate calcareous shale and marl. The uniform bedding thickness, nodular and wavy beddings and large subaqueous slumps (Fig.2.74-75) are characteristic features of this formation. There are four to five sedimentary cycles commencing from pure carbonate and terminating into shale or argillaceous carbonate. Some of the cycles are incomplete and truncated by the next cycle. The detailed lithology of this formation in the Lalung section is furnished in Fig. 2.76c and Appendix-XIII. In view of discovery of abundant radiolarian and calcispheres remains (Bhargava and Gadhoke, 1988) in samples around 14m above its base, it is necessary that the entire Chomule Formation be closely sampled for micropalaeontological studies.

The Chomule Formation more or less maintains its thickness throughout the Spiti Valley and is consistently developed in the Gyamthing Valley on a spur two kilometres east of Manchap *Thach* and on the Dunthi Peak in the Baspa Valley.

Age : The Chomule Formation corresponding to the *Daonella* Limestone and *Halobia* Beds is interpreted to range in age from late Ladinian to early Carnian.

2.4.1.D ***Sanglung Formation***

Named after a locality in the Lingti Valley (inadvertently referred to as the Pin Valley in Bhargava, 1987), the Sanglung Formation shows equally good or better exposures in the Pin Valley. This formation has been subdivided into three members each of which, in fact, could be raised to formational level. However, due to rugged terrain and complicated folding, it has not been possible to map these members in all the sections. In sections where the middle calcareous unit pinches out, it becomes difficult to distinguish between the lower and upper units. Moreover, though the pinching of any of these units can be viewed in several sections, it has not been possible to closely examine whether the pinching is sedimentologic or tectonic. Due to such constraints, it has been thought judicious to accord member status to these subdivisions and differentiate them on map, wherever possible. To avoid multiplicity of names, these members have been designated as A, B and C.

2.4.1.D$_1$ ***Member A*** : It is well developed at Sanglung and also in the Pin, Pare and Giu Valleys. It corresponds to the Grey Beds of Diener (1912). The Member A constitutes gentle to steep slopes (Fig.2.76) and selectively can be picked in aerial photos. It has an intercalated contact with the Member B.

The Member A comprises grey shale which, on weathering, acquires ash grey shade. Limestone/dolomite, earthy dolomite (marly) and siltstone interbeds occur in specific sequential arrangement at different stratigraphic levels, forming part of different cycles. Each cycle initiates with pure carbonate and terminates into shale/siltstone unit. Some cycles are incomplete. Nine such cycles were identified in the Lingti section. Cephalopod wheeling traces are known from this member (Fig.2.87). Its sequence, as exposed in the Lingti Valley, is given in Fig. 2.78a and Appendix-XIV a.

Age : The Member A is regarded to represent a middle Carnian age corresponding to the Grey Beds (Diener, 1912).

2.4.1.D$_2$ ***Member B*** : It is also well exposed at Sanglung, opposite Lalung village and in the Pin Valley. Intricately folded, it forms precipitous slopes (Fig.2.73). Due to steep topography and vertical distortion it is selectively picked up in the aerial photos. The Member B is the lithostratigraphic equivalent of the *Tropites* Bed. It has an intercalated contact with the Member C.

It is made up of bedded grey limestone, dolomite (cherty in upper part), subordinate shale, siltstone and sandstone. These lithounits are repeated at several stratigraphic levels forming parts of different cycles. Each cycle begins with carbonate and culminates in a shale/sandstone bed. Bhargava and Gadhoke (1988), have reported conodont *Gladigondolella tethydis* and foraminifers *Ophthalmidium triadicum* (Tollman) and *Arenovidalina chialingchiangensis* Ho from this member. The details of sequence of the Member B, as exposed in the Lingti Valley, are depicted in Fig.2.78b and Appendix-XIV b.

Age : It has the same age as that of the *Tropites* Bed *i.e.* late Carnian (Diener, 1912).

2.4.1.D$_3$ ***Member C*** : It is well developed along the Atargoo-Guling road and in the Hal Nala forming

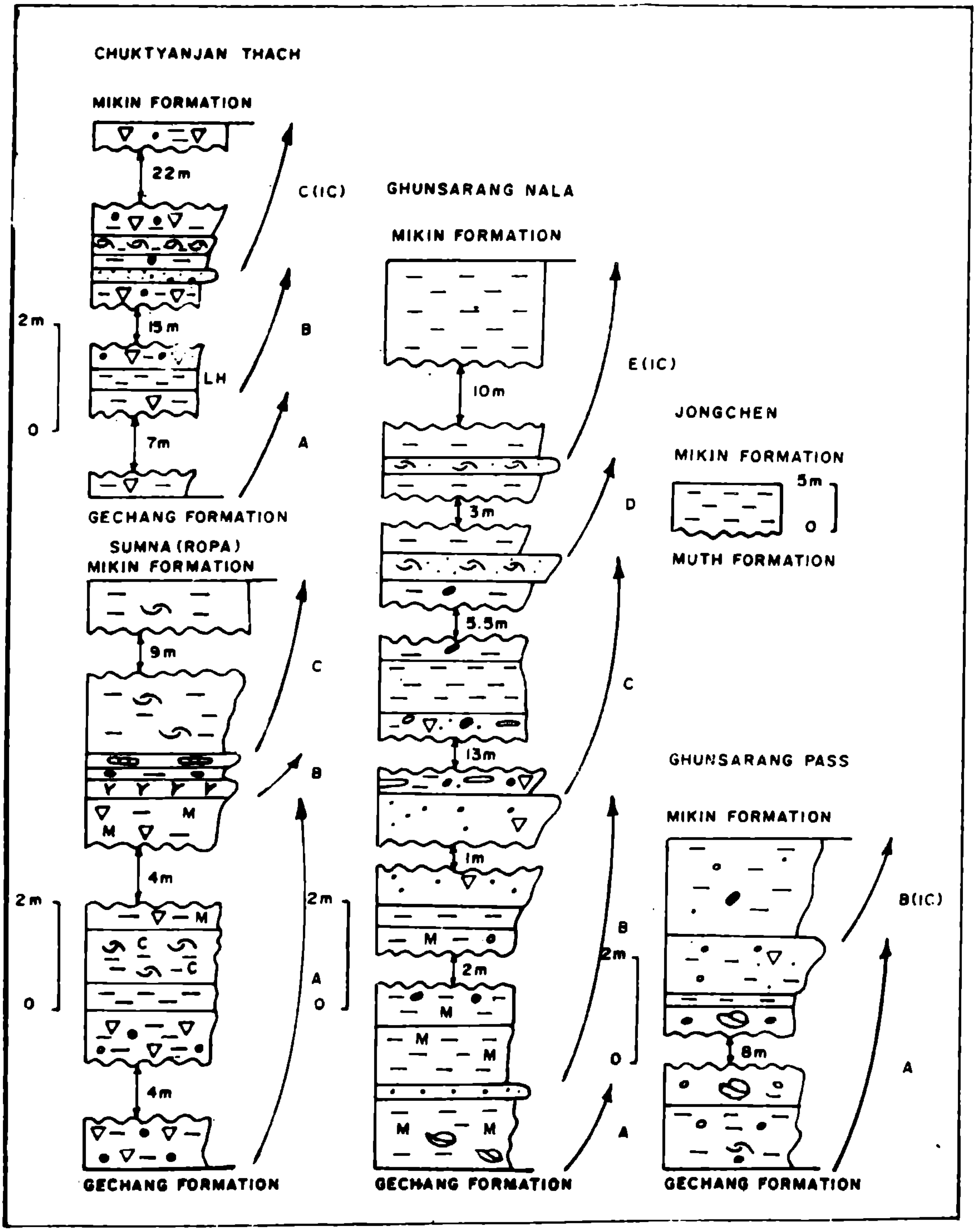


Fig. 2.65. Lithologs of the Gungri Formation. For Index see Fig. 2.66.

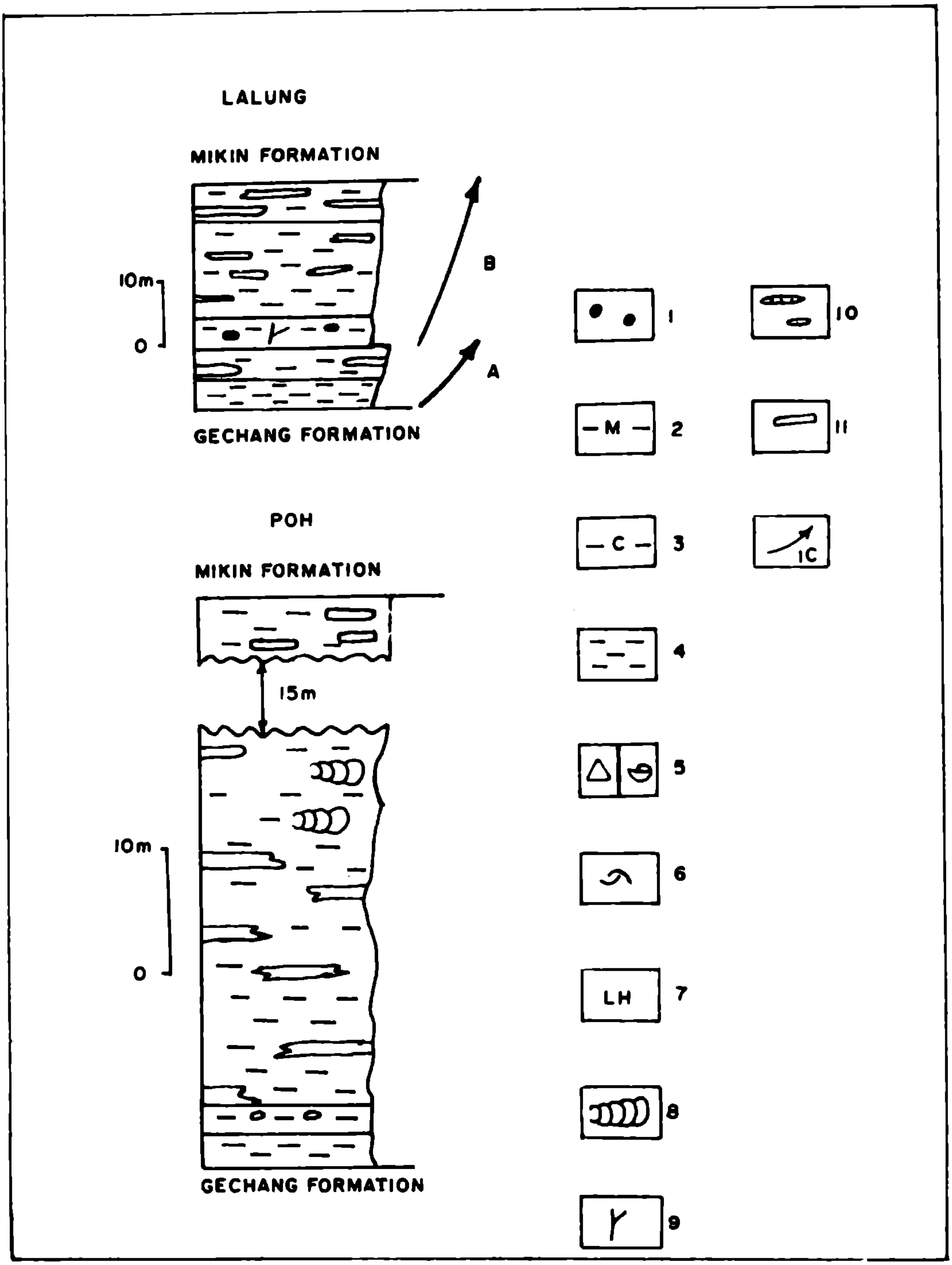
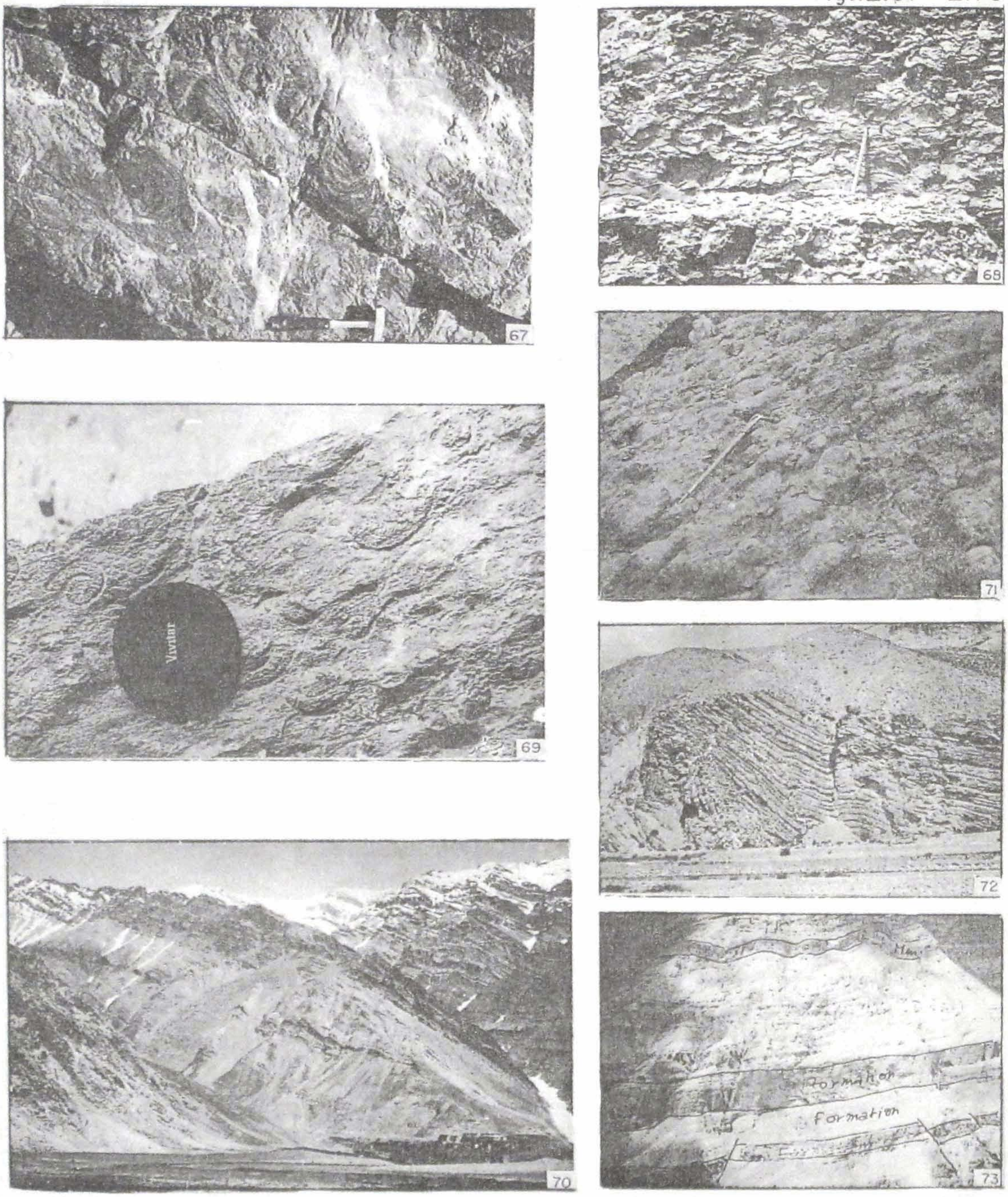


Fig. 2.66. Lithologs of the Gungri Formation. Expl: 1. Nodules, 2. Micaceous shale, 3. Calcareous shale, 4. Shale, 5. Brachiopod, 6. Shells, 7. Lammimargus himalayensis, 8. *Zoophycos*, 9. Bioturbation/burrows, 10. Sandstone lens and 11. Siltstone lens. IC - Incomplete cycle.

Figs.2.67 – 2.73



Explanation of Figs.2.67 - 2.73

Fig. 67. *Zoophycos* in the Gungri Formation. Loc. Lingti section. **Fig. 68.** Nodular bedding and ferruginous network in the Mikin Formation. Loc. Guling section. **Fig. 69.** Ophiceratids in the Mikin Formation. Loc. Guling section. **Fig. 70.** Mikin, Kaga, Chomule, Sanglung Formations in hill behind the Mud village. The remaining formations of the Lilang Group are exposed in the distant hill. **Fig. 71.** Cephalopod occurring as dropstones, in Kaga Formation. Loc. Kaga *Nala*. **Fig. 72.** Even-bedded Chomule Formation. Loc. near Rama, (Lingti Valley). **Fig. 73.** A view of part of the Lilang Group. Loc. Lingti right bank, Lalung.

steep to gentle slopes (Fig.2.73). It corresponds to the *Juvavites* Beds. The Member C has a sharp to intercalated contact with the Hangrang Formation.

The Member C is constituted of shale, ferruginous cross-bedded sandstone and breccia with angular to subangular boulder to cobble size fragments of limestone and sandstone (*e.g.* Hal *Nala section*). The shale and siltstone on weathered surface are of brown to greenish in colour.

The sandstone shows low-angled cross-bedding. Interference ripple marks are present in the dolomite and sandstone beds. 15 to 29 cycles are present in the Member C, each cycle commencing with carbonate and terminating in shale. Bhargava and Gadhoke (1988) recorded ostracodes *Bairdia mesotriassica* Goel *et al*, (1984) and *Hungarella* sp. from this member. Complete sequence of this member, as exposed at Atargoo-Guling and Lingti sections, is presented in Fig. 2.78c and Appendix-XIV c.

Age : The Member C (≡ *Juvavites* Bed) represents early Norian age (Diener, 1912).

In eastern Kinnaur, the Sanglung Formation is exposed in the Gyamthing Valley.

2.4.1.E *Hangrang Formation*

Named after the Hangrang Pass, this formation, besides at the type locality (Fig.2.82), shows good development at Tapuk (Kinnaur), Giu *Nala*, Chidang, Pin-Parahio confluence, Lalung section and Rangring (Fig. 2.83, spelt as Rangrik in the latest toposheet). Occurring in between the Sanglung Formation (Member C) and Alaror Formations, the Hangrang Formation provides a steeper face and can be recognised from a distance (Fig. 2.82). This formation is equivalent of the Coral Limestone. It has an intercalated to sharp contact with the Alaror Formation.

The Hangrang Formation comprises light to grey massive dolomite. In most of the sections, it shows abundance of coral and hydrozoan in hand specimen. Corals in 'in-growth' position indicate reefoid nature (Fig.2.84-86). The dolomite in between such reefoid structure varies from coarse ooidal to fine micritic. In the Hangrang area, below the main coral colonies, there occur large solution cavities filled by material mostly having ferruginous contents. These possibly provided hard substrate for coral growth. There are numerous microfacies in the Hangrang Formation which inter-finger within short stretches. Thus no sequence of microfacies can be built, though reef at Pin-Spiti confluence (Bhargava and Bassi, 1985) and Hangrang do show some zoning. The reefoid structures vary in size from a few square metres (*e.g.* Lalung section) to about one kilometre (at Hangrang). Its outcrops at Hangrang occur at different topographic levels and localities due to structural complications (Fig. 2.79). In general, the sequence commences with a zone of solution cavities of various sizes having a horizontal floor and an irregular roof filled with ferruginous, micritic, quartzose and sparitic materials. It is followed by a solitary coral zone. Two to three such cycles of reef growth are identifiable in different sections. The reef part of the Hangrang Formation at the type section was studied at three places, *viz.* A, B and C (Fig.2.79). The details of these sequence are given in Fig.2.80 and Appendix-XV. The Hangrang Formation shows wide thickness variations. In most sections it shows both sedimentological pinching as well as tectonic pinching (*e.g.* Hangrang Pass). Though present everywhere, it has been plotted in map where actually examined.

Age : The Hangrang Formation , equivalent to the Coral Limestone, represents Norian (Diener, 1912) or early middle Norian age (Bhargava and Bassi, 1985).

2.4.1.F *Alaror Formation*

This name, suggested by Srikantia (1974, 1981) after a locality between Kioto and Lagudarsi Pass, has been adopted in the present work. The Alaror Formation, as redefined here is , however, different in the lithologic assemblage from the one defined by Srikantia (1981). This formation resting conformably over the Hangrang Formation is excellently developed along the Atargoo-Guling road, about one kilometre upstream of the Pin-Spiti confluence and forms gentle to steep slope. However, its resolution is not very clear on aerial photos. It has a normal conformable contact with the underlying and overlying Hangrang and Nunuluka Formations respectively. It corresponds to the biostratigraphic subdivision of the *Monotis* Shales.

The Alaror Formation consists of dark grey to brownish shale with subordinate limestone and dolomite. In the Lalung section, it shows tempestite layers of shells, followed by low angled cross-bedding. In sections where the Hangrang Formation is not developed, it is difficult to distinguish it from the Member C (Sanglung Formation), hence in the map it has been given same colour as the Sanglung Formation. Three complete sedimentary cycles are identifiable in the Alaror Formation of the Atargoo road section. The lowest cycle is incomplete and begins with shale and terminates in shale with nodules. The next cycle commences with shale and limestone and ends up with shale. The remaining cycles begin with argillaceous limestone and end in clastics. The detailed sequence is illustrated in Fig.2.81a and tabulated in Appendix-XVI. The Alaror Formation is more or less uniformly developed in the Spiti basin and in the Gyamthing Valley of the Kinnaur basin.

Age : The *Monotis* Shale, which is the biostratigraphic equivalent of the Alaror Formation, has been assigned a Norian age (Diener, 1912)- possibly late middle Norian.

2.4.1.G *Nunuluka Formation*

The best exposures of this formation are available along the Atargoo-Guling road. Since no locality name exists in this section, this formation has been named after Nunuluka, which is a locality nearest to its best section. The Nunuluka Formation has a gradational, intercalated and conformable contact with the Alaror Formation and also with the overlying Kioto Formation. This Formation is equivalent to the Quartzite Series (Hayden, 1904). In several sections it acquires yellowish colour on weathering and can be recognised from distance. Its resolution in aerial photographs is, however, not apparent.

The basal part of the Nunuluka Formation comprises gritty, grey to pale white sandstone showing low-angled cross-bedding, sub-parallel bedding with low truncation surfaces and ripple marks. Upward, it is followed by coarse argillaceous sandstone. Subordinate interbeds of grey shale and arenaceous dolomite occur within this sequence. Rare pebbles, along with broken shell in the upper part, are recorded along Atargoo-Guling road. In this section three main cycles, each beginning with carbonate and ending with clastics, are identified. The sequence of this formation, as observed along the Atargoo-Guling road, is presented in Fig.2.81b and Appendix-XVII.

Hayden (1904) regarded the Quartzite Series (≡ Nunuluka Formation) as a marker bed. In the present mapping, this formation was found to be absent in several sections. This absence was explained by Fuchs (1982) as due to tectonic elimination and by Bhargava (1987) by sedimentary overlap.

In the Kinnaur basin, it is exposed at Tapuk in the Gyamthing Valley.

Age : The Quartzite Series (≡ Nunuluka Formation) has been assigned a Norian age (Diener, 1912).

2.4.1.H *Kioto Formation*

This name was suggested by Hayden (1904). Its sequence, especially the lower part, was also referred as Megalodon Limestone by Diener (1912). Srikantia (1981) proposed Simokhomda for the same sequence. In the present write-up, the name 'Kioto' is being retained. The Kioto Formation occupies a major part of the Spiti Valley, mostly forming precipitous slopes. Due to this reason, it has not been possible to measure any complete section of this formation. It forms steep topography and can be recognised in field from a distance and also in the aerial photos (Fig.2.44).

In fully developed sections, the Kioto Formation rests conformably along a gradational contact on the Nunuluka Formation. In other sections, it rests abruptly over older formations (*e.g.* over the Alaror at Lidang and over the Lipak in Phiphuk section). It is divisible into two members, *viz.* the Para and the Tagling Members. These members, on the basis of their broad lithologic characters, can be mapped in most of the sections.

2.4.1.H_1 Para Member : It is a successor to the Para Limestone of Stoliczka (1865) and Para Stage of Hayden (1904). It forms conspicuous and steep topography and is excellently exposed along the Atargoo-Guling road and above the Ki village.

The Para Member is made up of grey, pale, creamish, sporadically cherty, massive to thick bedded ooidal and pisoidal dolomite and limestone. Pisoidal structures are visible along the Ki-Kibber road (Fig. 2.88). Recrystallised, whole as well as fragmented, megalodontid shells are abundant in most of the sections. There are innumerable cycles commencing with oolitic or coarser material, ending into a medium to fine grained carbonate. Small representative sections of the Para Member, as exposed near the Ullah *Nala* and near Rangring, are presented in Fig.2.91.

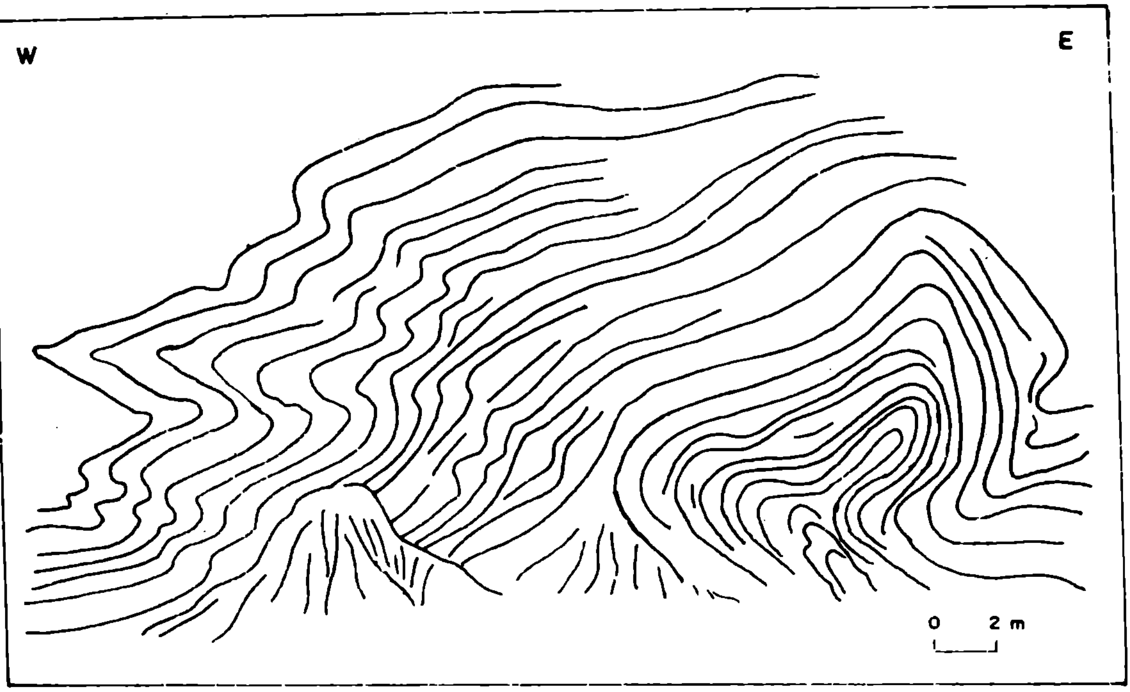


Fig. 2.74. Subaqueous gravity slumps in the Chomule Formation. Loc. Hal *Nala* section, about 3km upstream of its confluence with the Spiti.

2.4.1.H_2 Tagling Member : Nomenclaturally, this member corresponds to the Tagling Limestone (Stoliczka, 1865). The presently defined Tagling Member, however, is broader based and has lithology rather than fossil contents as basis of its definition. It is excellently exposed near Sakti, Giumal and Kibber areas. It forms somewhat softer topography and is recognisable in aerial photos. It has an imperceptible conformable contact with the Para Member and a sharp contact with the overlying Spiti Formation.

The Tagling Member comprises dark greyish blue, fine grained, cherty dolomite, shell hash limestone, lenticular conglomerate, arenaceous limestone, ooidal, pisoidal and peloidal limestone, dolomite and marl. All these units are ferruginous, which on weathering, acquire an earthy brown colour. The conglomerate bed in its upper part at Sachibang has an uneven contact with both the underlying and overlying units. It shows wavy and parallel bedding and large cavities filled with arenaceous material and clasts in the Sachibang section. The upper part of the Tagling Member is rich in clam shells and *Belemnites* fossils, which at places show hash texture. In Tangmor section, shell hash limestone shows several coquina bands and sub-parallel to low angled cross-bedding. It is conspicuously bioturbated in Salache-Sakti area. Locally occur 30cm^2 to 1m^2 sized reef knobs mainly made of *Thecosmilia* colonies. Bhargava and Gadhoke (1988) have reported foraminifers *Diplotremira* sp. (Fig.2.89), *Endothyra* sp., *Textularia* sp., *Tetrataxis* sp. and *Trochamina* sp. and some biserial form (Fig.2.90) from this member.

The Kioto Formation is ubiquitously developed in Spiti, Kinnaur (Gyamthing Valley), Kumaon and Zanskar. The Tagling Member, as defined here, is possibly an equivalent of a part of the Laptal 'Beds' of Kumaon.

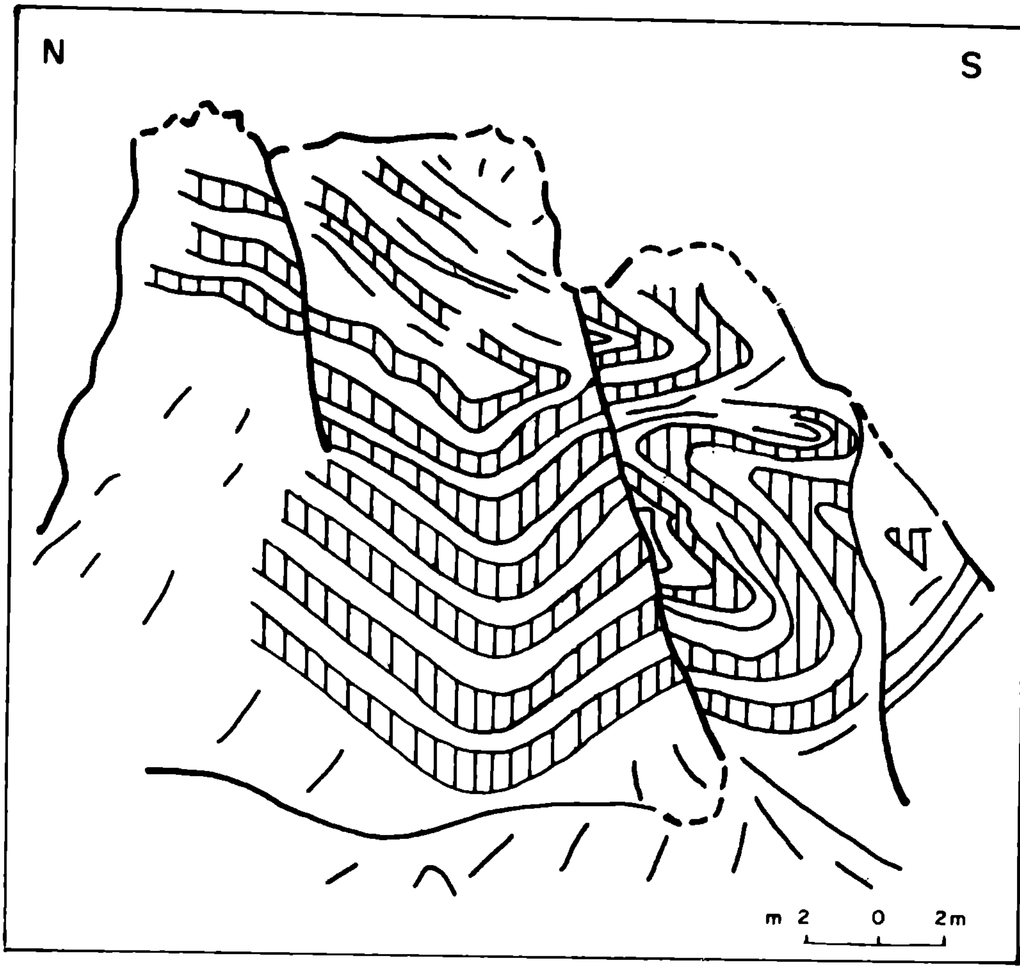


Fig. 2.75. Subaqueous gravity slumps in the Chomule Formation. Loc. in a *Nala* section about 2km west of Kiomo.

Age : The basal part of the Kioto Formation was assigned a Rhaetian (Stoliczka, 1865; Greisbach, 1891) age, later a Norian age was suggested (Pascoe, 1968). Lower Kioto (≡ Para Member) was assigned latest Triassic age by Gaetani *et al*, (1986).

Its upper age limit has been defined as middle Jurassic on the basis of fossil resembling *Stephanoceras coronatum*, which occurs about 112m below the base of the Spiti Formation (Pascoe, 1968). Late Liassic to early Dogger age was suggested by Gaetani *et al*, (1986). Bhargava (1987) suggested Rhaetic to Dogger age for the Kioto Limestone. However, the fossil control is not unambiguous and the age range of the Kioto Formation certainly needs refinement. It may possibly represent an early Rhaetic to Lias age, as was originally suggested.

2.4.2 LAGUDARSI GROUP

The Spiti, Giumal and Chikkim Formations were earlier classified under the Kibber Group by Srikantia (1981). Kibber village is situated over the Kioto Formation near its contact with the Spiti Formation. The Giumal and Chikkim Formations are nowhere exposed in its vicinity. The name Kibber is, therefore, inappropriate. Since this name has not been subsequently used, the present authors propose a new group name after the Lagudarsi Pass, situated on the Spiti Formation near its contact with the Giumal Formation. The Chikkim Formation is exposed about 500m west of this pass.

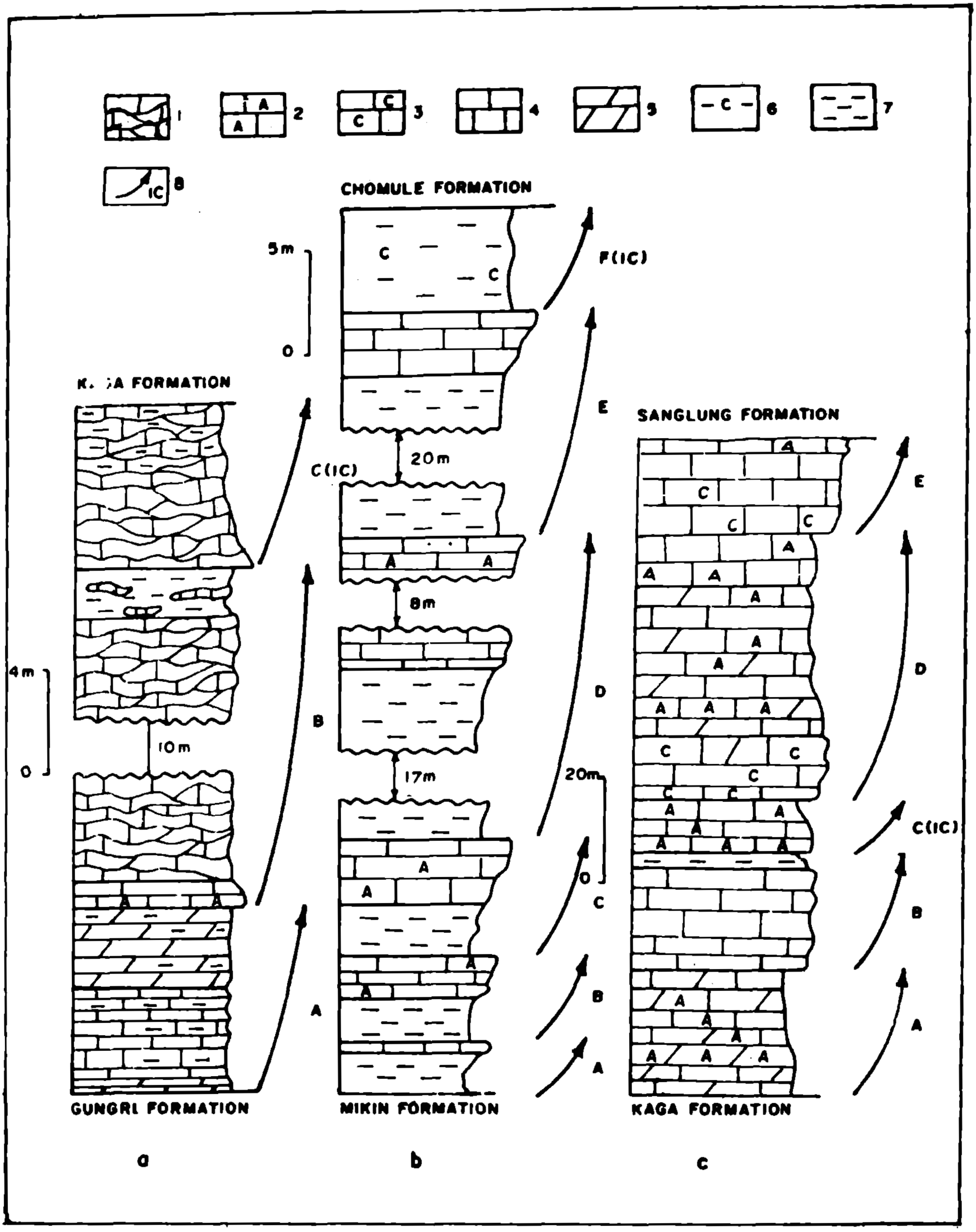


Fig. 2.76. Lithologs of the (a) Mikin, (b) Kaga and (c) Chomule Formations. Expl: 1. Nodular bedding, 2. Argillaceous limestone, 3. Cherty limestone, 4. Limestone, 5. Dolomite/dolomitic limestone, 6. Calcareous shale, 7. Shale. Arrows with A, B sedimentary cycles, and I.C. Incomplete cycles.

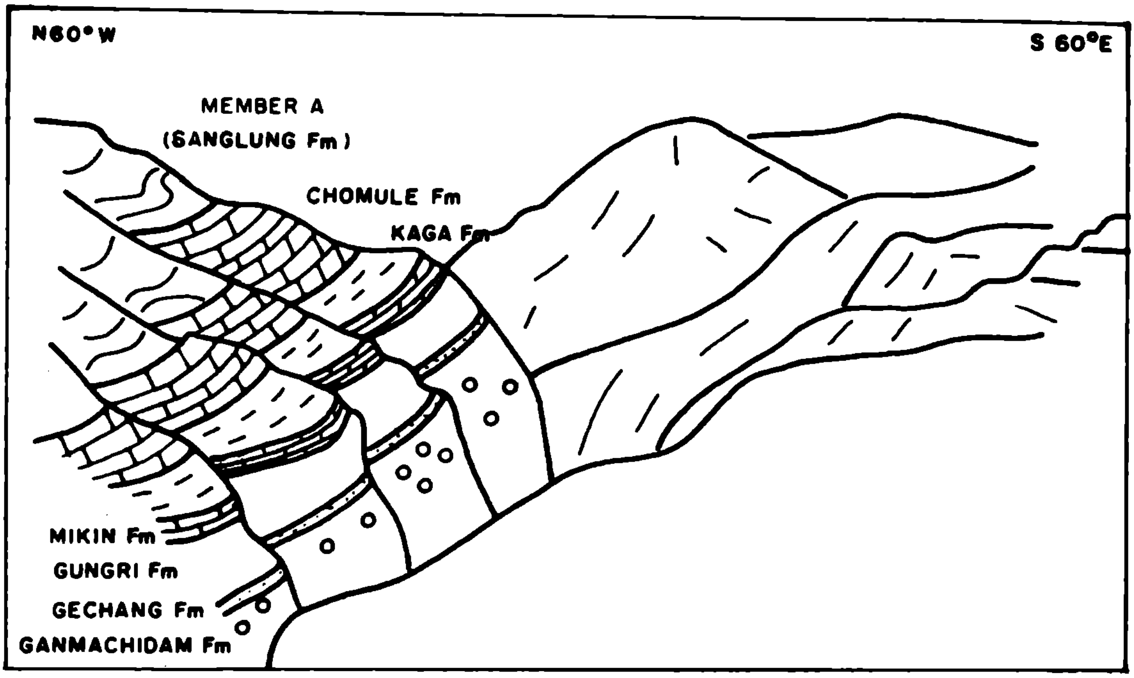


Fig. 2.77. A view of the Ganmachidam, Gechang, Gungri, Mikin, Kaga, Chomule Formations and Member A (Sanglung Formation) from the Lalung village.

2.4.2.A *Spiti Formation*

The name Spiti Shale was proposed by Stoliczka (1865) for a sequence resting above the Kioto 'Limestone' and below the Giumal 'Sandstone'. Srikantia (1981) redesignated it as the Spiti Formation. The Spiti Formation is exposed in isolated synclinal outliers. It forms a subdued topography, which can be easily deciphered in aerial photos. Due to its black colour it can be recognised from a great distance. The Spiti Formation has a sharp contact with the underlying Kioto Formation and an intercalated contact with the overlying Giumal Formation.In the Lingti section (*e.g.* near Sachibang), the sequence of the Spiti Formation commences with grey, non-carbonaceous lenticular, ferruginous, fine grained sandstone/ siltstone, varying in thickness from one to two metres. In Salache section, its thickness is 2 cm to 10 cm. Within this bed occur dark grey ferruginous oolitic bands which, for considerable distance, occupy the same stratigraphic level. This part is rich in *Belemnites* which occur aligned parallel to the bedding. This oolitic sequence has a gradational contact with the Kioto Formation of which it is considered to be a part. It is succeeded along a sharp contact by a sequence of micaceous shale. This part encloses *Astarte* shells. The nodules in this sequence are mostly cherty, oval to spherical and vary in size from four to eight centimetres. In the adjoining section, there occur small lenses of shelly limestone in the basal part of the Spiti Formation, which have a sharp contact with the underlying Kioto Formation. In the upper reaches of the Phiphuk *Nala*, the contact between the Spiti Formation and the Kioto Formation looks apparently conformable. In this section, fine grained sandstone bands occur in the middle part of the Spiti Formation. Local boulder bed exists in the upper part of the Spiti Formation in the Giumal section (Bhargava *et al*, 1987). The matrix, as well as the clasts, are of fine silty material. Phosphatic, cherty and calcareous nodules, varying in size from a few centimetres to 20 cm, are distributed throughout the sequence. Several nodules enclose fossils as nucleus. The shale locally includes fine laminae of chert. Large ammonite shells and occasionally shale have formed hard ground and are encrusted by burrows. The lamellibranchs are both thin and thick shelled. The siltstone and sandstone beds in the Spiti Formation display rare parallel and graded beds of limited thickness. The shale of the Spiti Formation weathers easily, hence outcrops are rare. Only gorges show good outcrops. As gorges are difficult to negotiate, no full section of the Spiti Formation could be measured. The thickness mentioned in the map is computed from various cross-sections, hence approximate. Jain and Mannikeri (1975) reported ostracode from the 'Chidamu Stage'

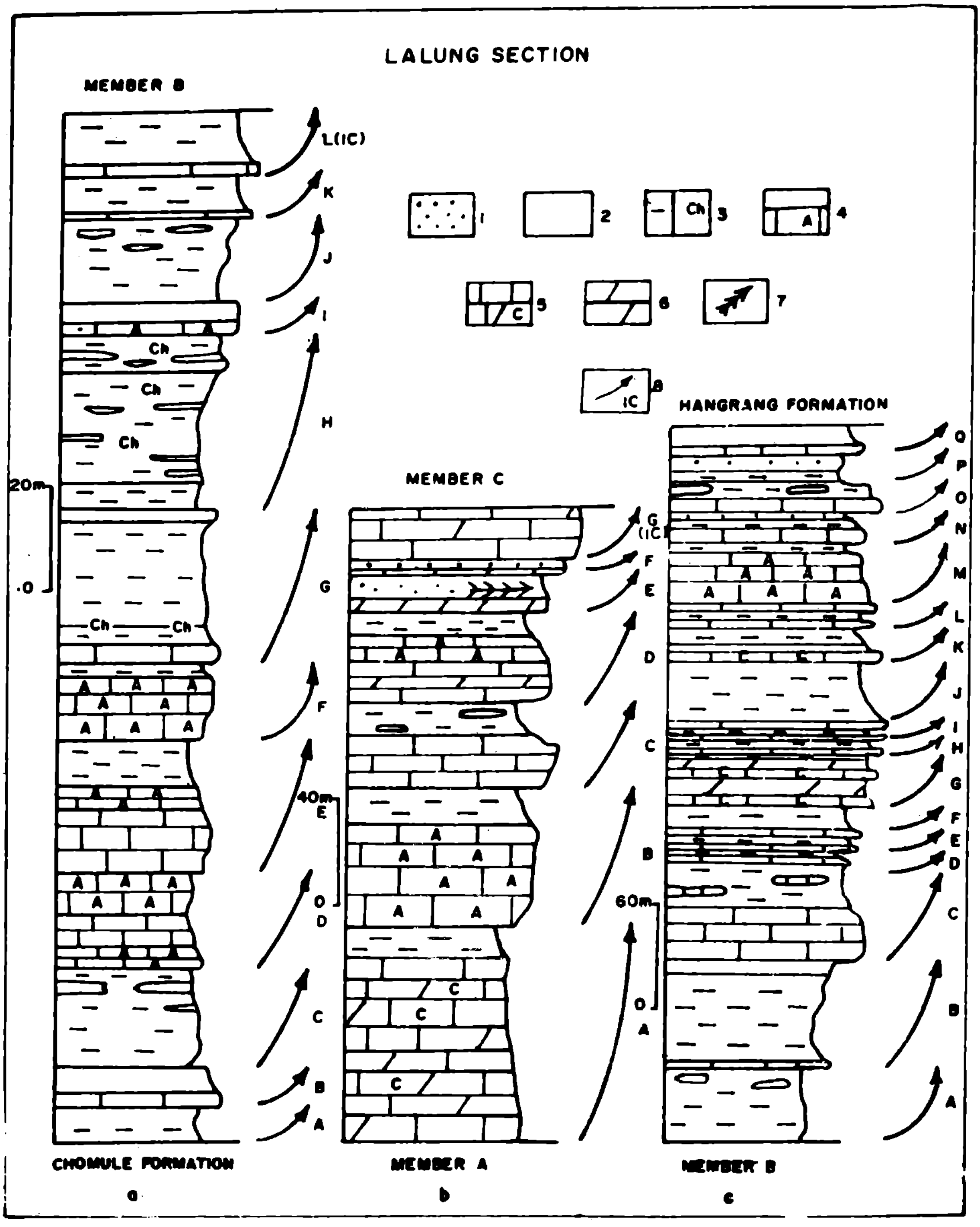


Fig. 2.78. Lithologs of the Sanglung Formation (a) Member A, (b) Member B and (c) Member C. Expl: 1. Sandstone, 2. Siltstone, 3. Shale (C) where cherty, 4. Limestone, (a) where argillaceous, 5. Dolomitic limestone (C) where cherty, 7. Herringbone cross-bedding. Arrows indicate sedimentary cycles. I.C. Incomplete cycle.

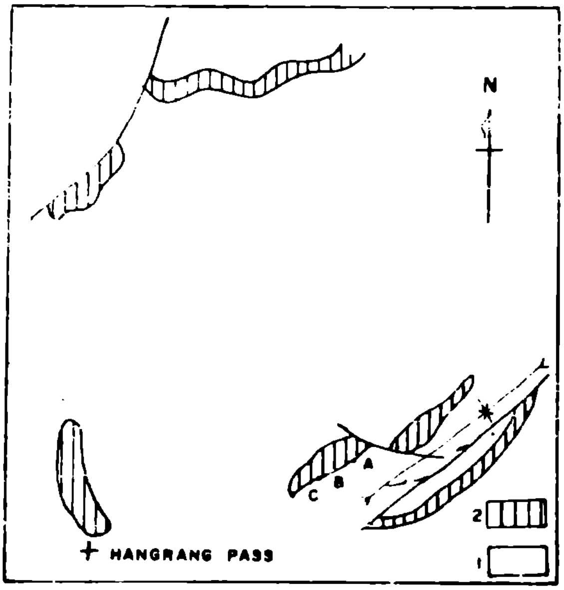


Fig. 2.79. Sketch map to show outcrops of the Hangrang Formation near Hangrang Pass. (Not to the scale). 1. Sanglung Formation, and 2. Hangrang Formation.

of the 'Spiti Shale' 'exposed near Kibber'. The outcrop of the Spiti Formation in the immediate vicinity of Kibber occurs as a huge landslide. This report, therefore, probably has no stratigraphic value. The Spiti Formation is developed from Zanskar to Kumaon in isolated synclines with identical lithology. It is exposed in eastern Kinnaur at Tangpa Dok in the Gyamthing Valley.

Flows/sills upto 30 cm thick are observed within this Formation in areas south of the Spiti River.

Age : The Spiti Formation was assigned an age between Oxfordian and latest Jurassic (Krishnan, 1982) to earliest Cretaceous. Heim and Gansser (1939), on the basis of their work in Kumaon, suggested a Portlandian to Tithonian age for this Formation. Based on ammonite remains, Jaikrishna (1983) in the Kumaon area assigned an age ranging from Oxfordian to Valanginian. Since the Spiti set-up is highly comparable with that of Kumaon, the present authors suggest the same age range for the Spiti Formation of Spiti-Kinnaur area as well.

2.4.2.B *Giumal Formation*

This name was suggested by Stoliczka (1865) after Giumal village (spelt as Domal in the modern toposheet). It was redesignated as the Giumal Formation by Srikantia (1974). It shows good exposures at Domal, Lagudarsi Pass, Langja and Sakti. The Giumal Formation forms conspicuous topography and on aerial photos shows darker tone. It has an intercalated contact with the underlying Spiti Formation and a rather sharp contact with the Chikkim Formation. The Spiti Formation develops sandy beds in the upper part and passes into the Giumal Formation.

The Giumal Formation comprises sandstone, siltstone, silty shale and shale with local conglomerate lenses. In the basal part, it is interbedded with black shale forming a sort of transition between the Spiti and Giumal Formations. The transition is best exposed at the Lagudarsi section. The sandstone in the basal most part is calcareous (Domal section) and is sporadically oolitic in Kinnaur (Fig.5.28). This horizon contains body and trace fossils. In the upper part, the sandstone is medium to coarse grained and glauconitic. The sandstone varies in colour from pale green, maroon, off white to grey. Both the clasts and matrix in conglomerate are composed of quartz.

In Latarse section, the Spiti Formation in its upper part contains white to pale white sandstone, which in top most level has lenses of fossiliferous limestone. It is overlain by carbonaceous siltstone with sandstone bands, which are locally glauconitic.

Upward it is followed by glauconitic shale which in the upper part has several gritty bands containing black shale pebbles. The overlying sequence is coarse to gritty, occasionally micaceous sandstone having variable glauconitic content. The uppermost unit immediately below the Chikkim Formation has a persistent gritty-marl horizon enclosing complete shells in clusters.

Near Tanglangba (Domal type section), the Giumal Formation has too many black shale bands in its basal part. The sandstone in the basal part is pale white, pale green, reddish grey, highly crystalline and is locally gritty. The basal part is rich in trace fossils. Just below the Charna Pass and near Domal Pass, the conglomerate has a few clasts of boulder size. The clasts, as well as matrix, are arenaceous. Shelly calcareous siltstone/marl is present in this section as well. The entire sequence represents four mega fining-up cycles. The succession of the Giumal Formation in the Lagudarsi-Chichim section is given in Fig.2.92a and Appendix-XVIII.The Giumal sandstone is exposed in eastern Kinnaur at Tangpa Dok.

Age : The Giumal Formation is considered to be not older than Valanginian or Lower Hautervian or younger than the Albian. (Krishnan, 1982).

2.4.2.C *Chikkim Formation*

The nomenclature of Chikkim was suggested by Stoliczka (1865) after the Chikkim peak (spelt as Chichim in the modern toposheet) in the Spiti Valley, where it is well-developed. This formation is divisible into two mappable members (Srikantia, 1981), *viz.*, (a) Limestone Member and (b) Shale Member.

2.4.2.C_1 Limestone Member : Earlier, this was referred to as the Chikkim Limestone. The colour contrast with the Giumal Formation makes the Limestone Member stand out in the field. However, due to limited thickness in a high relief terrain, it is not easily noticeable in aerial photos.

The Limestone Member, conformably resting over the Giumal Formation, comprises greyish blue dolomitic limestone. At its base occurs an argillaceous limestone with broken shells. NW of Chichim village, Srikantia (1981) reported a 2m metres thick carbonaceous shale with 20-30cm thick quartzite bands along the Giumal Formation-Limestone Member contact. The upper part of this Member is well-bedded and argillaceous. Within the carbonate sequence, there are a few thin siliciclastic bands and sporadic dark grey pyritous limestone. Three complete and one incomplete sedimentary cycles are recognisable in the Chichim area. The earliest cycle begins with sandy carbonate and ends with shale through argillaceous limestone with shale partings. The subsequent cycles begin with marly limestone and end up in shale. Sequence of the Limestone Member, as exposed at the Chikkim peak section, is shown in Fig. 2.92b and Appendix-XIX. The units 'f' to 'i' form a transition from the Limestone Member to the Shale Member.

Age : The age of this Member may range from Cenomanian to Turonian (Kohli and Sastri, 1956).

2.4.2.C_2 Shale Member : This member in earlier literature was referred to as the Chikkim Shale. It forms a subdued topography and is at once identifiable in field and aerial photos.

The Shale Member rests conformbly, along a transition to intercalated contact, over the Limestone Member. This Member, having a thickness of about 254m in Chichim section, comprises grey, ash grey silty shale, shaly limestone/marl, and fine siltstone bands. It shows parallel to poorly developed graded bedding. Jain and Gupta (1973) have recorded a foraminiferal assemblage from the Chikkim Shale without assigning it to any stratigraphic level. The Chikkim Formation in the Spiti Valley is developed at Chikkim peak and Sakti area. It is absent in Kinnaur. Its equivalent is exposed in Kumaon, which has been referred to as Jhangu Formation by S.Kumar *et al*, (1977). It is also known from the Zanskar area, where it is succeeded by the Palaeocene-Eocene sequence.

Age : It has been assigned a Campanian to Maestrichtian age on the basis of various species of *Globotruncana* recovered from these shales.

2.5 QUATERNARY

The Quaternary sediments are present throughout Spiti and Kinnaur and provide useful material for Quaternary sedimentological studies in a young mountainous terrain, which selectively still retains first order topography. However, except in a few isolated sections, no detailed study of the Quaternary sediments was carried out during the present mapping. In the present study, the Quaternary sediments have been classified under four major subheads, viz. (a) glacial to fluvio-glacial deposits, (b) fluvial deposits, (c) lacustrine deposits and (d) semi-to unconsolidated scree/ fan /talus.

2.5.1 Glacial-Glaciofluvial Deposits

These deposits are mainly confined to the higher reaches of the slopes and valleys. True glacial deposits are found only along the present day glaciers as lateral, terminal and surface moraines. Elsewhere, these have been reworked by fluvial agencies. These deposits comprise erratics, boulders, cobbles and pebbles with total percentage of clasts around 20% embedded in a rock flour varying in size from sand to clay. Many of the clasts have been well rounded by subglacial streams. These outcrops are disconnected and lenticular in nature.

2.5.2 Fluvial Deposits

The fluvial deposits are present as terraces within the Satluj and Spiti Valleys and also along the tributary valleys. Mainly three levels of terraces have been recorded.

The fluvial deposits present a complex history of sedimentation. These deposits can be subdivided into (i) true fluvial deposits, which were and are being deposited along the river course, between river bed and flood plain (Fig.1.12, 2.93), (ii) the fan material which was partly reworked and modified by the axial

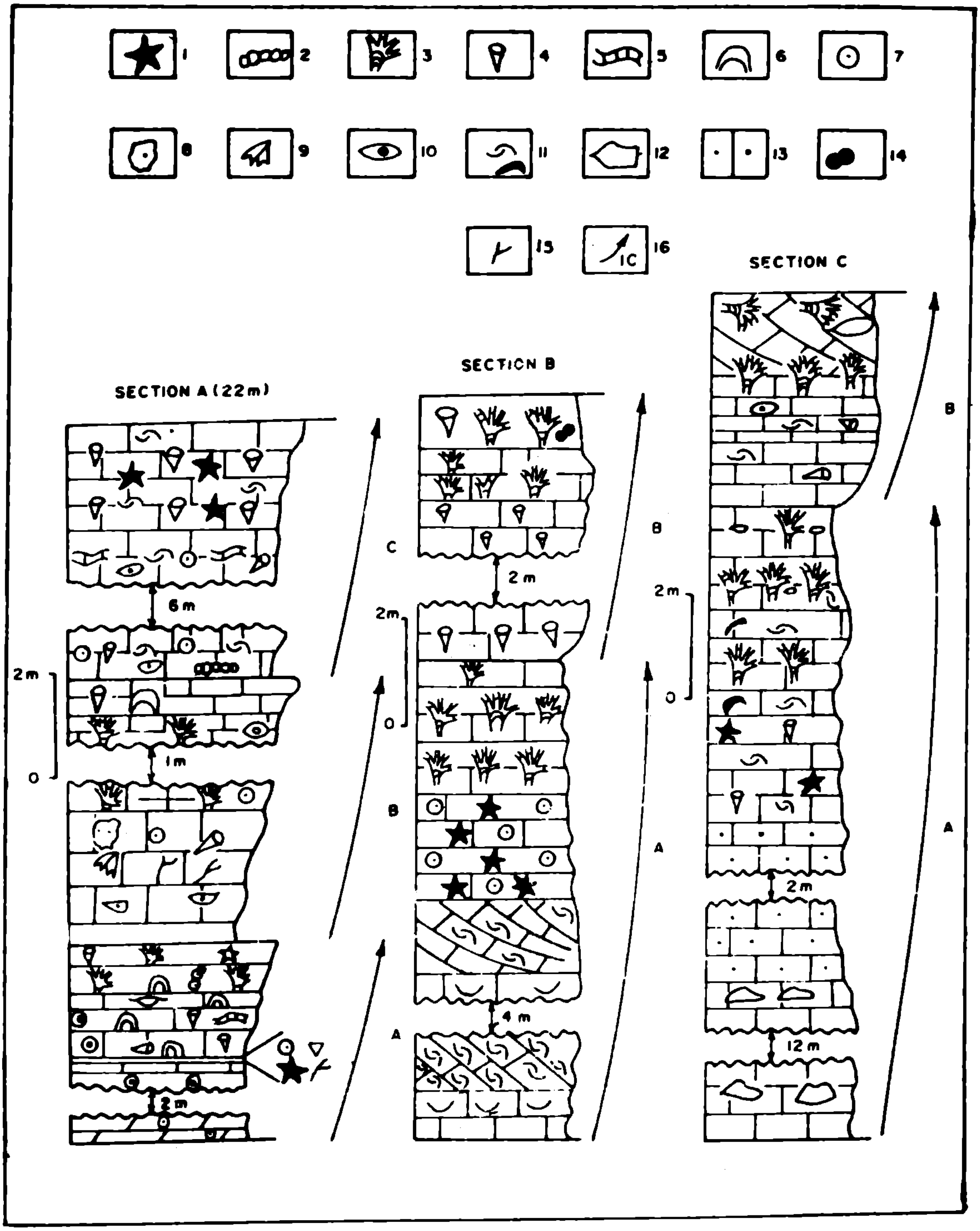


Fig. 2.80. Litholog of the Hangrang Formation at Hangrang. Expl: 1. Crinoid, 2. Sponge, 3. *Thecosmilia* Colony, 4. Solitary corals, 5. Algal bedding, 6. Stromatoporoid, 7. Oolites, 8. Oncolite, 9. Brachiopod, 10. Bird's eye, 11. Fossil debris, 12. Cavities, 13. Arenaceous limestone, 14. Chain coral 15. Burrows/bioturbation. 16. Incomplete cycle.

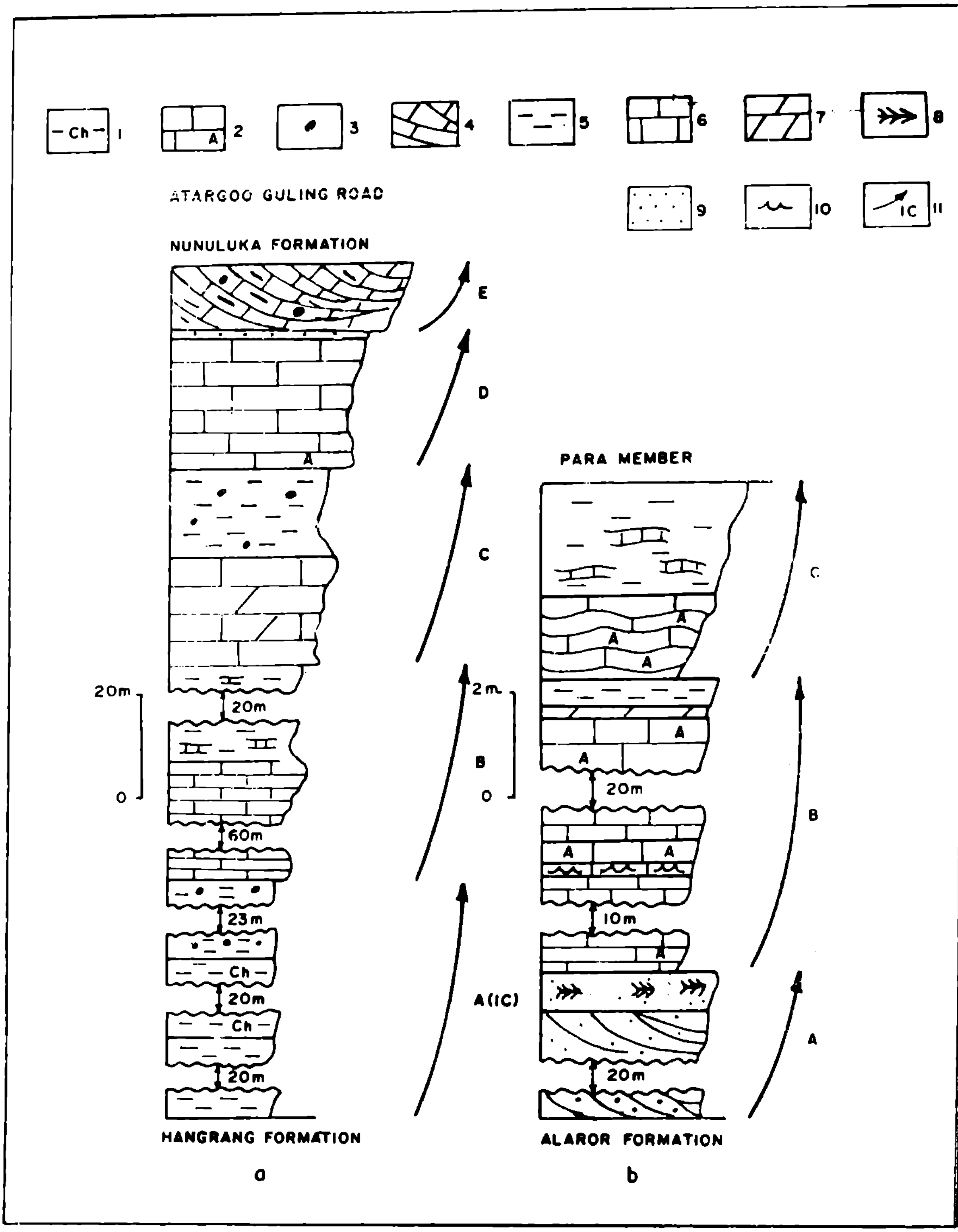
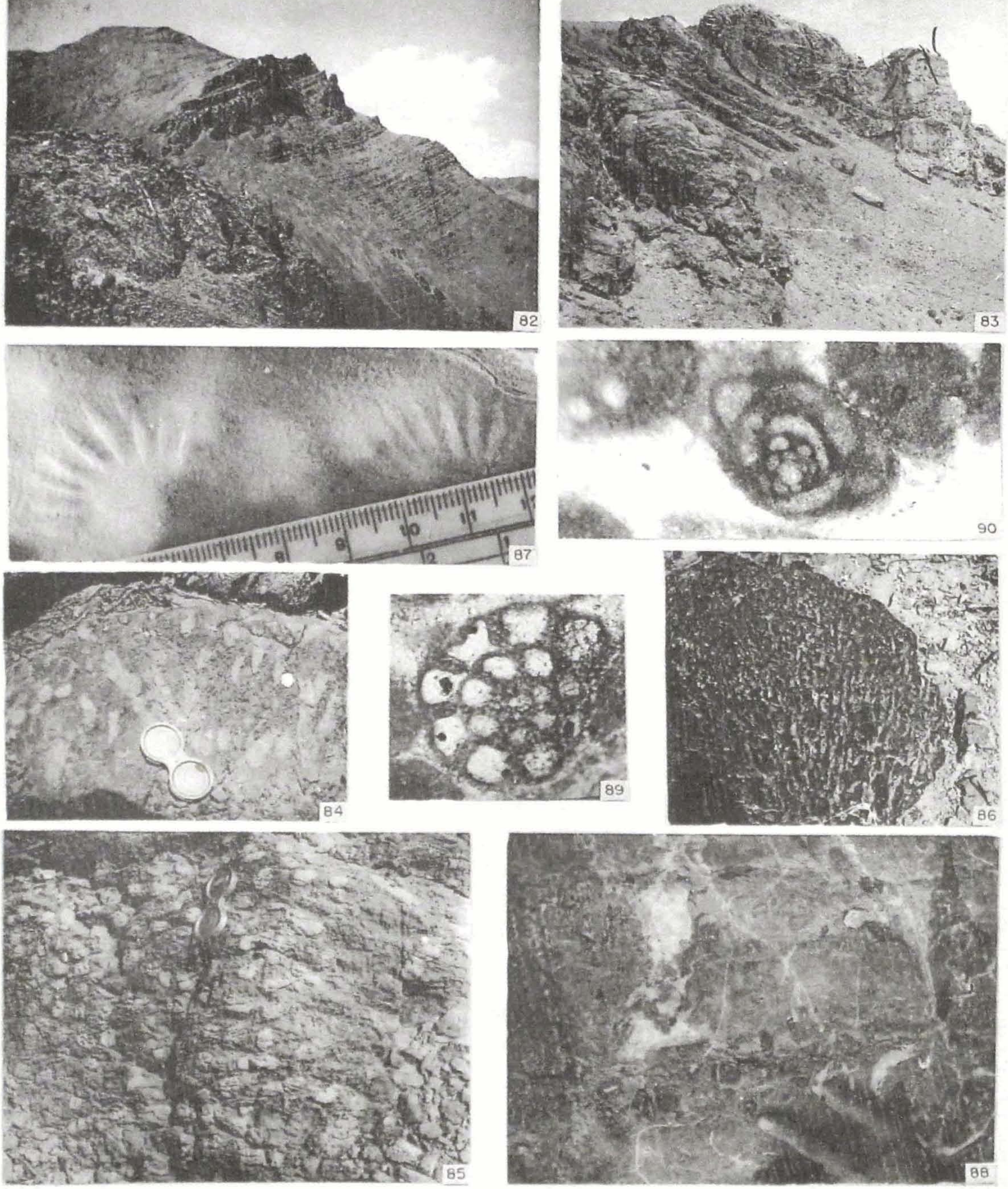


Fig. 2.81. Lithologs of (a) Alaror and (b) Nunuluka Formations. Expl: 1. Cherty shale, 2. Argillaceous limestone, 3. Nodules, 4. Cross-bedding, 5. Shale, 6. Limestone, 7. Dolomite, 8. Herringbone cross-bedding, 9. Sandstone, 10. Ripple bedding and 11. Arrows indicate sedimentary cycles, I.C. Incomplete cycles.

Figs. 2.82 – 2.90



Explanation of Figs.2.82 - 2.90

Fig. 82-83. A view of mid-Norian reef (Hangrang Formation) in the Hangrang (82) and Rangring (83) areas. **Fig. 84.** and **Fig. 86** *Thecosmilia* colonies in vertical view, at Pin-Spiti confluence (84) and Lalung (86). **Fig. 85.** *Thecosmilia* colonies, top view at Pin-Spiti confluence. **Fig. 87.** Wheeling traces, Sanglung Formation (Member A). Loc. Larsa Pass (Scale in cms). **Fig. 88.** Pisoidal structures in the Para Member (Kioto Formation) along Ki-Kibber road. **Fig. 89.** *?Diplotremina* sp. Tagling Member. Loc. Kibber. **Fig. 90.** *Endothyra* sp. Tagling Member. Loc. Kibber. (Bar scale is 5 cm for Figs.2.84 and 2.86 and 0.1 mm for Figs.2.89 and 2.90).

drainage and (iii) partially reworked lacustrine deposits. A typical fluvial sequence is shown in Fig.2.94.

The fluvial deposits occur as moderately sorted to well sorted layers having clasts of various sizes. Each individual layers within itself is moderately well sorted and shows fining of sediments towards the physical top. Within the coarser clastic layers occur syndepositionally deformed clay layers. A good section of the fluvial deposits, exposed at Rangring, shows clasts mainly of quartzite (white-Muth 19%; pink-Thango 17%; green-Kunzam *La* 15.5% and buff 7%), limestone (cherty 17%; grey 14; earthy 2%), conglomerate (5%) and granite (3.5%). These clasts are contributed mainly by the Kunzam *La*-Thango (45%), Muth (19%), granite (3%) and remaining 33% by the rocks from the Lilang Group. The clasts are rounded (18.4%), subrounded (59%), subangular (20.5%) and angular (1.5%). The composition-wise rounding is as follows:

	Pink Quartzite	Green Quartzite	White Quartzite	Carbonate
Rounded	20%	43%	-	10%
Subrounded	60%	43%	50%	76%
Subangular	20%	14%	50%	15%
Augular	-	-	-	0.5%

Most of the clasts of quartzite falling in rounded-subrounded category belong to the Kunzam *La* Formation (green quartzite), followed by pink quartzite (Thango Formation). The Kunzam *La* Formation is exposed farthest from Rangring while the Muth is nearest, with Thango having an intermediate position. The roundness of quartzite clasts, with all other factors remaining constant, seems to be directly proportionate to the distance travelled by the rock. The carbonate rocks, though exposed in the vicinity, also show high degree of roundness. This can be related to the hardness of the rock involved.

The present day sediments occur along various bars, islands in braided channels and partly overbanks. Along the first two, it is mainly the coarser clasts, while sand and grit occur along the overbank and the silt along local ponds/pool of water. Sand and finer fractions are also present in fossil valleys. Erosion takes place all the year round while most of the load is transported on the onset of the melting of snow and excessive melting of glaciers, which supplies enough energy to the stream water. As the melting ceases towards September, the carrying capacity of the rivers is reduced and most of the coarser clastics are deposited and finer material is carried down stream. It is only during local flood/ponding that finer sand is deposited in valleys of the torrential rivers of these areas.

2.5.3 Lacustrine Deposits

These deposits are present along the Satluj-Spiti and tributary valleys. The wide terraces occurring along these valleys, as a rule, are made up of lacustrine deposits (Fig. 1.12). These are excellently developed at (a) Kioto, (b) Phaldhar, (c) Atargoo (Fig.2.95), (d) Hurling, (e) Sumdo (Fig.2.96), (f) Shalkar, (g) Chango (Fig.2.97), (h) Ganfa (Fig.1.18), (i) Shiasu and (j) Kupa (Baspa Valley). Besides these, the lake deposits occur discretely within the fluvial deposits (Fig.2.98). The lacustrine sediments near Atargoo rest over a poorly sorted rudaceous zone. This coarser clastic zone occurs as a prism and is traceable up the hill with a reduction in the thickness. The overlying lacustrine sediments at Atargoo are composed of loosely consolidated, varved, fine sand, silt and rare grit and pebble beds. Locally, these sediments show syndepositional slumps.

The Sumdo lacustrine deposit extends in the Spiti as well as Pare *Chu* catchments. In Spiti, the sediments extended at least two kilometres upstream of Sumdo. These show coarser lenses aligned in NE-SW direction with size of clasts increasing towards NE. Locally, coarser elements are N-S oriented with increase in size of clasts towards north. There are at least three major sedimentary cycles between Sumdo and Kaurik in the Pare *Chu* catchment. The main lake mud is, however, not exposed. The coarser material, comprising grit, pebbles and coarse sand invariably shows cut and fill structure within the finer unit (medium to fine sand). The finer material, due to superincumbent loading, has been squeezed and syndepositionally deformed (Fig.2.99). It shows ripple bedding, climbing ripple lamination (Fig. 2.100), lenticular bedding (Fig.2.101) and cross-bedding. Moving away from fan source, *i.e.* towards central part of the 'lake', the material gradually becomes finer. The sequence at Sumdo is terminated by coarser clastic which is capped by a mud layer. These sediments are juxtaposed against hard rocks east of Sumdo and have been dissected by subsequent fluvial cycle.

Jain *et al*, (1969) have described *Chara* and Subrecent (? late Pleistocene) ostracodes *Cypridopsis vidua* (Mueller), *Herpetocypris* sp and *Candona candiola* (Mueller) from the lake sediments at Jete in Spiti.

2.5.4 Talus Deposits

All along the slopes, on either bank of the Spiti Valley, occur thick scree cones (Fig.1.12). These contain angular fragments from uphill country rocks and are unconsolidated to loosely consolidated.

The scree represents talus formed due to diurnal temperature variations. The meteoric water/dew percolating in the cracks and joints of the rocks freezes and expands during nights. This process over the years disintegrated the rocks into smaller fragments. Percolation of carbonate-rich meteoric water through the limestone country has caused partial cementation and consolidation of the talus scree.

2.6 GRANITOIDS

The acid igneous rocks occur as intrusive into the early Proterozoic-Eocambrian and Carboniferous rocks. These can be broadly classified, from south to north, as :

(i) Wangtu Granite forming a part of the Rampur Window Zone
(ii) Gahr Gneiss associated with the Kulu Group.
(iii) Granitic rocks associated with the Jutogh Group.
(iv) Rakcham Granitoid in the Vaikrita Group and
(v) Nako Granite intrusive into the Vaikrita Group and the Lipak Formation.

2.6.1 Wangtu Group

2.6.1.A ***Granite***

It is mainly exposed in the area north of the Satluj River in Western Kinnaur. Smaller bodies are observed around the Wangtu bridge and near Nugalsari. Granite is leucocratic, fine to coarse grained, equigranular to porphyritic, showing textural variation from granular to hypidiomorphic. It is largely foliated except in extreme core parts. Ameta and Swain (1980), based on foliation, enrichment of quartz, K-felspar and muscovite and nature of contact, divided these into syn-and late-kinematic types.

The Wangtu Granite contains xenoliths of pelitic and porphyroblastic gneisses, amphibolite and tremolite-actinolite schist. The xenoliths of basic rocks are angular and show sharp contacts. These are felspathised and intruded by quartz veins. These granitoids have been dated 2025 ± 86 Ma by using Rb-Sr method (Kwatra *et al*, 1986)

2.6.2 Kulu Group

2.6.2.A ***Gahr Gneiss***

It occurs as thin slivers above the Kulu Thrust. It is augen, streaky to porphyroblastic in nature. Samples from Baragaon in the Satluj Valley have been dated 1430 ± 150 Ma using Rb-Sr method (Bhanot *et al*, 1978).

2.6.3 Jutogh Group

2.6.3.A ***Granite***

A leucocratic granite body occurs as intrusive in the Jutogh rocks along Karcham-Sangla track. The granite is medium grained and foliated along the margins.

2.6.4 Vaikrita Group

2.6.4.A ***Rakcham Granite***

This granitic body, occurring in an arcuate pattern in SW Kinnaur, was named Rakcham Granite (Tewari *et al*, 1978). Further NW, it extends into the Parvati Valley of the Kulu district, whereas, towards SE through the Baspa-Chorgad valleys it joins the Gangotri Granite of the Garhwal Himalaya. It is a medium grained to porphyritic granite with biotite as a constant mafic mineral. The granite shows zoning defined by the finer grained margin, wider porphyritic zone followed by the medium grained non-foliated core. The outer zone is crudely foliated and contains numerous xenoliths and roof pendants of varying dimensions. Towards the northern contact, the xenoliths of slate, quartzite and schist resembling the rocks of the Batal and Morang Formations are present. Towards the southern contact, the gneissic element is prominent. The xenoliths of the metamorphic rocks show tightly folded foliation planes. The medium grained granite south of Thangi contains irregular bodies of fine grained brownish granite with biotite. The nodular xenoliths of tremolite-actinolite are observed between Thangi and Lambar. Pink granite is exposed around Rangchil Dogri.

The Rakcham Granite is emplaced along the contact of the Kharo Formation and the Morang and the Batal Formations. It shows concordant to discordant relationship with the country rock. Along the southern contact with the Kharo Formation, injection gneisses and migmatites are observed. Occasional tongues and apophyses occur along the northern contact which is more or less sharp. Biotite in the host rock has crystallised along this contact with addition of tourmaline indicating boron metasomatism. Pyrite in the Batal Formation also shows recrystallisation close to the contact.

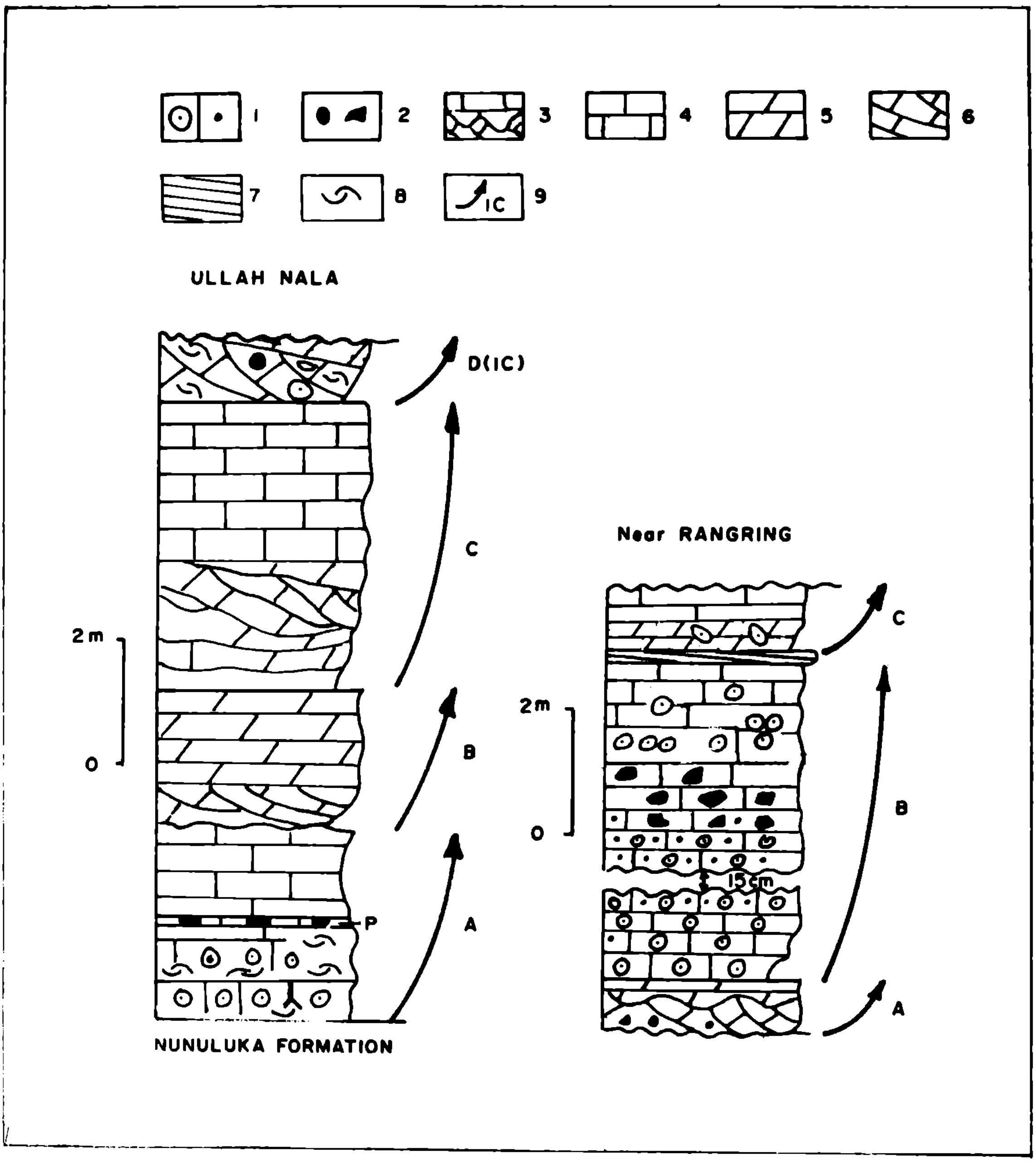


Fig. 2.91. Lithologs of a part of the Para Member. Expl: 1. Gritty/Oolitic rock, 2. Sharpstone, Conglomerate lenses, 3. Channel with fills, 4. Limestone, 5. Dolomite, 6. Cross-bedding, 7. Dolomite with sub-parallel bedding and low angle truncations, 8. Shells, and 9. Arrows indicate sedimentary cycles, I.C. Incomplete cycle.

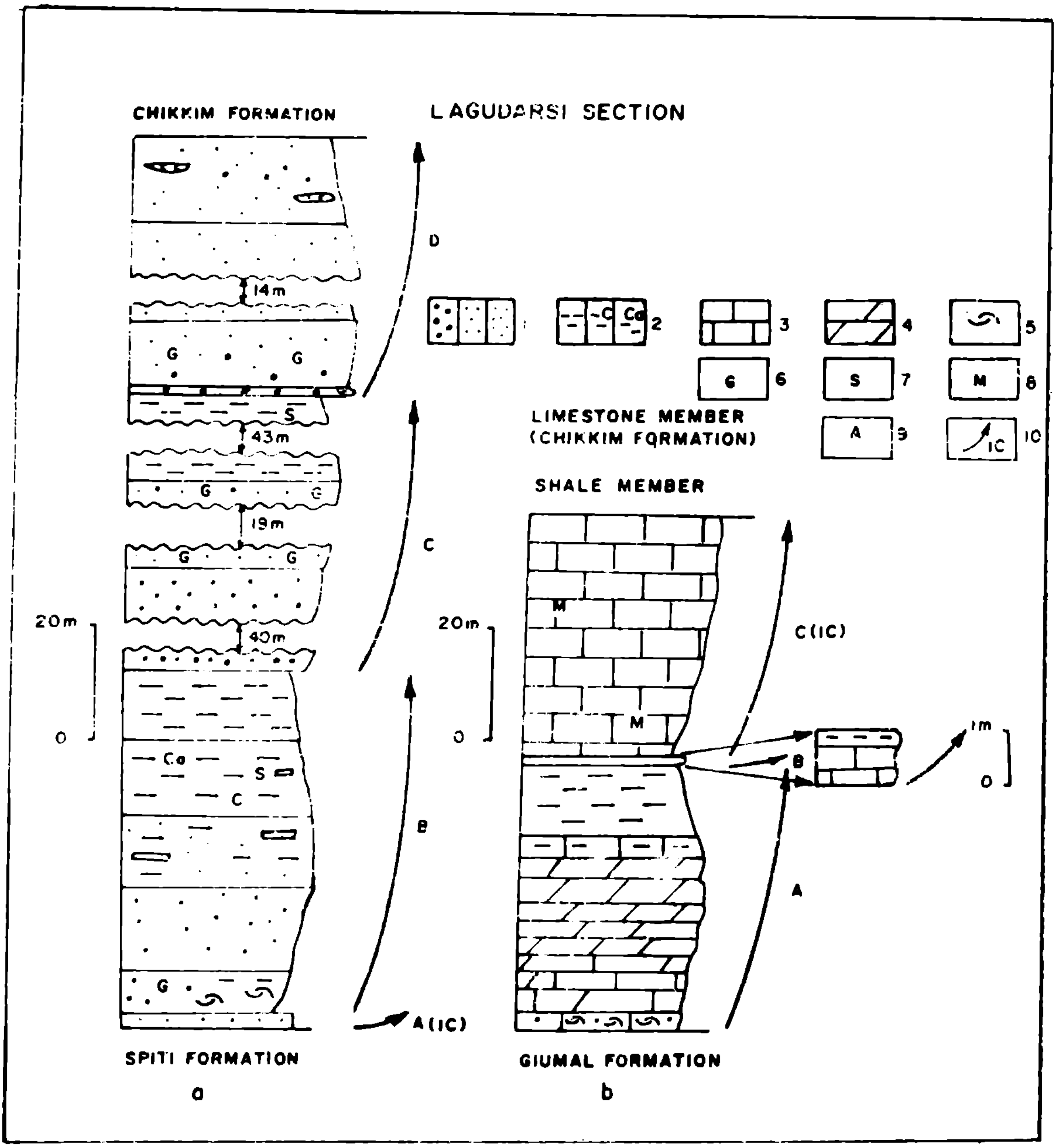


Fig. 2.92. Lithologs of the (a) Giumal Formation and (b) Limestone Member (Chikkim Formation). Expl: 1. Sandstone, coarse, medium fine, 2. Shale, calcareous, carbonaceous, 3. Limestone, 4. Dolomite, 5. Shells, 6. G-Glauconite, 7. S-Siltstone, 8. M-Marly 9. A-Argillaceous limestone, 10. Arrows indicate sedimentary cycles.

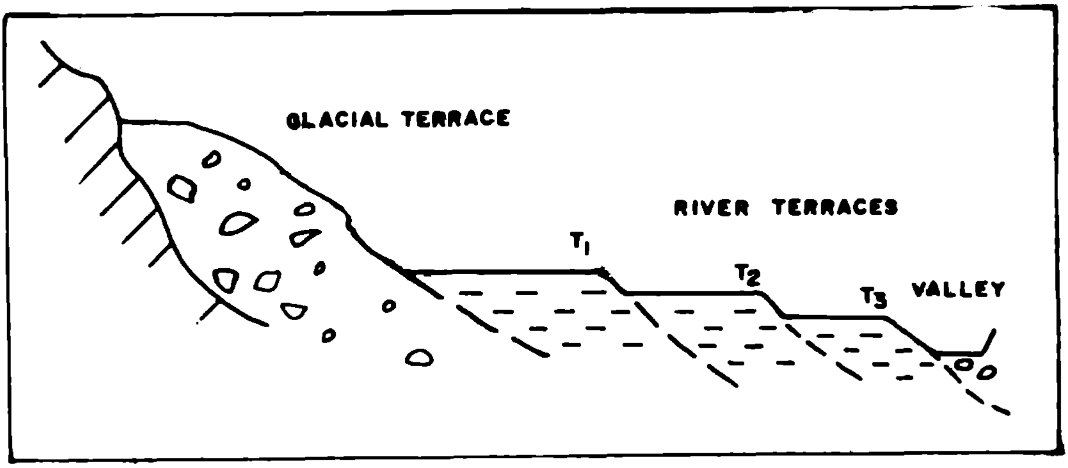


Fig. 2.93. Sketch showing three levels of fluvial terrace deposited over a glacial (fluvio-glacial) terrace. Loc. Thuku Lungba near Kiomo.

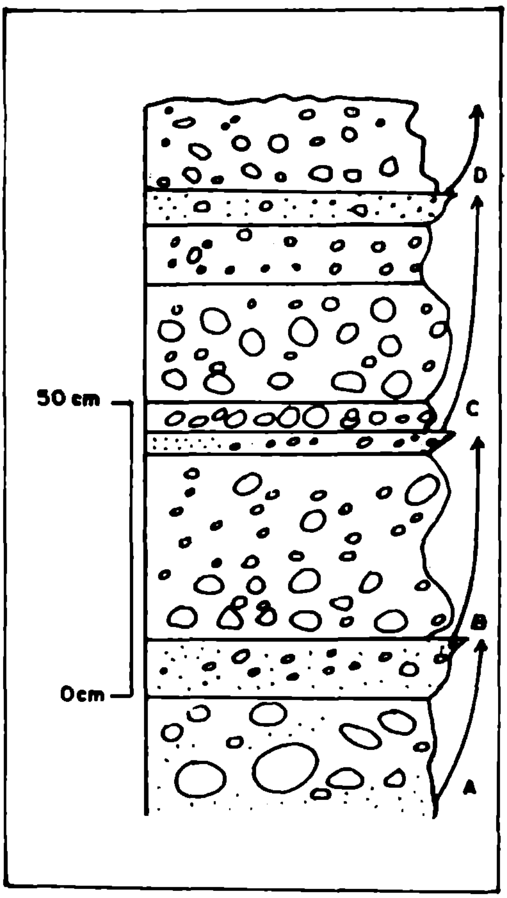


Fig.-2.94. Litholog of a part of the Quaternary fluvial deposit to show fining-up cycles. Loc. Thuku Lungba, near Kiomo.

Small bodies of leucocratic tourmaline granite have extensively intruded these granites in the Chorgad Valley which are identifiable from a distance. The later phases associated with the granite are pegmatite and aplite. In Kombo area, quartz-siderite-chalcopyrite and galena-sphalerite-pyrite veins are observed. The intensity of pegmatite veins is inversely proportionate to the distance from the contact; the outer periphery contains only quartz veins. The paragenesis of these phases, as inferred from field relationship, is biotite granite-tourmaline granite-pegmatite-aplite-quartz vein-quartz sulphide vein-quartz veins.

The steeply inclined easterly contact, general non-foliated character, sharp contact, finer grained margin and numerous xenoliths of the host rocks suggest that the Rakcham granite is intrusive into the Vaikrita-Haimanta Group rocks.

The Rakcham Granite has been dated 495±50 Ma by Rb-Sr method (Sharma, 1983), whereas, the tourmaline-leucogranite of the Jadhganga Valley yielded a K-Ar age of Miocene (Seitz *et al,* 1974).

2.6.4.B *Nako Granite*

It is exposed mainly in the Tashigang-Nako-Leo Pargial area, smaller bodies of which are observed right from Khab-Shipki to Pare *Chu* Valley in the north. The Nako Granite locally forms large outcrops. However, similarity in character of isolated outcrop suggests these to be part of a single granite body having batholithic dimension, which due to limited erosion has not been fully exposed. The outcrops of this granite are restricted to the area east of Kaurik Fault Complex, *i.e.* on the footwall side only.

The Nako Granite is massive, non-foliated, leucocratic and contain both tourmaline and biotite. Outcrops east of Tashigang and SW of Namgiya are biotite rich, foliated and yellow-brown stained. Along NH-22, between Kah Dogri and Yangthang, it shows local concentration of acicular tourmaline and biotite-rich bands. The Nako Granite is intrusive into the Precambrian Morang Formation and the early Carboniferous Lipak Formation. The contact effect on Morang schist is not very pronounced though it has thermally metamorphosed the Lipak Carbonates into marble (Pyroxene-hornfels facies) and associated gypsum to anhydrite. Numerous pegmatite and aplite veins of varying dimensions are observed around these granites. These cut through folds, occupy the flexures and fill up the crests of the folds. The composition of the pegmatite is quartz-felspar + biotite + muscovite + tourmaline + kyanite + beryl + garnet. Some of these show anomalous value of lithium. The aplite is devoid of biotite.

The Nako Granite has been dated 108 $\pm$ 17 Ma by Rb-Sr method (Kwatra *et al*, 1987). The modal mineral analysis of the Nako Granite (Table-2.2) defines it as a granite-alkali granite (Streckeisen, 1976). The chemical analyses of fifteen representative samples are given in Table 2.3A-B and the CIPW norm calculated from these analyses are presented in Table-2.4. The Or-Ab-An plots (Fig.2.102) in general fall in the granite field with one each in granodiorite and tonalite and one along the line dividing these two fields. The K_2O-Na_2O-CaO plots mostly lie in the Quartz-monzonite-granodiorite field (Fig.2.102) with two samples falling in the tonalite field. The variation to tonalite is shown by samples G-1 and 2 which have high CaO. The high CaO presumably could be due to assimilation of the country rock which is marble in this particular case. Na_2O/K_2O ratio (Table-2.5) also suggests granitic-granodioritic composition. The Al_2O_3/Na_2O+K_2O plots (Westra and Keith, 1981) show that the rock is per-aluminous. The high corundum value (4.08-13.87) in the CIPW norms and the greater than one A/CNK ratio (Table 2.5) substantiate the above surmise. These conclusions when viewed along with high Sr_{87}/Sr_{86} ratio (0.7225+0.0011, Kumar, 1986) suggest that these are typical S-type granites.

The total Fe-Na_2O-K_2O and SiO_2-Al_2O_3/ (Na_2O+ K_2O) plots (Fig.2.102) lie exclusively in the calc-alkaline field. Such suites are largely believed to have been generated in the shallow mantle wedge above lateral compressive zones of oceanic crust destruction and are related to compressional tectonism (Brown, 1979).

The K–57.5 values of this granite (Table-2.5) are in general above 2 which is characteristic of the molybdenum bearing granites.

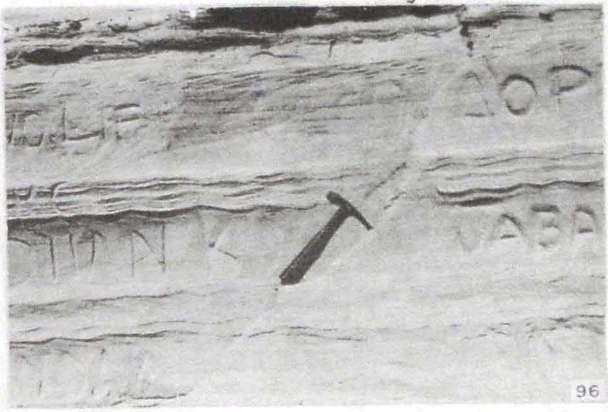
Table 2.2

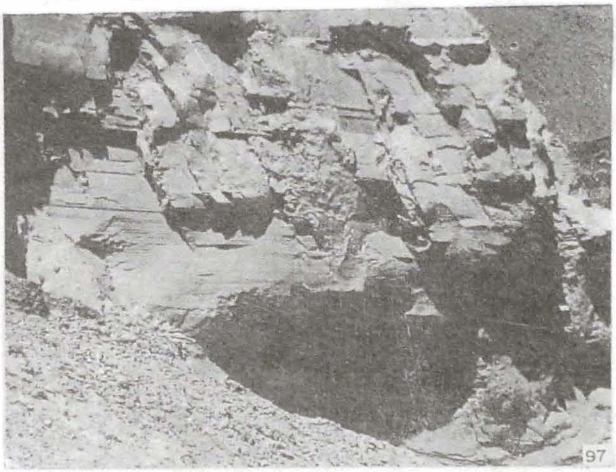
Modal Composition of Nako Granite, Kinnaur

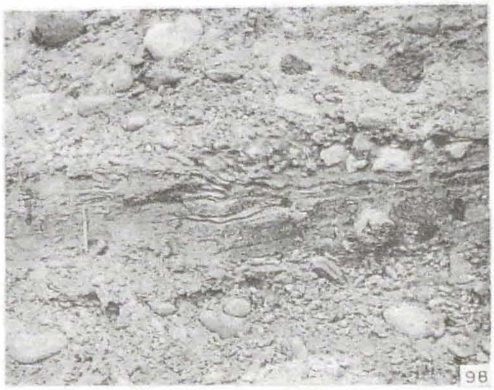
	B_1	B_2	B_8	B_9	B_{14}	B_{20}	B_{20A}	B_{29}	B_{32}
Quartz	50.00	44.00	54.40	44.40	22.10	54.70	45.10	30.30	28.70
K-felspar	29.00	37.10	22.80	40.10	50.20	15.70	27.60	34.80	59.10
Plagioclase	13.30	6.60	7.20	9.40	16.20	5.90	4.30	13.10	3.60
Biotite	1.20	-	13.80	-	7.50	3.30	-	-	3.10
Muscovite	6.50	3.30	1.80	6.10	4.00	20.40	10.20	6.40	0.50
Tourmaline	-	6.90	-	-	-	-	12.80	8.40	-
Opaques	0.10	2.10	0.10	-	-	0.20	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.20	100.10	100.10	100.00

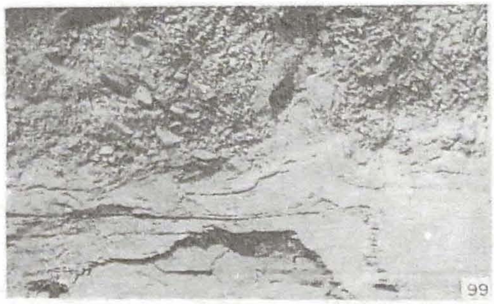
Nomenclature---Granite---------------------------------------Alkali Felspar Granite

Figs. 2.95 - 2.101









Explanation of Figs. 2.95 - 2.101

Fig. 95. Quaternary lacustrine rhythmites resting over a palaeo-avalanche slide. Loc. about one kilometre from Atargoo bridge along Guling road. **Fig. 96.** Quaternary lacustrine deposits at Sumdo showing wavy bedding. **Fig. 97.** Quaternary lacustrine rhythmites at Chango. **Fig. 98.** Fine sand to silt bed in a fluvial sequence, representing local ponding of the River. About 500m south of Rangring bridge. **Fig. 99.** Flame structure formed by squeezing of finer material due to load of superincumbent coarser material in Quaternary lacustrine deposit. Loc. Along NH-21 at left abutment of the Sar *chu* bridge (Lahaul). **Fig. 100.** Climbing ripple lamination in Quaternary lacustrine deposit. Loc. Sumdo. **Fig. 101.** Lenticular bedding in Quaternary lacustrine deposit. Loc. Sumdo.

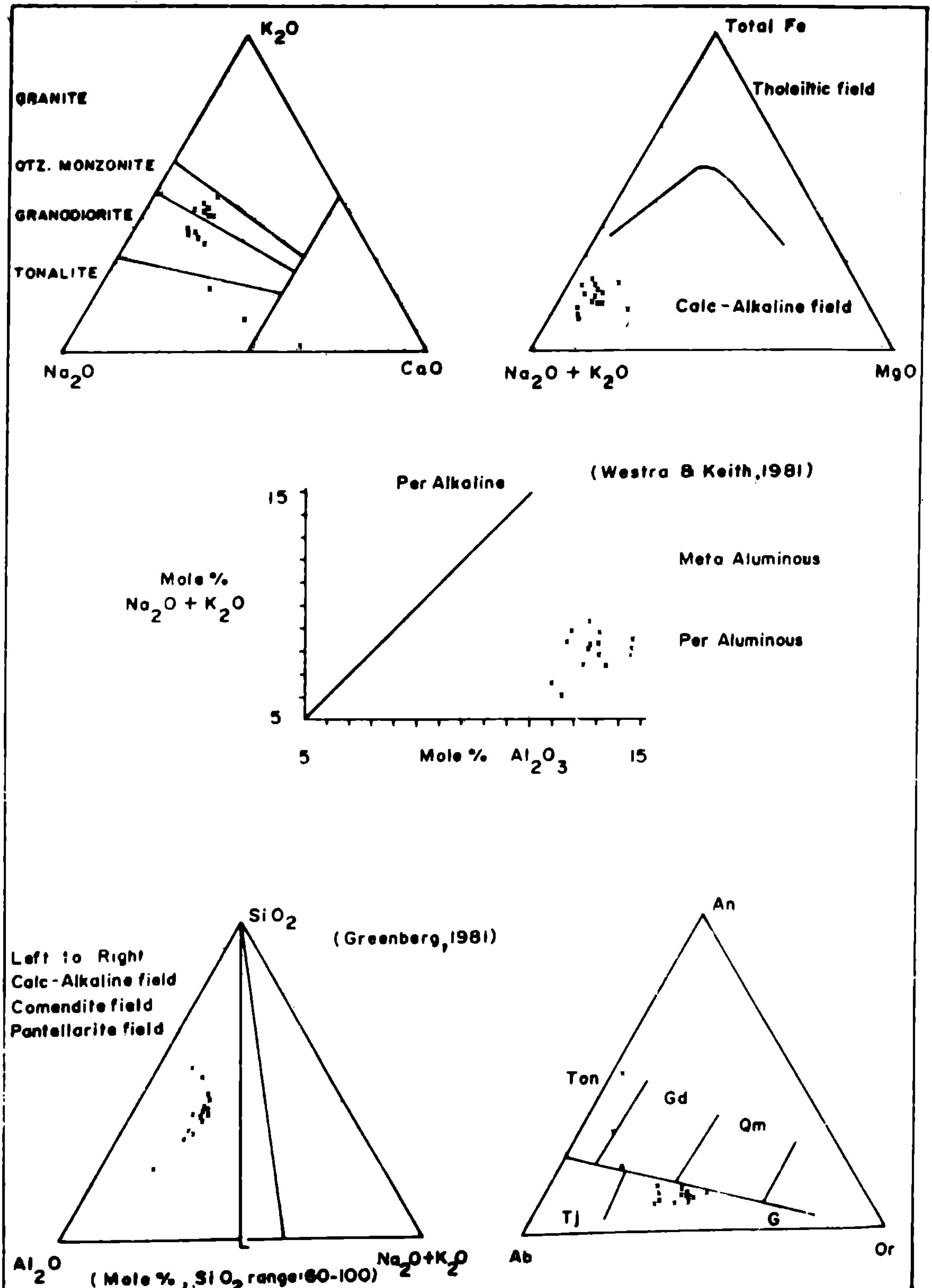


Fig. 2.102. Various chemical plots of Nako granite.

Table 2.3a

Chemical analysis (major elements) of Nako Granite, Yangthang area

Sl No	Sample No	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	FeO %	CaO %	MgO %	Na_2O %	K_2O %	$+H_2O$ %	$-H_2O$ %	MnO %	TiO_2 %	P_2O_5 %	CO_2 %	L.O.I.
1	B-8	71.00	18.00	1.40	0.40	1.40	0.40	3.00	3.20	0.80	0.20	<0.01	<0.01	0.15	-	-
2	B-10	70.40	18.00	1.50	0.30	1.30	0.60	3.80	3.00	0.80	0.20	<0.01	<0.01	0.10	-	-
3	C-3	70.80	17.20	0.34	1.08	1.40	1.10	3.53	2.90	1.30	0.20	<0.01	<0.01	0.05	-	-
4	C-4	72.30	17.00	0.80	0.50	1.40	0.80	3.40	2.70	0.80	0.20	<0.01	<0.01	0.10	-	-
5	C-5	72.00	17.00	0.80	0.30	1.40	0.60	3.00	3.40	1.00	0.20	<0.01	<0.01	0.10	-	-
6	F-1	68.50	20.00	0.37	0.54	1.40	0.70	2.70	3.88	1.50	0.10	<0.01	<0.01	0.05	-	-
7	F-3	70.20	18.80	1.10	0.40	2.20	0.60	3.60	1.40	1.00	0.20	<0.01	<0.01	0.10	-	-
8	F-4	70.10	18.90	1.40	0.40	0.90	0.80	3.10	3.10	0.85	0.30	<0.01	<0.01	0.05	-	-
9	F-5	68.66	19.86	1.15	0.30	1.40	0.80	2.77	3.10	0.70	0.70	<0.01	<0.01	0.10	-	-
10.	J-5	70.30	17.97	1.50	0.60	1.10	0.60	2.80	3.40	0.60	0.40	<0.01	<0.01	0.05	-	-
11	H-3	68.55	19.95	0.70	0.60	1.60	0.90	3.30	2.50	0.70	0.40	<0.01	<0.01	0.10	-	-
12.	H-4	68.86	18.50	0.60	0.60	1.40	0.60	3.10	3.60	1.10	0.10	<0.01	<0.01	0.10	-	-
13	H-5	74.40	16.70	0.32	1.26	0.80	1.00	2.50	2.24	-	-	0.04	0.20	0.05	-	0.78
14.	G-1	65.30	25.00	0.89	0.20	2.95	0.60	3.10	0.72	-	-	TR	TR	TR	-	0.92
15.	G-2	74.10	16.25	0.16	0.36	4.42	0.80	2.40	0.20	-	-	TR	0.20	TR	-	0.94
16.	G-3	64.20	13.50	0.13	0.36	9.44	1.12	2.40	2.40	-	-	0.05	0.10	0.03	-	5.96

(Analysed at the Central Chemical Laboratory, GSI, Calcutta by S/Shri M.C. Borai, a.K. Mukherjee, N.K. Sinha and S. Lahiri)

Table 2.3b

XRF analysis (minor elements) of the Nako Granite, Ynagthang area

Sl.No.	Sample No.	Sn ppm	Cr ppm	Ga ppm	Bi ppm	Ag ppm	Mn ppm	Zr ppm	Ba ppm	Sr ppm	Be ppm
1.	B-8	G-1000	1-10	1-10	1-10	1	200	1-10	40	1-50	1-10
2.	B-10	400	1-10	10	1-10	1-1	500	20	1-10	1-50	30
3.	C-3	300	1-10	1-10	1-10	1-1	150	1-10	80	1-50	1-10
4.	C-4	200	1-10	1-10	1-10	1-1	100	1-10	60	1-50	1-10
5.	C-5	100	1-10	1-10	1-10	1-1	100	1-10	150	1-50	1-10
6.	F-1	80	1-10	10	1-10	1-1	150	10	150	1-50	1-10
7.	F-3	70	1-10	1-10	1-10	1-1	200	20	30	1-50	1-10
8.	F-4	70	1-10	10	1-10	1-1	250	1-10	120	1-50	1-10
9.	F-5	80	1-10	1-10	1-10	1-1	100	1-10	100	1-50	1-10
10.	J-5	80	1-10	1-10	1-10	1-1	150	1-10	200	1-50	1-10
11.	H-3	80	1-10	10	1-10	1-1	100	10	250	1-50	1-10
12.	H-4	10	1-10	1-10	1-10	1-1	50	1-10	160	100	1-10
13.	H-5	40	15	1-10	1-10	1-1	250	1-10	50	1-50	1-10
14.	G-1	30	1-10	10	0-15	1-1	1-10	1-10	1-10	100	10
15.	G-2	10	1-10	1-10	1-10	1-1	1-10	1-10	1-10	100	10
16.	G-3	10	1-10	10	30	1-1	250	1-10	1-10	300	10

(Analysed at the Central Chemical Laboratory, GSI, Calcutta, by S/Shri D.K. Indria, P.Ray Chaudhury and D.K. Banerjee)

Table 2.4

CIPW normative mineral percentage of the Nako Granite

Mineral	B-8	B-10	C-3	C-4	C-5	F-1	F-3	F-4	F-5	J-5	H-3	H-4	H-5	G-1	G-2	G-3
Rock analysis	99.97	100.02	99.92	100.04	99.82	99.76	99.62	99.42	99.56	99.34	99.32	99.58	100.09	99.68	99.83	99.93
Quartz	38.52	33.84	34.32	38.70	38.40	34.26	39.24	37.86	37.20	38.16	35.76	34.74	48.12	37.50	49.20	26.58
Orthoclase	18.90	17.79	17.24	16.12	20.57	23.35	8.34	18.35	18.90	20.57	15.01	21.68	12.23	4.45	1.11	15.01
Albite	25.68	32.49	30.39	28.82	25.68	23.06	30.92	26.72	24.10	24.10	28.30	26.72	21.48	26.72	20.44	21.48
Anorthite	6.12	5.56	6.95	6.12	6.12	6.95	10.29	4.45	6.12	5.56	7.23	6.12	3.89	14.73	22.24	20.29
Diopside C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.94
Diopside M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.00
Diopsite F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.53
Hypersthene M	1.00	1.50	2.80	2.00	1.50	1.80	1.50	2.00	2.00	1.50	2.30	1.50	2.50	1.50	2.00	-
Hypersthene F	-	-	1.72	0.26	-	0.79	-	-	-	-	0.53	0.53	1.85	-	0.13	-
Ilmenite	-	-	-	-	-	-	-	-	-	-	-	-	0.46	-	0.46	0.15
Magnetite	1.39	0.93	0.46	1.16	0.93	0.46	1.39	1.39	0.93	1.86	0.93	0.93	0.46	0.70	0.23	0.23
Haematite	0.48	0.80	-	-	0.16	-	0.16	0.48	0.48	0.32	-	-	-	0.48	-	-
Corundum	7.45	-6.53	5.81	6.32	6.22	9.08	7.75	8.57	9.97	7.75	9.38	7.34	8.98	13.87	4.08	-
Wollastonite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.35
Apatite	0.34	0.34	-	0.34	0.34	-	0.34	-	0.34	-	0.34	0.34	-	-	-	-
Total Normative %	99.87	99.77	99.69	99.84	99.91	99.75	99.92	99.82	99.86	99.82	99.77	99.90	99.97	99.95	99.89	99.68

(Computerised analysis from AMSE, GSI, Bangalore)

Table 2.5
K-Test for Nako Granite, Yangthang area

Sl.No.	Sample No.	K-57.5 Value	A/CNK Ratio	FeO/FeO + MgO	K_2O/Na_2O
1.	B-8	2.59	1.64	0.81	1.07
2.	B-10	2.45	1.62	0.73	0.79
3.	C-3	2.36	1.50	0.66	0.82
4.	C-4	2.15	1.64	0.60	0.79
5.	C-5	2.72	1.62	0.63	1.13
6.	F-1	3.26	1.79	0.66	1.44
7.	F-3	1.15	1.64	0.70	0.39
8.	F-4	2.54	1.82	0.67	1.00
9.	F-5	2.60	1.90	0.63	1.12
10.	J-5	2.78	1.76	0.76	1.21
11.	H-3	2.10	1.81	0.58	0.76
12.	H-4	2.96	1.60	0.66	1.16
13.	H-5	1.58	2.15	0.61	0.82
14.	G-1	0.63	2.22	0.63	0.23
15.	G-2	0.16	1.33	0.39	0.08

3. PETROGRAPHY

The petrography of the Tethyan sedimentary sequence, with which this write-up mainly deals, is described here. Clastic and carbonate rocks have been dealt with separately.

3.1 CLASTICS AND ASSOCIATED VOLCANOCLASTIC ROCKS

3.1.A Haimanta Group

3.1.A$_1$ *Kunzam La Formation*

Volcanic-Volcaniclastic rocks : The volcanic suite of the Kumzam *La* Formation includes rhyolite tuff. volcaniclastic ash fragments, quartz crystal tuff, carbonaceous chert, magnetite tuff and sachharoidal carbonate rock (Bassi and Chopra, 1984). The rhyolite tuff is white in colour and is made up of partially altered Na-plagioclase, interlocking fine grained quartzose material, muscovite, zircon, leucoxene, siderite rhombs, primary pyrite and fragments of devitrified glass. The volcaniclastic ash is represented by cryptocrystalline to opalline silica, magnetite dust and fragments of partially devitrified glass with palagonite rim (Fig.3.2). Some of the rims show iron-leaching. The magnetite tuff consists of magnetite octahedra (Fig.3.3) in an opalline to very fine quartz-ash matrix with partially devitrified glass fragments. The glass fragments have a colourless core and brownish/greenish rim. The magnetite octahedra do not show any abrasion and occur as ash fall. Partial devitrification of glass enveloping the magnetite grains has formed fibrous silica along the crystal boundaries. Ash occurs as inclusions in magnetite. Magnetite contains following trace elements (Bassi and Chopra, 1984).

Elements	Cu	Ni	Co	Ba	Ga	V	Cr	Ti	Zn
Values (in ppm)	30	20	10	10	10	300	60	160	30

The X-ray study revealed the presence of minor silica and absence of maghemite, indicating either absence of water or lack of rapid oxidation at low temperature during its formation.

A number of tuffaceous lenses containing euhedral quartz and felspar in a matrix of fine dust occur upstream of Lamoche in the Hojis Valley and in the Chorgad Valley near Nakurche. Spindle shaped lapilli-like clasts are observed in the tuffs of the Hojis Valley. The rock at Nakurche is calcareous and contains recrystallised carbonate, biotite, chlorite, sphene, apatite and octahedral magnetite, possibly of pyroclastic origin.

Clastic rocks : The siltstone and wacke of the unit A (Parahio section) comprise poorly sorted, subangular to subrounded quartz grains and rare felspar in a matrix (50%) of sericite, clay and quartz. Some microsections show rippled cross lamination (Fig.3.4). A few rock fragments of biotite schist and slate occur in the rocks. The rocks of the basal part of the unit A contains heavy mineral group represented by staurolite, chlorite, zircon, zoisite and tourmaline.

The greyish white, micaceous and felspathic quartz-arenite of the unit B is fine grained, poorly sorted rock having as much as 15% of plagioclase felspars. The other minerals are brownish and green biotite, tourmaline and apatite.

The siltstone and quartzwacke of the unit C are composed of poorly sorted, subangular to subrounded quartz in a clayey-sericitic-quartzitic matrix. Grey green micaceous siltstone and quartz-wacke of this unit are texturally immature and are made up of poorly sorted subangular to subrounded quartz in an argillaceous matrix. The quartzarenite of the unit C is made up of fairly well-sorted subangular quartz in a subordinate argillaceous matrix.

Pink, green and white quartzarenite of the unit D is made of sorted subrounded to rounded quartz (65-98%) set in an argillaceous-fine quartzitic matrix.

3.1.B Sanugba Group

3.1.B$_1$ *Thango Formation*

The sandstone and siltstone of the Thango Formation comprise moderately sorted to poorly sorted, subangular to subrounded and moderately to well spheric quartz (70-75%) in a clayey to cryptocrystalline ferruginous/calcareous matrix. In most of the sections palagonite fragments have been noticed. The early siliceous cement has been replaced by ferruginous and carbonate cements. Opaques (73%), epidote (9%), muscovite (9%), zircon (4.5%) and light brown tourmaline (4.5%) constitute the heavy mineral assemblage.

3.1.B_2 *Takche Formation*

The grey fine grained sandstone of Lankapanug section contains fine angular quartz (75%), felspar, opaques, shell-fragments in an argillaceous matrix, while one in the Manchap section contains well sorted angular to subangular quartz, a few grains of tourmaline and calcite.

3.1.C Kanawar Group

3.1.C_1 *Muth Formation*

The quartzarenite is composed of moderately sorted, subrounded to well sorted and well rounded quartz (90-95%), varying in size from 60 to 250 microns (average being around 150 micron). Most of the quartz grains showing authigenic growth occur in a cryptocrystalline matrix (2-5%) and are cemented by silica, which has been partially replaced by secondary ferruginous cement. Felspar (0.2%), quartzite fragments (0.15%) and iron oxide grains (0-0.5%) form the accessories.

3.1.C_2 *Lipak Formation*

The dark greyish arenite is poorly sorted, subarkosic with subangular quartz (50%) and felspar (10%), embedded in an argillo-arenaceous matrix. Tourmaline and opaques constitute the accessory minerals. The white quartzarenite is moderately sorted, fine grained rock with about 90% of clean fine and subhedral quartz grains embedded in mainly arenaceous/siliceous matrix. Occasional felspar, biotite flake or muscovite and some opaques are also observed. The quartz grains in arenite show authigenic growth.

3.1.C_3 *Po Formation*

The siltstone and fine grained sandstone of the Po Formation are made up of moderately to well sorted, subangular to subrounded, 15-45 micron size mostly turbid quartz having minute inclusions. The matrix is mostly argillaceous and at places ferruginous. Silica forms the primary cement, which has been replaced by iron oxide. Sodic plagioclase and rare palagonite occur as accessories.

3.1.C_4 *Ganmachidam Formation*

The gritty sandstone (Fig. 3.5) is made of rounded to well rounded, poorly sorted quartz (55%) with extensive authigenic growth and corroded margins in a crystalline silt-size matrix. Early silica cement has been largely replaced by ferruginous and micritic cements. The rock fragments (20%) are of micrite, chert, sandstone, shale, siltstone and fossils.

The lithicwacke is poorly sorted, stratified and comprises non-undulatory rounded quartz (15)% in the size range of 60-120 microns and 250-750 microns in a ferruginous-argillaceous matrix (60%). The accessories are of ferroan sparry calcite and sporadic muscovite, iron oxide and felspar.

3.1.D Kuling Group

3.1.D_1 *Gechang Formation*

The sandstone varies in composition from calcareous quartzarenite to quartzwacke. The latter consists of moderately sorted, rounded to well rounded quartz (50-55%) in two main size ranges of 100-250 microns and 300-650 microns, with a few grains as large as 1000 microns. The matrix (35-40%) is micritic, ferroan-calcitic to silty quartzose. The cement is ferruginous which is partially/replaced by secondary silica. The rock fragments (10%) are exclusively of sedimentary rocks.

3.1.D_2 *Gungri Formation*

The thin lenticular arenite beds are made up of fine to silty quartz grains (70%) in an argillaceous matrix. The nodules are observed to be composed of chert-collophane or chert along with pyrite grains, biomorphs and bioclasts of cephalopod, brachiopod, crinoid and endothyrid foraminifer.

3.1.E Lilang Group

3.1.E_1 *Nunuluka Formation*

The sandstone is constituted of moderately sorted, rounded to subrounded quartz cemented by calcite (5-15%), which has peripherally replaced the quartz grains. The calcite cement has been partly replaced by secondary ferruginous cement.

3.1.F Lagudarsi Group

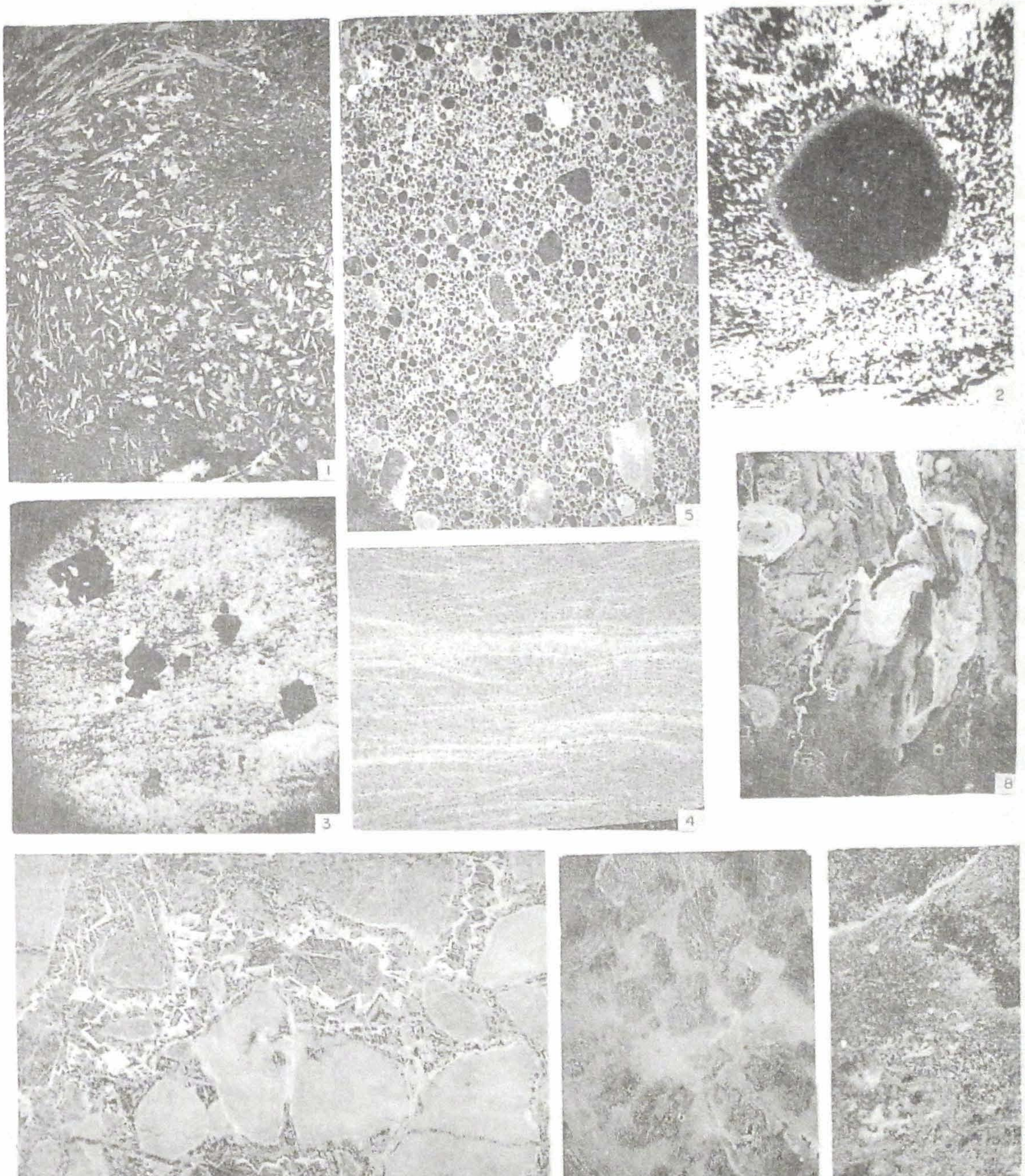
3.1.F_1 *Spiti Formation*

The sandstone comprises poorly sorted rounded to subrounded 250-350 micron size quartz (80%) and felspar (microcline and plagioclase together forming about 10%) in a silty to clayey homogeneous matrix. The primary ferruginous cement has been replaced by siliceous cement.

3.1.F_2 *Giumal Formation*

The sandstones are of following four types. (a) Quartzarenite to quartzwacke which are made up of poorly sorted, rounded, subrounded to subangular, bimodal quartz (85-90%) of moderate sphericity in an argillaceous matrix (8-10%) with pigmentary glauconite. The accessories are formed by potash felspar, soda-plagioclase, clay and

Figs. 3.1 – 3.9



Explanation of Figs. 3.1 - 3.9

Fig. 1. Sillimanite bearing schist, (Slide print, henceforth SP) Morang Formation. Loc. Khab. **Fig. 2.** Palagonite rim around devitrified glass in volcanoclastic ash, Kunzam *La* Formation. Loc. Mangsu *La*. **Fig. 3.** Magnetite octahedra in tuff, Kunzam *La* Formation. Loc. Mangshu *La*. **Fig. 4.** Rippled cross-lamination in siltstone, Kunzam *La* Formation (SP). Loc. Moppo. **Fig. 5**. Gritty sandstone, Ganmachidam Formation (SP). Loc. Mardang *Nala*. **Fig. 6.** Collapse breccia with iron coated micrite fragments in sparitic matrix, filled by coarser sparitic cement. Stylolites, high peaked, mostly along cement-matrix contact, (SP) Kunzam *La* Formation. Loc. Baralacha Pass. **Fig. 7.** Bioturbated mottled, carbonate mudstone, Kunzam *La* Formation (SP). Loc. Baralacha Pass. **Fig. 8.** Pisoids with micritic rim. Bird's eye fillings (SP). Kunzam *La* Formation. Loc. Baralacha Pass. **Fig. 9.** *Epiphyton* in mudstone. Note ferruginous material along stylolites (SP), Kunzam *La* Formation. Loc. Baralacha Pass. (Bar scale is 2mm for Figs. 3.1,3.4 - 3.8 and 1mm for Figs. 3.2 - 3.3 and 3.9)

glauconite. The authigenic silica, ferruginous matter and pigmentary glauconite constitute the cement. (b) Glauconitic quartzwacke with two subvarieties comprising (i) moderately sorted, rounded and bimodal quartz (70-80%) of moderate sphericity showing authigenic growth, felspar and biotite inclusions, potash felspar and soda-plagioclase (5%), glauconitic-argillaceous-quartz cryptocrystalline matrix (10%) and ferruginous, siliceous and glauconitic cements (5-7%), (ii) moderately sorted, subangular to subrounded fractured glauconite coated quartz (70-75%) and pigmentary limonitic-margined pellets of glauconite (25-30%), the latter could be modified faecal matter (c) Calcareous quartz subwacke composed of moderately sorted, subrounded quartz (75%), felspars mainly plagioclase (1%), ovoidal to pigmentary glauconite (5%), with interspace entirely filled by sparry calcite (10-15%). (d) Felspathic quartzwacke constituted of moderately sorted, subrounded quartz (80-85%) of moderate sphericity, microcline, orthoclase and plagioclase (combined percentage 5-8%) in a cryptocrystalline matrix of quartz and clay with siliceous cement.

3.1.F$_3$ *Chikkim Formation*

The shale is made up of 15-39 micron size subrounded to rounded quartz (10-20%) in a marly paste (40-70%) with ferruginous cement.

3.2 CARBONATE MICROFACIES

3.2.A Haimanta Group

3.2.A$_1$ *Kunzam La Formation*

The carbonate microfacies recorded in this formation are (a) mudstone with (i) fenestral fabric filled with sparite, (ii) collapse breccia, brecciated micrite with Fe-rim and filled by sparite strongly stylolitised (Fig. 3.6), (iii) micritic peloids, with sparite, (iv) bioturbation (Fig. 3.7), (v) bioclasts (trilobite), (vi) upto 0.3cm size pisoids occasionally broken and with micritic rims, (vii) bird's eye filling (Fig. 3.8) and (viii) micro-colonies of *Epiphyton* (Fig. 3.9) having inhomogeneous matrix showing micritic and cleaner and coarser mud with contact defined by ferruginous cement filled stylolites, a few recrystallised ooids, secondary sparitic cement, and (b) bioclastic wackestone and lithoclastic/ peloidal wackestone.

3.2.B Sanugba Group

3.2.B$_1$ *Thango Formation*

Lenticular calcareous beds occurring in the basal part of this formation at Hango and in the Tidong Valley are represented by bioclastic mudstone. The bioclasts are mainly of crinoids.

3.2.B$_2$ *Takche Formation*

The microfacies of this Formation have been described by Bhargava and Bassi (1986). Only important types are being illustrated here.

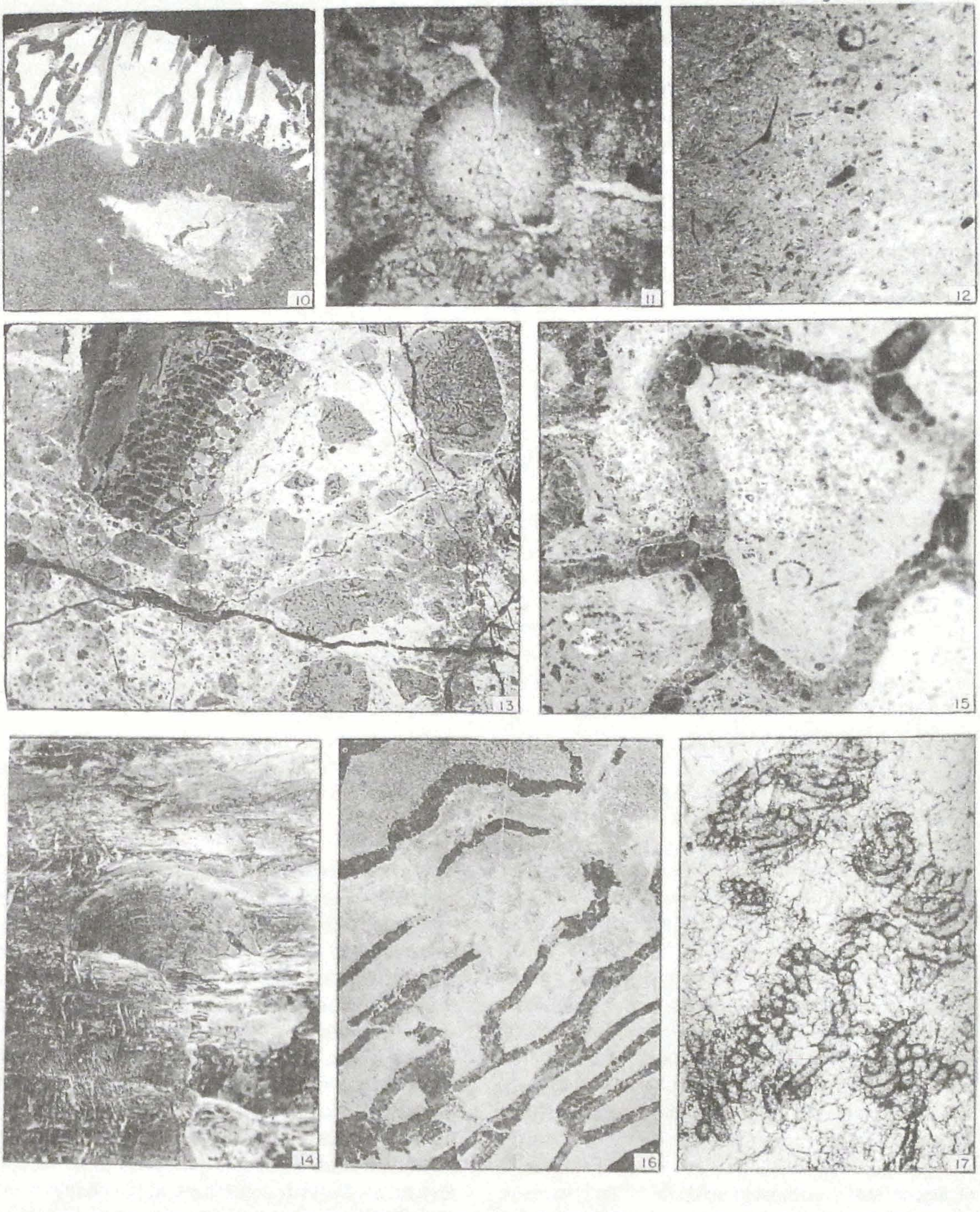
Takche section : (a) Arenaceous mudstone containing moderately sorted quartz, (b) bioclastic quartz wackestone and calcareous quartz wackestone containing subrounded to rounded moderately sorted quartz, (c) calcareous sandstone, (d) fossil wacke/ packstone containing *Halysites*, crinoid ossicles, brachiopods and trilobite fragments.

Parahio section : (a) Calcareous siltstone containing coarse angular well sorted silt with micritic cement partially replaced by ferruginous cement, (b) bioclastic wacke/packstone with clasts of *Favosites*, *Halysites*, crinoids, echinoid plates, trilobite fragments and recrystallised sparite, (c) bioturbated mudstone, (d) *Thamnopora* (?) framestone, (e) *Halysites* boundstone (Fig. 3.16), (f) *Plasmoporella* (?) boundstone. Chambers of *Favosites* and *Halysites* are filled with spherulitic chert and open spaces with equant ferruginous calcitic cement.

Pin Valley : (a) Bioturbated mudstone, (b) bioclastic/wacke/packstone having clasts of crinoids, corals, brachiopods and trilobites, (c) sponge-stromatoporoid boundstone (d) *Halysites* boundstone.

Leo section : (a) Mud/wackestone containing fossil fragments and rare complete fossils with syntaxial to sparitic cement. (b) Pack/grainstone forming the bulk of the microfacies (60%) which can be subdivided into (i) bioclastic pack/grainstone (ii) lithoclastic pack/grainstone and (iii) layered bioclastic pack/grainstone, the matrix in these rocks being homogeneous, ferruginous to micritic and constitutes 30-80% of the rock; the bioclasts include crinoids (mainly in the basal part), brachiopod shells, echinoid spines, bryozoans, ostracodes, and corals. (c) Bioclastic floatstone containing clasts of stromatoporoids, brachiopods and corals. (d) Bindstone divisible into (i) *Ecclimadictyon* bindstone showing arched nodular colonies encrusting *Halysites* (Fig. 3.10), (ii) encrusting solitary corals, (iii) *Parachaetetes* bindstone and (iv) bryozoan bindstone. (c) Framestone constituted of (i) stromatoporoid, (ii) *Halysites* and (iii) *Favosites*.

Figs. 3.10 – 3.17



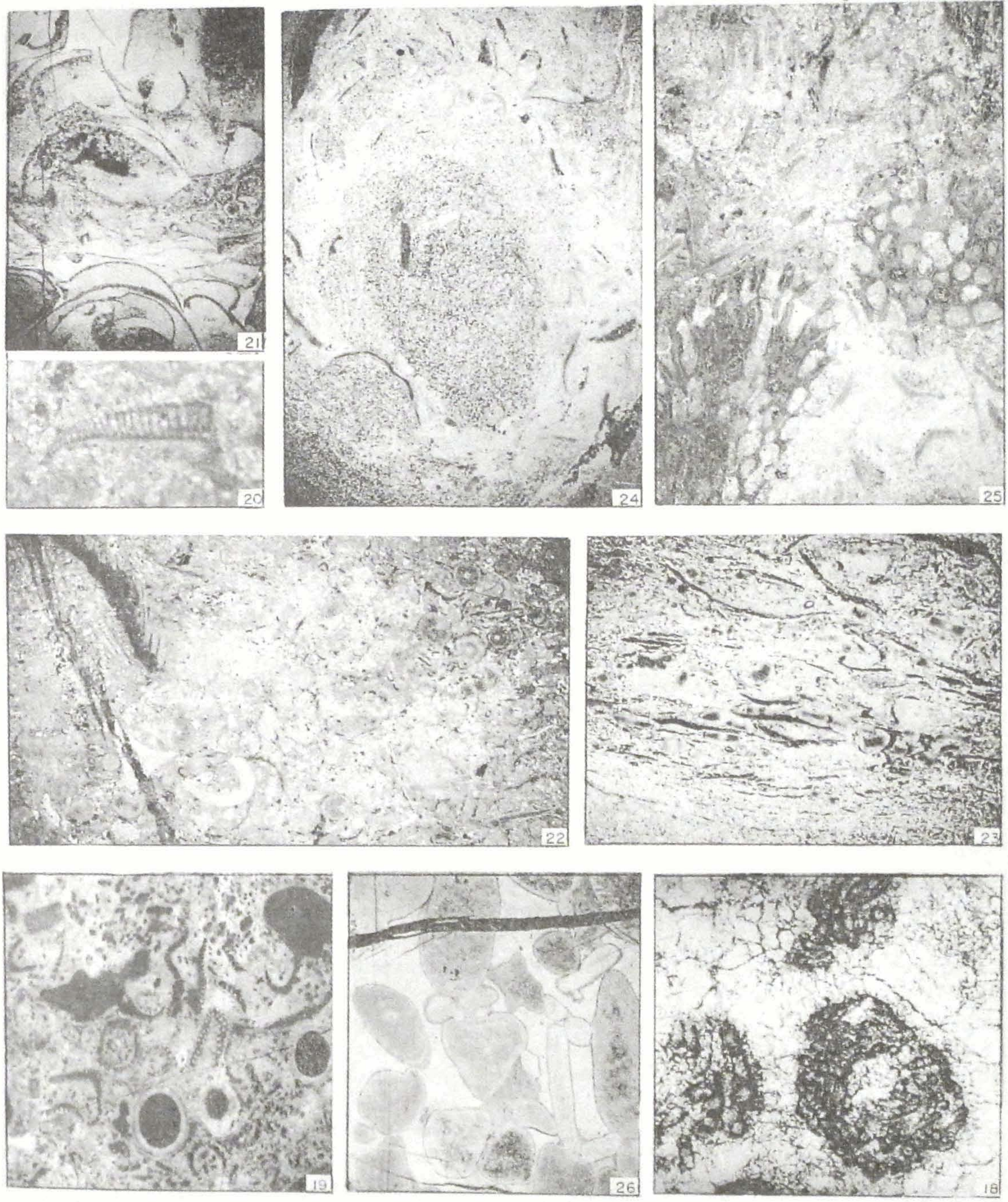
Explanation of Figs. 3.10 - 3.17
(Unless specified all are slide prints)

Fig. 10. *Halysites* encrusted by *Ecclimadictyon* stromatoporoid, Takche Formation. Loc. Manchap. **Fig. 11.** Flask shaped microproblematica, Takche Formation. Loc. Manchap. **Fig. 12.** Sponge - spicule wackestone, Takche Formation. Loc. Manchap. **Fig. 13.** *Favosites - Vermiporella* rudstone, Takche Formation. Loc. Manchap. **Fig. 14.** Basket shaped *Favosites* colony, Takche Formation. Loc. Manchap. **Fig. 15.** *Halysites* - framestone, within chain occur *Vermiporella* and *Plasmoporella* debris, Takche Formation. Loc. Manchap. **Fig. 16.** *Halysites* framestone, Takche Formation. Loc. Gechang. **Fig. 17.** Filamentous *Girvanella*, Takche Formation. (Positive print). Loc. Manchap. (Bar scale is 2mm for Figs. 3.10, 3.13, 3.15, 3.16, 2mm for Fig. 3.14. and 0.5mm for Figs. 3.11, 3.12, 3.17)

Manchap section : Carbonate microfacies found in the Takche sequence of the Manchap section are as follows. (a) Syndepositionally deformed laminated and bioturbated mudstone. (b) Bioclastic-quartz wackestone made up of argillaceous and ferruginous materials mixed with micritic clotted matrix. The clasts are silt-size quartz, brachiopods (most common), echinoid spines, crinoids, ? gastropods, bryozoans, trilobites, tabulate corals, nodosarids and other foraminifers, coated pseudo-ooids and flask-shaped microproblematica (Fig. 3.11). The cement varies from micritic, sparitic to syntaxial, the last one occurs along the echinoid plates. The brachiopod's and bryozoa's open spaces are generally filled by sparitic and partly by micritic material. This facies is confined to the basal part of the sequence. (c) Sponge-spicule wackestone (Fig. 3.12) which also contains recrystallised clasts of gastropods, echinoids and crinoids cracks having filled with sparitic material. This facies occurs in the upper part. (d) *Vermiporella*-echinoid wackestone which sporadically occurs in the middle part. (e) Packstone grainstone facies including (i) *Vermiporella* packstone/grainstone, (ii) bryozoa-trilobite packstone, (iii) layered algal-bryozoa packstone and (iv) brachiopod-lamellibranch pack/grainstone. All these are intensely bioturbated, made of poorly sorted micritic matrix with uniformly distributed sparitic and ferruginous materials. Some of the packstones show graded bedding and also geopetal fabric. The clasts are of algae, tabulate corals, bryozoans, lamellibranchs, gastropods, cephalopods, trilobites, stromatoporoids, crinoids, sponge-spicules, ostracodes, echinoid spines, ? *Tentaculites* and ooids. (f) Float/rudstone at several levels in middle and upper parts of the Takche Formation is represented by (i) *Favosites-Vermiporella* rudstone containing angular clasts of *Favosites* colonies and *Vermiporella* debris (Fig. 3.13). The clasts vary in size from 2mm to 10mm. The matrix is constituted of dolosparite with scattered ferruginous and micritic material; (ii) halysitid-bryozoal floatstone showing mud-filled *Halysites* and bryozoan clasts; (iii) coral-stromatoporoid rud/floatstone enclosing fragments of rugose corals, stromatoporoids, bifoliate bryozoans, and shell fragments; (iv) bryozoa-coral floatstone enclosing complete corals and fragments of *Hallopora* and *Halysites*. In this sub-facies, the matrix is layered and comprises sparite and micrite. (g) Boundstone occurs throughout, though prominent in middle and upper parts of the sequence. The boundstone facies has limited vertical as well as lateral extent. Basket shaped *Favosites* colonies are most conspicuous (Fig. 3.14). This facies is divi- sible into (i) *Halysites-Vermiporella-Plasmoporella* framestone, showing interspace in between *Halysites* chains filled by *Plasmoporella*, *Vermiporella* and micrite (Fig.3.15); (ii) *?Plasmoporella-Vermiporella* framestone showing *?Plasmoporella* growing over *Vermiporella* debris the other dwellers being echinoids, gastropods and ostracodes with the open space filled with sparitic cement; (iii) stromatoporoid-rugose coral framestone; (iv) *Favosites* framestone; (v) *?Thamnopora* framestone shows clotted matrix; (vi) *Halysites* framestone mainly showing recrystallised coral filled with clear sparite and dolosparite, matrix mostly micritic with impurities of quartz and mica; (vii) bryozoan bindstone showing several branches of bryozoa colony within which occur micritic material (Fig. 2.29), the clasts of brachiopods and ostracodes and the bores in the bryozoa filled with sparite except one with silica; (viii) coral-stromatoporoid bindstone showing a rugose coral encrusted by *Ecclimadictyon* stromatoporoid in a micritic matrix; (ix) *Girvanella* bindstone showing *Girvanella* in filamentous (Fig. 3.17) and spherical (Fig. 3.18) forms in a micritic medium; (x) *Vermiporella* bindstone (Fig. 3.19) made up of *Vermiporella*, micrite in interspace and clasts of gastropod and algae with some parts of gastropods filled with sparite; (xi) *Kamaena* bindstone/wackestone (Fig.3.20) amd (xii) bafflestone displaying floating colonies of *Hallopora*.

Cements : The cements in the Takche Formation are siliceous, ferruginous, micritic and sparitic and rarely ferruginous subequant calcite. Clear siliceous and chalcedonic cements form the first generation cements in *Favosites* and *Halysites* framestone facies. Replacement by micritic and sparitic cement is common. Clear sparite occurs in open spaces, veins, fractures and chambers of fossils. Ferruginous micritic and sparitic cements fill the chambers of corals. The sparitic cement seems to be of first generation. The rare ferruginous and subequant calcite cements are observed in the open spaces of *Halysites* colonies at Gechang which may represent a fresh water phreatic environment with active water circulation (Longman, 1980). Fibrous and micritic cements in alternating layers were found in only one floatstone occurring in the uppermost part of the Leo reef. Sparry calcite occurs both as primary precipitate and as recrystallised micrite with which it retains hazy and irregular boundary.

Figs. 3.18 – 3.26



Explanation of Figs. 3.18 - 3.26

(Unless specified all are slide prints)

Fig. 18. Nodular form of *Girvanella*, Takche Formation (Positive print). Loc. Manchap. **Fig. 19.** *Vermiporella* bindstone (Positive print), Takche Formation. Loc. Manchap. **Fig. 20.** *Kamaena* wackestone (Positive print), Takche Formation. Loc. Manchap. **Fig. 21.** Shell packstone, Lipak Formation. Loc. Takche. **Fig. 22.** Crinoidal bioclastic packstone, Lipak Formation. Loc. Takche. **Fig. 23.** Layered bioclastic packstone with cortoidal *Tentaculites*, Lipak Formation. Loc. Yulang Dogri. **Fig. 24.** Burrows showing circular arrangement of filled material, Lipak Formation. Loc. Takche. **Fig. 25.** Whole fossil (Corals, Thamnoporid) wackestone, Lipak Formation. Loc. Yulang Dogri. **Fig. 26.** Peloidal grainstone, Lipak Formation. Loc. Yulang Dogri. (Bar scale is 0.5mm for Figs. 3.18, 3.20 and 2mm for 3.19, 3.21 - 3.26)

3.2.C Kanawar Group

3.2.C$_1$ *Lipak Formation*

The microfacies in the Lipak Formation include (a) packstone, (b) mudstone, (c) wackestone, (d) grainstone and (e) boundstone. The packstone is represented by (i) layered and (ii) bioclastic/ lithoclastic varieties. The former shows alternation of sparite and micrite with shells (Fig. 3.21), echinoid spine, recrystallised crinoids (Fig. 3.22), algae cortoids of *Tentaculites* occurring parallel to the bedding along with corals (Fig. 3.23).The sorting within the layers is moderate. Shells in sparitic layers show umbrella effect. The matrix shows ferruginous content which is more pronounced in the sparitic layers. Some slides show graded bedding. The early cement is clean to dark micritic, in cracks/open spaces it is followed by dogtooth spar and coarse sparite. The lithoclastic variety includes clasts of well rounded ill-sorted sparitic rock while the bioclastic variety shows clasts (60%) of brachiopods, echinoids, recrystallised algae, ? trilobites, gastropods, bryozoans, cortoids of *Tentaculites* and corals in a micritic, fine peloidal to partly sparitic matrix. The cement in this type is largely sparitic; some of the packstone are bioturbated showing circular arrangement of grains in the burrowed part (Fig. 3.24).

The mudstone is made up of clean, ferruginous and clotted micrite. Some of these show (?) shrinkage cracks which have been filled with sparite. The burrows in the mudstone are filled with peloidal material.

The wackestone shows variation to mudstone on the one hand and to packstone on the other. The clasts in wackestone are represented by calcite, quartz, echinoids, brachiopods and peloids. In one section each of (i) whole-fossil wackestone (Fig. 3.25) and (ii) well sorted thin-shelled packstone carbonaceous to little coarser matrix were encountered. The cement is largely sparitic.

The grainstone at places shows variation to packstone. Various varieties are (i) ooidal grainstone, the oolite (60%) having micrite, calcite and rarely shell fragments as nucleus. The oolites show 2-4 alternate dark and light layers. Most of these are simple and only a few are poly-ooids. The matrix is sparitic and contains a few well-winnowed, clotted, micritic and echinoid clasts. Some ooids are deformed and impinge into adjoining ooid showing packing during semi-consolidated stage; (ii) bioclastic grainstone containing clasts of corals, *Tentaculties*, ooids, peloids, crinoids and lamellibranchs; (iii) peloidal grainstone containing peloids (60-70%) (Fig. 3.26), cortoids of shells, *Tentaculites* and crinoids. The cement is small in volume, largely sparitic and only rarely micritic.

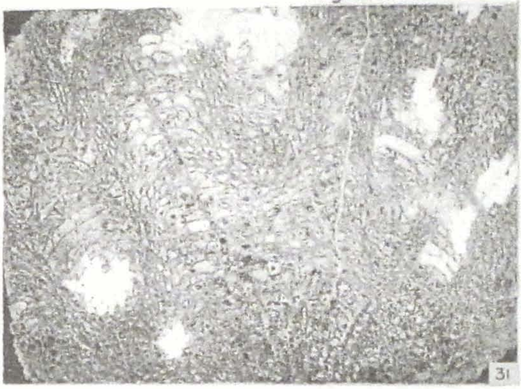
The boundstone facies found in minor proportions is represented by (i) algal bindstone, showing algae/cryptalgal bedding with bird's eye structure (Fig. 3.27-29). The burrows are filled with ooidal/ peloidal material. The cement along the margins of the bird's eye is micritic and sparitic in central part; (ii) coral framestone (Fig. 3.30) shows mud-filled recrystallised corals. The coral colonies are burrowed and mud-filled (Fig. 3.31); these and also the interspaces have been filled with carbonaceous micrite and communited bioclasts. The cement in burrows is sparitic. Micritic cement is seen with hard ground (Fig. 3.32).

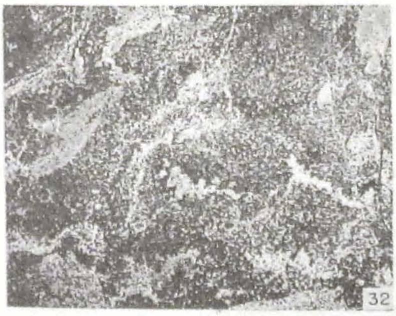
A white marble bed observed at Chango and Phiphuk contains wollastonite and tremolite with a few quartz grains. The tremolite is partially altered into talc. The associated quartz veins are wholly made up of sheared quartz. The marble bands at Yangthang contain wollastonite, garnet, diopside and tremolite.

3.2.D Lilang Group

3.2.D$_1$ *Mikin Formation*

In thin section, most of the rocks appear as extensively stylomottled, filamentous wackestone/ packstone facies. This main variety shows following variations. (a) Whole fossil wackestone/mudstone having light grey homogeneous matrix (70-80%), sparitic skeletal fragments and complete thin shells of larval cephalopods, lamellibranchs and ?ostracods showing partial orientation. The matrix is partly bioturbated with voids filled with sparitic material. The stylolites are mostly along matrix and bioturbated zones. (b) Thin-shelled cephalopod wackestone/packstone showing highly variable percentage of matrix (20-70%) with fragments of juvenile cephalopods, lamellibranchs, ?gastropods and ostracods (Fig. 3.33). Stylolites are hummocky to irregular along contact margins and show ferruginous material along the seams. (c) Cephalopod-gastropod packstone shows fairly well sorted thin shelled cephalopods and gastropods in a homogeneous micritic matrix (50-60%). The subsolution voids are filled by coated fossils and/or ferruginous micrite. The cement is dark micritic and partly sparitic. (d) Thin shelled filamentous packstone (Fig. 3.34) shows thin shells, Figs.3.27– 3.32



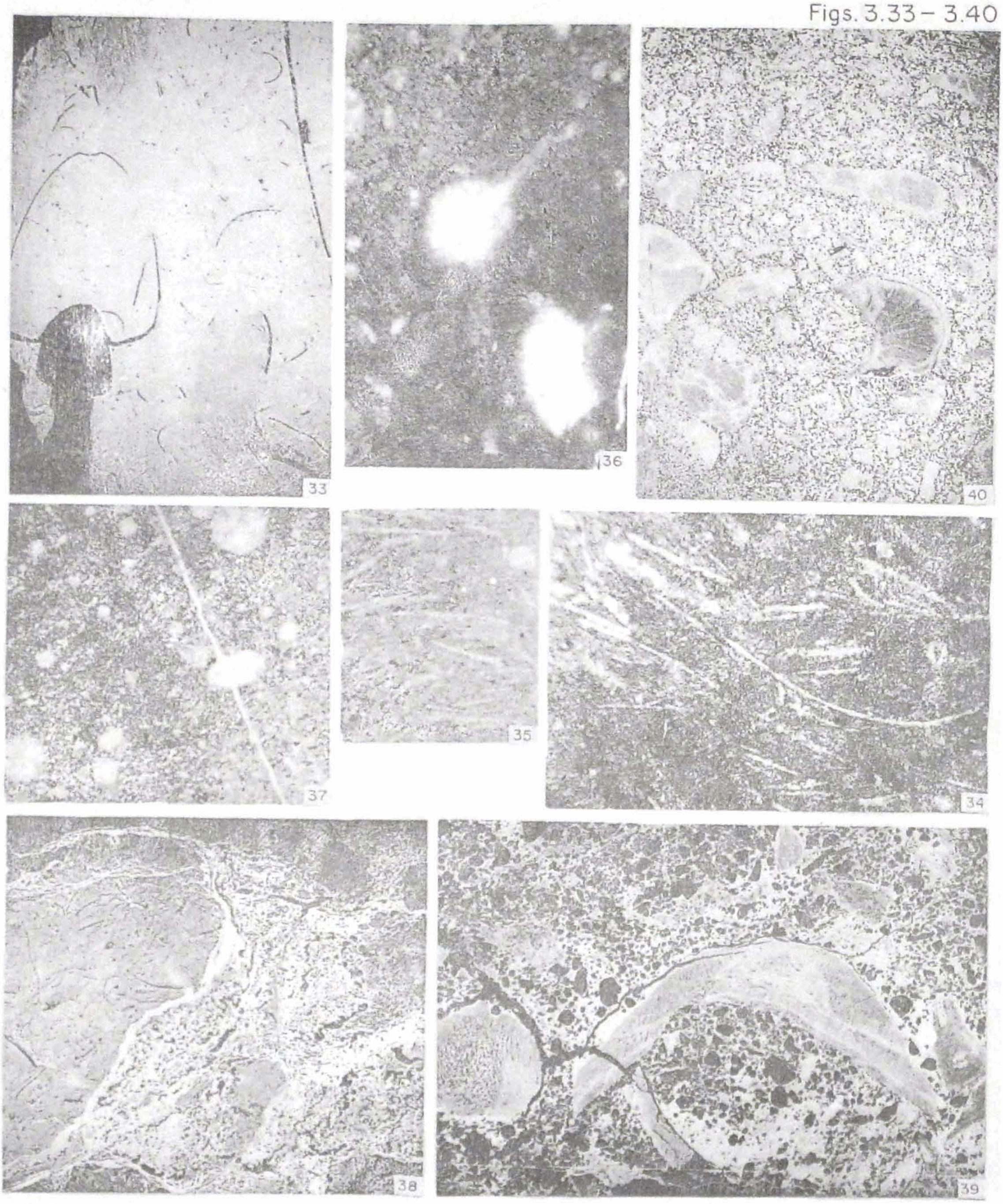


Explanation of Figs. 3.27 - 3.32

(Unless specified all are slide prints)

Figs. 27 - 29. Algal bindstone with burrows and bird's eye structures, Lipak Formation. Loc. Takche. **Figs. 30 - 31.** Coral framestone. Transverse section of *Lithostrotion* (30) and vertical of hexagonarid (31) sections, Lipak Formation. Loc. Takche. **Fig. 32.** Hardground (light coloured) in micrite of a coral framestone, Lipak Formation. Loc. Takche. (Bar scale is 2 mm)

Figs. 3.33 – 3.40



Explanation of Figs. 3.33 - 3.40

(Unless specified all are slide prints)

Fig. 33. Thin-shelled cephalopod wackestone, Mikin Formation. Loc. Lalung. **Fig. 34.** Thin-shelled filamentous packstone, Mikin Formation. Loc. Lalung. **Fig. 35.** Calcisphere in thin-shelled filamentous packstone, Mikin Formation. Loc. Lalung. **Fig. 36.** Calcitised radiolaria wacke/packstone, Chomule Formation. Loc. Lalung. **Fig. 37.** Calcisphere wacke/packstone, Chomule Formation. Loc. Lalung. **Fig. 38.** Thin-shelled stylo-brecciated packstone, Member A, Sanglung Formation. Loc. Lalung. **Fig. 39.** Sandy bioclastic floatstone. Member A, Sanglung Formation. Loc. Lalung. **Fig. 40.** Lithoclastic bioclastic grainstone, Member B, Sanglung Formation. Loc. Lalung. (Bar scale is 2mm for Figs. 3.33, 3.38, 3.40 and 0.5mm for 3.34 - 3.37 and 3.39)

locally calcispheres and radiolarians (Fig. 3.35) in grey micritic matrix and stylobrecciated and nodular stylolites. (e) Bioturbated molluscan packstone of light to pale grey homogeneous micritic matrix (40-80%) having an average of 20-60% clasts. The molluscs are thin to moderately thick shelled lamellibranchs, gastropods and cephalopods. The clasts are poorly to moderately sorted, generally lack orientation and are of ostracods, echinoids, foraminifers and sparite. Some clasts have thin micritic film around them. The bioturbated portions show circular arrangement of particles with sparitic cement in the centre. The other microfacies is represented by mudstone showing variations to cherty mudstone of light grey to pale white micritic material with thin shelled gastropods, lamellibranchs, cephalopods; at places their percentage is as high as 30%. A distinct fabric is imparted by stylolites having ferruginous material along the seams. The stylolites are stylonodular to stylobrecciated with local variation to stylomottled type. It shows local planes of disconformities.Locally occur sporadic thick shells.

3.2.D$_2$ *Kaga Formation*

The carbonate microfacies are (a) filamentous packstone/wackestone having juvenile as well as adult *Daonella*, dark rimmed echinoid spines, subangular to angular ?organic debris as recrystallised sparite. The cracks in the rocks are filled with dark-rimmed sparitic material; (b) layered medium shelled (lamellibranch) packstone with aligned and broken shells occurring along local planes of disconformities; (c) cephalopod dropstone in layered thin shelled *Daonella* packstone. The dropstone is recognised by sagging of bottom micritic layer, truncation of layers at cephalopod level and undisturbed overlying layer, the shells also showing settling fabric; (d) thin shelled lamellibranch packstone along layers of disconformity, with the overlying layer filling in the uneven portion of the underlying layer; (e) dark grey mudstone with a few skeletal grains.

Most of the bioclasts in the Kaga Formation are thin shelled, some with dark rims. Stylolites are low peaked. The burrows are filled with dark micritic material and fine organic debris, Fe-rich micrite and rarely with blocky sparite. The cement is inconspicuous and is micrite.

3.2.D$_3$ *Chomule Formation*

It shows the following microfacies. (a) Filamentous lamellibranch wackestone/packstone containing shells of *Daonella/Halobia* in dark grey micritic matrix, the shells showing moderate alignment and sorting. (b) Thin shelled gastropods wackestone/packstone showing calcispheres, radiolarians, a few mica flakes and ferruginous material. (c) Calcitised radiolarians wackestone/packstone showing radiolarians mostly with broken spines together with calcisphere (Fig.3.36-37). The rock shows layering. (d) Mudstone made up of grey micrite with uniformly distributed ferruginous material and 1-5% clasts of dark-rimmed sparite.

Bioturbation is rare and is identifiable by circular arrangement of grains. Stylolites are more or less common and vary from low-peaked to brecciated types. Cement is rare to inconspicuous and is micritic.

3.2.D$_4$ *Sanglung Formation*

3.2.D$_{4a}$ Member A : The following microfacies encountered in ascending stratigraphic order. (a) Bioclastic-lithoclastic wackestone/packstone having a pale brown to pale yellow homogeneous matrix (70-80%) with minor silt to fine sand-size dark rimmed angular, subrounded and rounded quartz. The bioclasts (10-20%) are of bryozoans, echinoid spines, molluscs, sponges, rare oolites and doubtful algae. All the clasts are dark-rimmed. The lithoclasts are of quartz and light coloured micrite, the latter possibly representing organic debris. Burrows are filled with ferruginous material. The stylolites are irregular and of low amplitude. (b) Bedded to massive mudstone, the bedding in the bedded variety defined by mica flakes, ferruginous material and a few elongated skeletal fragments, burrows filled with sparite and the stylolites irregular to faintly stylobrecciated. (c) Thin shelled stylobrecciated packstone comprising light grey homogeneous micritic matrix (60-70%) with thin shelled clasts of lamellibranchs and gastropods, iron coated echinoid spine, a few thick fragments of thick shells and crinoid ossicles and recrystallised ooids (Fig. 3.38). (d) Calcareous sandstone made up of 40-45% rounded to subrounded, corroded quartz in ferruginous sparitic matrix. The bioclasts are subangular and are of corals, tabulozoans and stromatoporoids. (e) Mudstone, bedded to massive, differing from the mudstone (b) in having bedding defined by sparite and thin mica flakes. (f) Bioclastic packstone comprising bioturbated dark brown more or less homogeneous micritic matrix (20-30%). The bioclasts are lighter coloured and are of bryozoans, echinoid plates and spines, crinoid ossicles, sponges, serpulids, foraminifers, ?fish teeth and lamellibranchs. The cement is micritic and syntaxial. The stylolites are irregular and of low amplitude. (g) Sponge-spicule mudstone made up of pale brown homogeneous micritic matrix. (h) Coral wackestone comprising micritic matrix with fine bioclastic debris; pelletal ooidal grainstone consisting of more than 60% of well sorted, well packed, coated sparitic matrix; the clasts being of foraminfers, turreted gastropods, bryozoans, lamellibranchs, *Microtubus cummunis* Flugel, oolites, ooids and the cement is sparitic. (j) Mottled mudstone/wackestone constituted of pale brown to pale green mottled micrite with silt size angular quartz (3%), foraminifera and biodebris (3%), the sparitic cement imparting a mottled appearance to the rock and (k) sandy floatstone showing clasts of bivalve, coral and hydrozoa (Fig. 3.39).

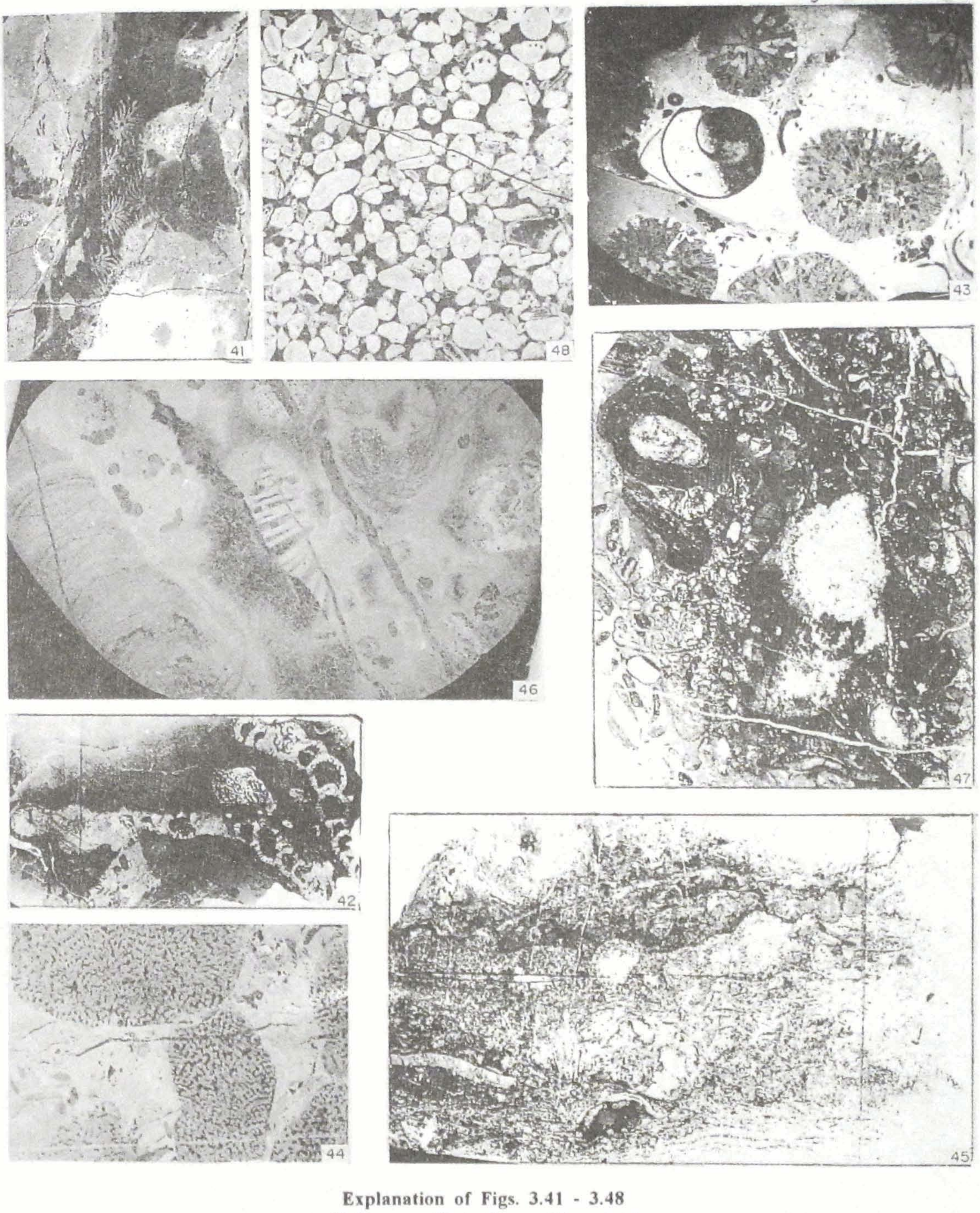
3.2.D$_{4b}$ Member B : The carbonate microfacies in this Member in ascending stratigraphic order are: (a) mottled mudstone/wackestone; (b) quartzose mudstone/wackestone showing quartz and mica in micritic matrix; (c) lamellibranch wackestone (most common upto upper part of the sequence) made up of homogeneous micritic ferruginous matrix with syntaxial to micritic cement; (d) lithoclastic-bioclastic grainstone (Fig. 3.40) comprising silt to fine sand-size homogeneous well sorted sparitic matrix and clasts of algae,echinoid, crinoid, bryozoa, ferruginous micrite and clasts of pre-existing packstone, the cement being not clear, possibly sparitic.

3.2.D$_{4c}$ Member C : The following microfacies in the Member C occur in ascending stratigraphic order. (a) Lamellibranch grainstone/packstone made up of oyster and crinoid fragments in a homogeneous sparitic matrix with a little argillaceous material. (b) Lithoclastic-bioclastic quartzose wackestone constituted of moderately to well sorted subangular to subrounded silt-size quartz (10-15%), light coloured micrite with rare oyster shells and marly material, the rock is sporadically bioturbated and has sparitic cement. (c) Micritic to sparitic bioturbated rock showing ferruginous-rich layers. (d) Hydrozoan bindstone showing micrite in inter space. The cracks and voids are filled with ooids and micritic material. The ooids are single to multilayered, many are compound. Primary cement is ferruginous followed by micritie and sparitie.

3.2.D$_5$ *Hangrang Formation*

Microfacies of the Hangrang Formation have been illustrated by Bhargava and Bassi (1985). Various microfacies are as follows. (a) Calcisponge bafflestone in typical slides shows recrystallised branched sponge, baffled material including micrite, echinoid spine, ostracode tests and lamellibranch shells. Cement is syntaxial and micritic and in cavities fibrous, followed by blocky cement, the rock is commonly bioturbated. (b) *Seriastraea*-calcisponge bafflestone (Fig. 3.41) containing hydrozoans, ferruginous, non-ferruginous micrite, echinoid spines, brachiopods, bivalves, a few aggregate grains and ooids with blocky cement along cracks. (c) *Colospongia*-hydrozoan bafflestone (Fig.3.42) with lamellibranch shells, a few aggregate grains and micrite as baffled material. (d) Tabulozoan framestone shows tabulozoan and solitary corals in the micritic matrix. The other organic remains are of echinoids, ostracodes, bivalves and gastropods. (e) *Thecosmilia* framestone (Fig. 3.43) shows micrite, sponges, gastropods, normal and compound ooids, oncoids and in some section coral encrusted by sponge. (f) Hydrozoan framestone shows micrite in open space together with brachiopod, *Pycnoporiduim? eomesozoicum* Flugel, mud filled corals, echinoid spines, ostracods, lamellibranchs and gastropods. The first generation cement is micrite followed by blocky sparitic cement. (g) *Stromatomorpha* framestone (Fig. 3.44) shows micrite in open space along with shell fragments and crinoid ossicles. (h) Algal bindstone shows algal filament encrusting hydrozoans and corals in a micritic matrix. (i) Thin bedded packstone/grainstone (Fig. 3.45) comprise micrite/sparite with ferruginous to non-ferruginous micritic to syntaxial cement and late diagenetic blocky cement. Stylolites are common, irregular and low amplitude types mainly along grain and matrix boundary. The clasts are of crinoids, hydrozoans, sponges, brachiopod shells, corals (Fig. 3.46) and coated grains. Some slides show micro-discordances. (j) Wackestone/packstone are represented by normal to well-packed oolite/oncoidal facies (Fig. 3.47-48). The matrix is homogeneous micritic, including sparitic material. The cement is micritic, syntaxial followed by secondary blocky type. In fractures and open spaces, it is fibrous, micritic and blocky. The skeletal clasts are of micro-cephalopods, sponges, algal grains, hydrozoans, echinoid spines, lamellibranchs and gastropods. Some oolites have fossil as nucleus. (k) Bioclastic cortoidal packstone/grainstone (Fig. 3.49), which have homogeneous micritic/sparitic matrix with clasts of corals, hydrozoans, brachiopods, echinoid spines and micritic cortoids. The primary cement around echinoid spines is syntaxial, otherwise it is micritic followed by blocky type. Some micritic grains show neomorphism. (l) Poorly sorted oncoidal bioclastic floatstone (Fig. 3.50) shows homogeneous micritic

Figs. 3.41 – 3.48

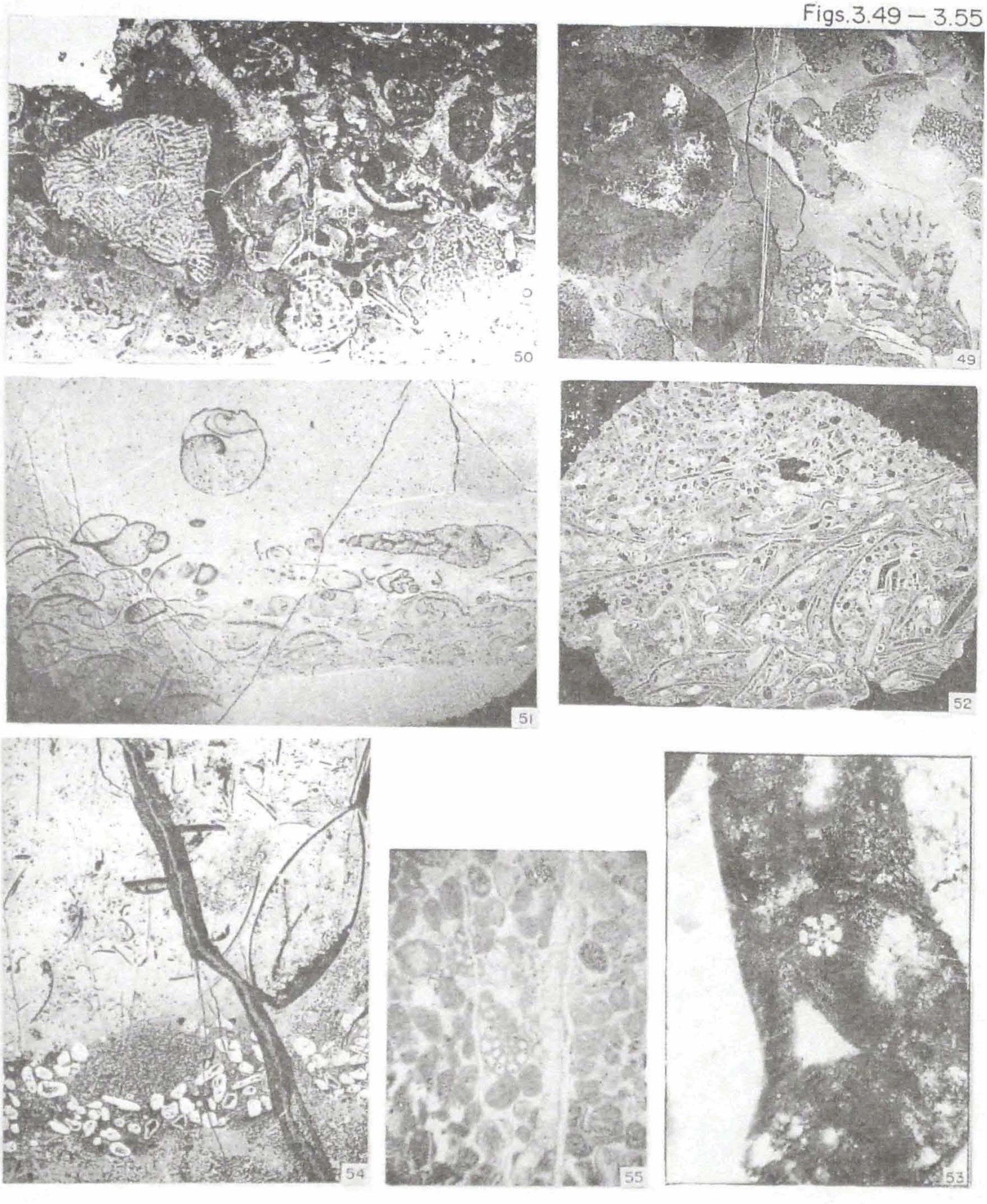


Explanation of Figs. 3.41 - 3.48

(Unless specified all are slide prints)

Fig. 41. *Seriastrea* - calcisponge bafflestone, Hangrang Formation. Loc. Pin-Spiti confluence. **Fig. 42.** *Colospongia* bafflestone with hydrozoa, Hangrang Formation. Loc. Pin-Spiti confluence. **Fig. 43.** *Thecosmilia* framestone, with gastropod in open space, Hangrang Formation. Loc. Tapuk. **Fig. 44.** *Stromatomorpha* framestone, Hangrang Formation. Loc. Hangrang. **Fig. 45.** Bedded bioclastic-calcisponge packstone, Hangrang Formation. Loc. Rangring. **Fig. 46.** Coralline algae, coral, bioclastic packstone, Hangrang Formation. Loc. Hangrang. **Fig. 47.** Oncoidal ooidal packstone, Hangrang Formation. Loc. Pin-Spiti confluence. **Fig. 48.** Ooidal packstone, Hangrang Formation. Loc. Pin-Spiti confluence. (Bar scale is 5mm)

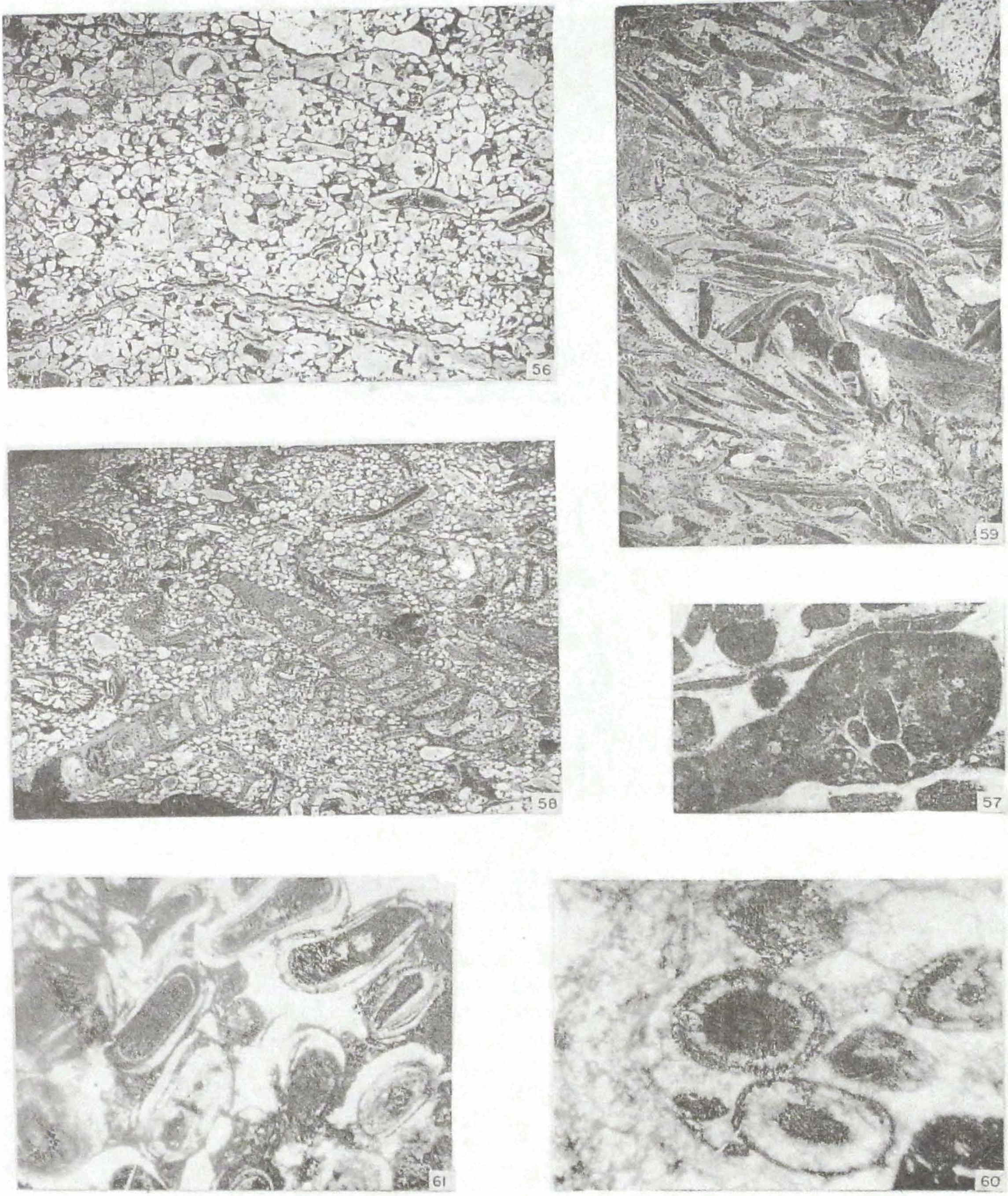
Figs.3.49 — 3.55



Explanation of Figs 3.49 - 3.55
(Unless specified all are slide prints)

Fig. 49. Coral - sponge - hydrozoa packstone, Hangrang Formation. Loc. Rangring. **Fig. 50.** *Thamnaestrea* - bioclastic floatstone, Hangrang Formation. Loc. Pin-Spiti confluence. **Fig. 51.** Layered mudstone with shells in tempestite layer, Alaror Formation. Loc. Atargoo. **Fig. 52.** Bivalve ooidal grainstone, Alaror Formation. Loc. Atargoo. **Fig. 53.** Filling in algal sheath/burrow, enlargement of part of Fig. 3.52 (Positive print). **Fig. 54.** Bioclastic wackestone/packstone with tidal channel deposit, Para Member, Kioto Formation. Loc. Kibber. **Fig. 55.** Peloidal foraminiferal packstone/grainstone, Tagling Member, Kioto Formation. Loc. Kibber. (Bar scale is 2mm for Figs. 3.49 - 3.52, 3.54 and 0.5mm for Figs. 3.53 and 3.55)

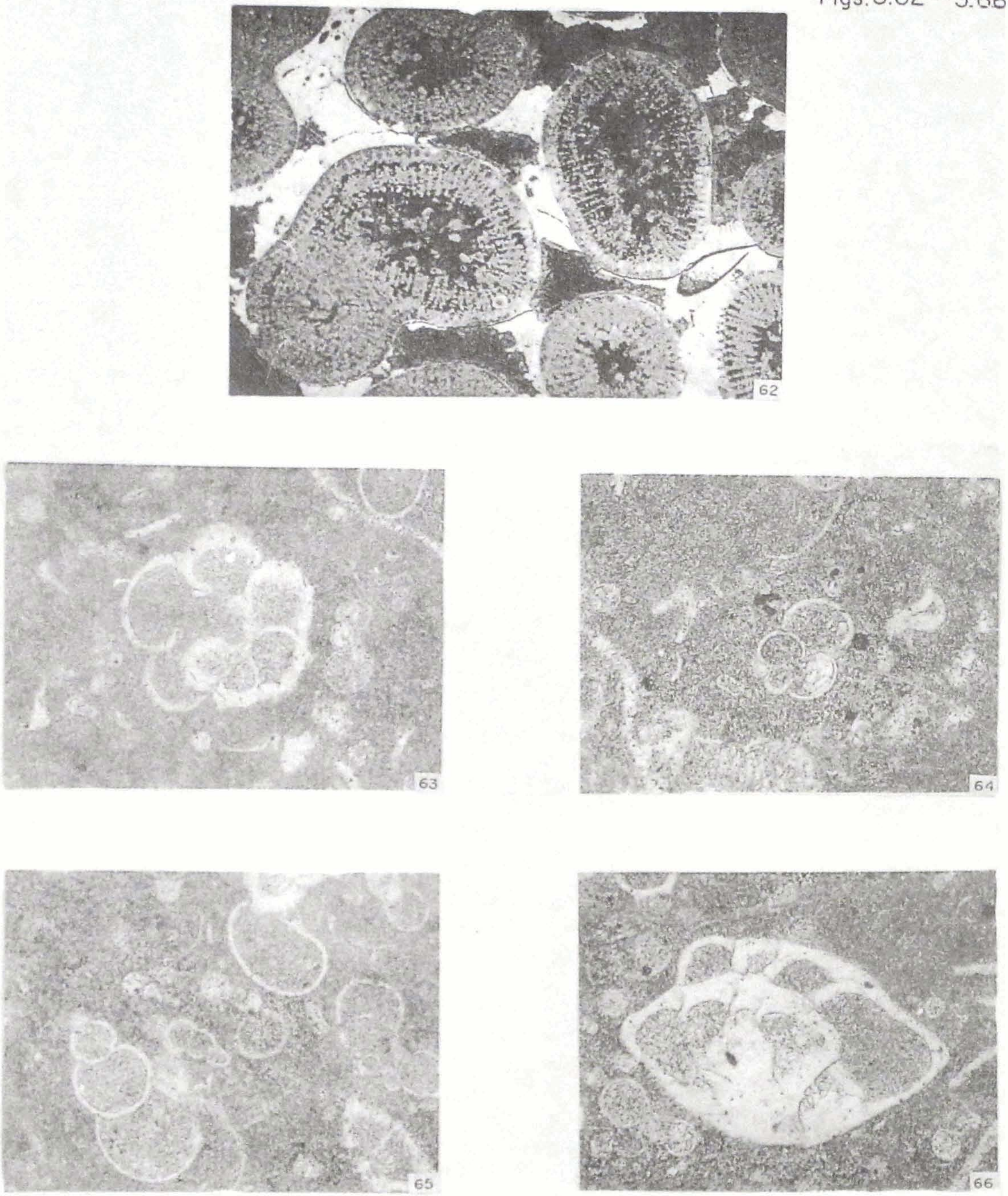
Figs. 3.56 – 3.61



Explanation of Figs. 3.56 - 3.61

Fig. 56. Peloidal aggregate lithoclastic grainstone (SP), Tagling Member, Kioto Formation. Loc. Kibber. **Fig. 57.** Ooids and bioclasts in a flask-shaped aggregate grain enclosed in an algal sheath, Para Member, Kioto Formation. Loc. Kibber. **Fig. 58.** Nerinid-ooidal well packed grainstone (SP), Tagling Member, Kioto Formation. Loc. Sakti. **Fig. 59.** Shell hash packstone (SP), Tagling Member, Kioto Formation, Loc. Kibber. **Fig. 60.** Ooidal grainstone, Tagling Member, Kioto Formation. Loc. Kibber. **Fig. 61.** Distorted glauconitised ooidal foraminifera packstone, Tagling Member, Kioto Formation. Loc. Kibber. (Bar scale is 2mm for Figs. 3.56, 3.58, 3.59 and 0.5mm for Figs. 3.57, 3.60 and 3.61)

Figs. 3.62 – 3.66



Explanation of Figs. 3.62 - 3.66

Fig. 62. *Thecosmilia* framestone (SP), Tagling Member, Kioto Formation. Loc. Sakti. **Figs. 63 - 66.** *Globotruncana* wacke/packstone, Limestone Member, Chikkim Formation. Loc. Chikkim peak section. (Bar scale is 5mm for Fig. 3.62 and 0.2mm for Figs. 3.63 - 3.66)

matrix with chain corals, solitary corals, branched corals, hydrozoans, gastropods, algal crusts and coated grains. (m) Bioclastic algal pelletoidal grainstone shows dasyclad algae and coral fragments in sparitic-micritic matrix.

3.2.D$_6$ *Alaror Formation*

The carbonate microfacies in the Alaror Formation are (a) sandy, ooidal grainstone/packstone showing turbid sparitic matrix with little micrite, moderately well sorted angular to rounded coarse sand-size quartz and coated superficial ooid; in some slides ooids are truncated and compound and occur in a silty to fine quartzitic matrix and a few radiating oolites and iron-coated dasyclads are also present; (b) layered mudstone with gastropods and lamellibranchs in tempestite layers in between mud layers (Fig. 3.51) and clasts are of bivalves, gastropods, algae and ooids; (c) bivalve ooidal grainstone/packstone (Fig. 3.52) showing simple, compound and complex oolites as fillings in a burrow/algal sheath (Fig. 3.53) in sparitic homogeneous matrix with a few algal fragments, the cement being equant and sparitic.

3.2.D$_7$ *Nunuluka Formation*

The carbonate microfacies of the Nunuluka Formation includes sandy ooidal-algal packstone. This facies comprises moderately sorted, angular to rounded coarse quartz, superficial ooid, rare radiating ooids. The cement in the rock is formed by blocky and turbid sparite.

3.2.D$_8$ *Kioto Formation*

3.2.D$_{8a}$ Para Member : The carbonate microfacies recorded in the Para Member are as follows. (a) Bioclastic wackestone/packstone (3.54-55) showing grey to pale brown micritic matrix in varying proportions. The bioclasts are of bivalve, partially filled with peloidal mud, ooid, coarse faecal pellet. Foraminifera form nucleus of a few oolites. The cement in micro-channel part being ferruginous micrite. (b) Foraminiferal peloidal grainstone/packstone having coated foraminiferal tests with sparitic cement. (c) Peloidal aggregate bioclastic, lithoclastic floatstone/packstone showing about 40-60% micritic matrix, various shaped and sized peloids, a few aggregate grains, bioclasts of bivalve, forminifera, algae and lithoclasts of sparite and peloidal wackestone.

3.2.D$_{8b}$ Tagling Member : The carbonate microfacies are as follows. (a) Peloidal aggregate-lithoclastic grainstone (Figs. 3.56-57) showing well-sorted dark rimmed rounded rod-shaped micrite (80%) and sparite (10-15%) clasts. The bioclasts (10-15%) are of quinqueloculinids, gastropods, echinoids, algae, bivalves, and aggregate grains. (b) Nerinid-ooidal-well packed grainstone/packstone showing multilayered radiating oolites in the chambers of nerinids, other bioclasts being of dark rimmed *?Pinacophyllum* and biserial foraminifers (Fig. 3.58). (c) Shell hash packstone (Fig. 3.59) with abundant shells, enclosing silt to fine-sand-sized quartz replaced by calcite shells showing umbrella effect and sparitic cement in voids. Other clasts are of echinoids and rare radiating oolites. Burrows are filled with micrite and smaller clasts. Stylolites are high and low peaked. (d) Normally packed bioclastic grainstone comprising skeletal remains of bivalves, bryozoans, ostracods and echinoids. The lithoclasts are of aggregate grains. (e) Oolitic grainstone with truncated and concentric ooids, pellets, ostracodes, and foraminifers in a sparitic matrix (Fig. 3.60). All the above facies have blocky sparitic cements. (f) Glauconitised distorted ooidal foraminiferal packstone (in upper part of the Member) showing ooids, echinoid spine fragments and foraminiferal tests cemented by glauconite (Fig. 3.61) and *Thecosmilia* framestone (Fig. 3.62) showing partially mud filled corals. The interspace is filled by cortoid and iron coated dasyclad clasts in a turbid sparitic matrix, occupied by dark peloidal mud and micrite. Ostracods and gastropods occur as reef dwellers. Cement in cavities is fibrous along lining and blocky in the central part.

3.2.E Lagudarsi Group

3.2.E$_1$ *Giumal Formation*

Bioclastic-ooidal wackestone is made up of normal, compound, broken, symmetrical, asymmetrical as well as deformed oolites which have been burrowed. Bioclasts are of echinoids, bryozoans and crinoids.

3.2.E$_2$ *Chikkim Formation*

It comprises light coloured (a) mudstone with (i) open spaces filled with fine micrite along cavity margins, dogtooth cement towards core and core of silty micrite/blocky sparite and (ii) uneven base of dense mudstone, followed by bioclastic mudstone with discontinuity surface in between having shells filled with both micrite as well as blocky cement and (b) foraminiferal wackestone contains biomorphs and poorly sorted bioclasts of globotruncanids, ostracods, gastropods and radiolarians the rock being bioturbated and showing low amplitude stylolites (Fig.3.63-66).

4. STRUCTURE

The regional spread of the Precambrian Crystalline Thrust Sheets, observed in the western Himachal Himalaya, has been telescoped in Kinnaur Sector. The Jeori-Wangtu Group, a gneissic complex, forms the basement for the Lesser Himalayan basin (Figs.2.7, 4.1a & b). It is exposed between Jeori and Karcham in Kinnaur. At Karcham, it is stratigraphically overlain by the Manikaran Formation (Rampur Group) along a decoupled contact. The Rampur Group is tectonically succeeded by the Kulu Group along the Kulu Thrust which has translated the Kulu Thrust Sheet across the Rampur-Larji sequence to rest over the Shali-Simla-Jaunsar Groups in the Dalhousie-Mandi-Baragaon-Kadiali stretch. The Jutogh Group, the next higher thrust sheet, translated along the Jutogh Thrust, rests over the Kulu Group. Towards SE, the Jutogh Thrust Sheet has advanced upto Rajgarh-Naura with an isolated klippe at Shimla (Pilgrim and West, 1928) to rest over the Jaunsar Group of rocks. The highest tectonic belt, constituted of the Vaikrita Group, is disposed over the Jutogh Group along the Vaikrita Thrust (= MCT). Towards NW, the Vaikrita Group, along the Vaikrita Thrust, tectonically conceals the Jutogh Group and, as a result, lies directly over the Kulu Group. It is folded into an antiform in the core of which is exposed the Rampur-Larji sequence as a window. This window is followed by the Pandoh synform towards west. The Vaikrita Group and Vaikrita Thrust link up with the Salkhala Group and Panjal Thrust of Jammu and Kashmir (Fig.4.1a & b) respectively. The Vaikrita Group forms basement for the Tethyan basin. The Kulu, Jutogh and Vaikrita Groups, with respect to the Kulu-Rampur Window, show minimum translations of 70km, 105km and 75km respectively. The crystalline rocks of these formations, as shall be discussed in the forthcoming pages, show five decipherable phases of deformation while, in the Tethyan rocks unconformably overlying the Vaikrita Group of rocks, only three deformational phases could be identified.

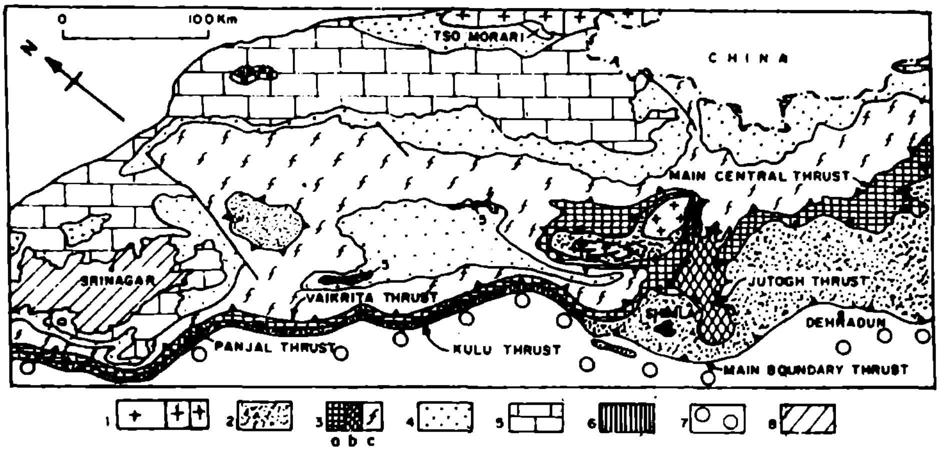


Fig. 4.1a. Geological sketch map of the Western Himalaya. Expl. 1.a. Jeori-Wangtu Group, b. Tso Morari Crystallines. 2. Parautochthonous Precambrian-early Cambrian Lesser Himalayan sequences. 3. a, b, c. Kulu (a) Jutogh (b) and Vaikrita (c) Thrust sheets. 4. Eocambrian-Palaeozoic sequences. 5. Mesozoic sequence. 6. Ophiolite nappes. 7. Tertiary. 8. Quaternary.

The Tethyan rocks of Spiti and Kinnaur occurring as synclinoria, though autochthonous *vis-a-vis* the Vaikrita rocks, are in fact allochthonous which tectonically hitch-hiked on the back of the Vaikrita Group. The allochthonous nature of the Tethyan rocks is best illustrated by the Kashmir basin (Wadia, 1928) across the Kishtwar Window (Fuchs, 1975, Bhargava, 1982) and the Chamba-Manjir-Katarigali sequence across the Rampur-Larji Window.

In the Tethyan rocks, both diastrophic and non-diastrophic structures are present. The large incongruent slump folds in the carbonate rocks of the Mikin and Chomule Formations are the examples of non-diastrophic structures (Fig.2.74-75, 4.2). The

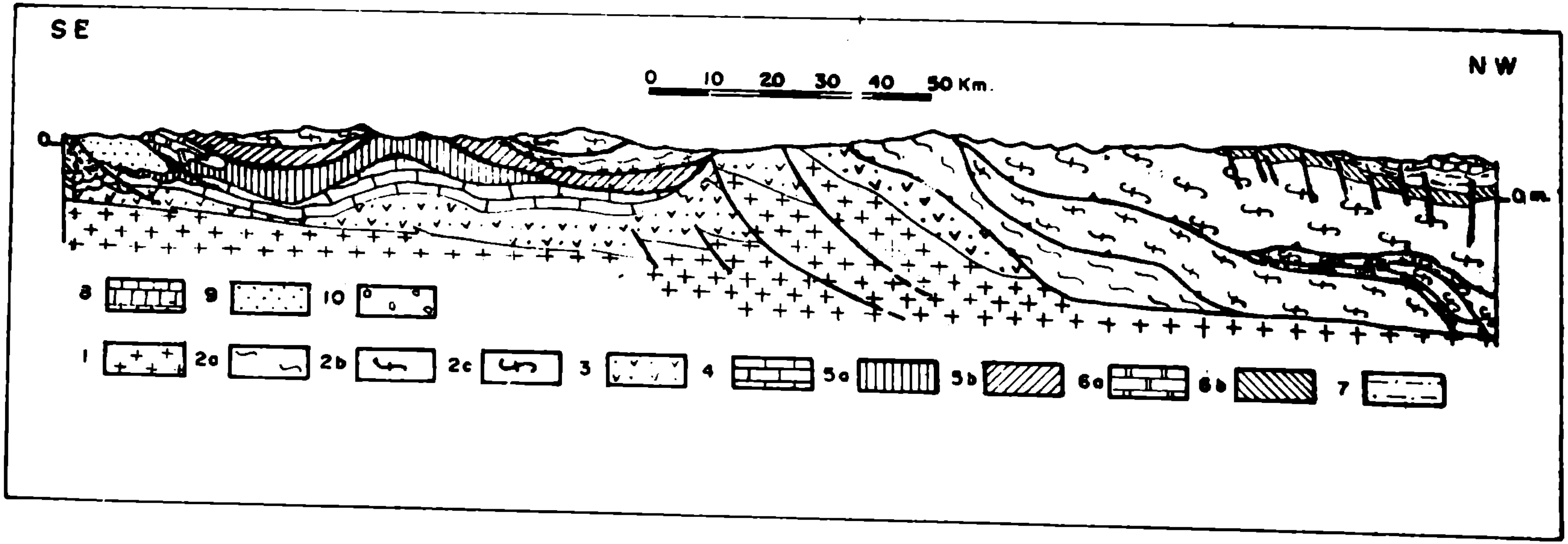


Fig. 4.1b. Schematic geological section from Siwalik near Kalka to Tethyan succession in the Spiti Valley. Expl. 1. Jeori-Wangtu Group (basement complex). 2a. Kulu Group. 2b. Jutogh Group. 2c. Vaikrita Group. 3. Rampur Group. 4. Shali-Larji-Deoban Group. 5a. Simla Group. 5b. Jaunsar Group. 6a. Blaini-Infra Krol-Krol-Tal Group. 6b. Batal Formation. 7. Kunzam *La* Formation-Sanugba -Kanawar and Kuling Groups. 8. Lilang and Lagudarsi Groups. 9. Subathu,Dagshai and Kasauli Formations. 10. Siwalik Group.

slumps in the basal part of the Thango Formation, identified as palaeoseismites, can also be classified as syn-depositional slumps.

The diastrophic structures are of various ages. The imprint of the Tertiary deformation in the Himalaya has been so severe that it has tended to mask the earlier structural elements. However, evidences leading to the recognition of pre-Tertiary structural elements, though fragmentary and indirect, do exist in some sections. A tentative attempt is made here to highlight such evidences to establish a case for pre-Tertiary tectonic events. The pre-Tertiary structural events, which can be identified, belong to : (1) Precambrian, (2) Cambrian, (3) Lower Carboniferous and (4) Cretaceous. These are followed by Tertiary and Neotectonic movements.

4.1 MANIFESTATIONS OF THE PRECAMBRIAN TECTONIC EVENTS

4.1.1 Rifting and Unconformity

The Rampur Group sediments of early Proterozoic to ? late Archaean age were deposited over the Jeori-Wangtu Group (basement complex). The basin for the Rampur Group, as suggested by the association of 2510 ± 09 Ma old tholeiite (Bhat, 1990) with its metasediments, was created by an intracratonic rifting almost at the Archaean-Proterozoic boundary. This possibly produced rise of thermal dome and gigantic faults in the basement. The former, perhaps, caused formation of the Gahr Gneiss. These basement faults were selectively reactivated during the Tertiary.

Presence of five deformations in the Vaikrita rocks, and absence of the first two of these in the Tethyan rocks, establish two pre-Batal deformations in the Vaikrita rocks. In other words, the Batal rocks were deposited over a folded Vaikrita basement. The angular unconformity in between these two is demonstrable one kilometre upstream of Spilo and Pooh where, along a low angled contact, the Batal Formation overlaps a steeper contact between the Morang and the Shiasu Formations. This plane of unconformity is not easily identifiable in local sections due to the homogenising effect of the Tertiary deformation and attendant metamorphism, which simultaneously affected the Vaikrita as well as the Batal rocks. The Batal basin also came into existence due to rifting near to the continental edge of the Indian Plate. This rifting was mainly lithospherie-activated, as is evident by the Manjir conglomerate and limited extent of basic flows in the Batal sequence.

4.1.2 Folds

There are total five generations of fold in the Vaikrita and also in the Jutogh rocks (Schwan, 1980). Of these, the earliest reclined, appressed and coaxial, upright to reclined E-W trending folds, referable to F_1 and F_2 of Naha and Ray (1971), are not found in the overlying Palaeozoic-Mesozoic rocks.

The E-W trend of the F_1 and F_2 folds, where least oriented, was interpreted by Naha and Ray (1971) as due to transportation from north. The mapping of the Jutogh and Vaikrita thrust sheet rocks has established that the roots of these thrust sheets lie in NE. The southerly direction of transport for these rocks, thus, could not have taken place during the Tertiary Orogeny. Also the E-W orientation of these folds is discordant with NW-SE trend of the regional folds in the western Himalaya. These E-W folds are, therefore, regarded as of Precambrian age, which also accounts for their absence in the younger sequences. Small magnitude rootless folds in the Morang Formation, exposed along the left bank of the Satluj near its confluence with the Tidong *Khad* at Morang, and hooks and interfolial folds preserved in the pelitic-psammitic alternating sequence of Morang and allied formations (Fig. 4.3-4.6), possibly, belong to the Precambrian age. These folds can be designated as Pr F_1 and Pr F_2.

4.1.3 Regional Metamorphism

The unmetamorphosed Lipak rocks rest over the metamorphosed Vaikrita rocks in eastern Spiti and northern Kinnaur. This observation suggests a pre-Lipak regional metamorphism of the Vaikrita rocks. This metamorphism is assigned a possible Precambrian age due to following evidences:

1. Only one phase of metamorphism represented by chlorite-biotite is recordable in the Batal rocks. The earlier two phases of metamorphism are, thus, regarded to be of pre-Batal age (Bassi, 1988a). These can be related to the E-W trending small magnitude Pr F_1 and Pr F_2 folds.

2. The presence of staurolite as a detrital mineral in the Batal rocks (Kumar *et al*, 1984) also indicates existence of staurolite-bearing rocks of pre-Batal age in the provenance which lay to the west of the Spiti basin. The Jutogh or Vaikrita rocks could possibly be this provenance.

3. Disoriented folded schist enclaves occur in early Palaeozoic Rakcham Granite (Fig.4.7) indi-

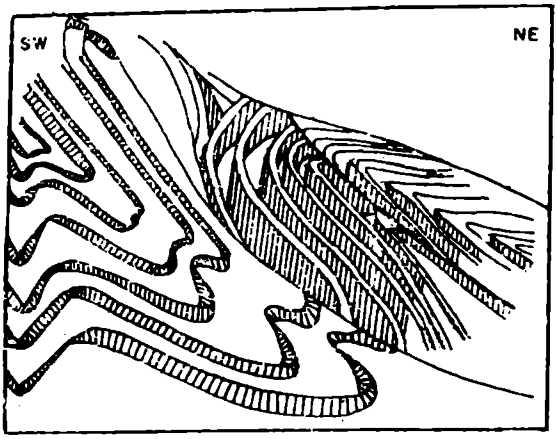


Fig.4.2. Subaqueous rotational slide in the Chomule Formation. Loc. Hal *Nala*, about 2.5 km upstream from its confluence with the Spiti River.

cating existence of pre-early Palaeozoic schist manifesting a metamorphism of Precambrian age.

4.1.4 Basement structures

The More Plain - Phirse *Phu* Fault (MPF), the Syarma Fault Complex (SFC), Kaurik Fault Complex (KFC) and Pin Fault Complex (PFC) demarcate and control (a) sedimentation pattern, (b) structural style, (c) grade of metamorphism and (d) occurrence of granitoids. The detailed effects of these faults are described below.

4.1.4.A MPF : The metamorphic facies of the Lower Palaeozoic rocks north of the MPF are altogether different from those encountered in the main Spiti Valley. The fossiliferous Po Formation occurs on either side of the MPF, the one on the northern side is metamorphosed to biotite grade.

The outcrops of the Rupshu granitoids are confined to the north of the MPF. The folds north of the MPF are mainly recumbent, whereas to the south of it, they are upright or rarely overturned.

4.1.4.B *SFC:* South of the SFC, there is more or less a continuous deposition from Ordovician to Carboniferous. Towards north of this fault, the early Carboniferous Lipak rocks rest over the Precambrian basement. The lithofacies of the Lipak Formation, north and south of the SFC, are altogether different.

The folds on the northern side of the SFC are recumbent (Fig.4.10), whereas to the south of this fault they are upright to gently overturned. SE of Lalung, though this fault is not observed, such a contrasting structural style continues; the SFC in this stretch is possibly blind.

The Lipak rocks north of the SFC enclose wollastonite indicating contact metamorphism, perhaps due to some granitoid which is still buried. The Lipak rocks to the south of SFC show no thermal effect.

4.1.4.C *KFC:* The Lipak Formation is developed on either side of the KFC. Only upper part of the Lipak Formation is developed on the eastern side (Yangthang side) of the KFC, whereas, towards west the entire sequence is exposed and has higher amount of arenaceous component.

The Lipak rocks on the Yangthang side have been metamorphosed to biotite grade and show spectacular recumbent folds (Fig.4.9) in contrast to unmetamorphosed state of rocks and upright folds (Fig.4.8) in the western side. The KFC also delimits the granitoid outcrops towards the western side.

4.1.4.D *PFC:* This fault complex broadly delimits the Mesozoic sedimentation in the Pin Valley. The Haimanta, Thango and Takche Formations to the west of the PFC are comparatively more metamorphosed.

The above mentioned faults, thus, seem to have controlled (a) the depth and shape of basin leading to different lithofacies on their either side since late Precambrian time, (b) the depth of burial leading to contrasting metamorphism of rocks on either side and also the emplacement of granitoids and (c) tectonic style which also, perhaps, was a function of the depth of burial. These faults are, therefore, considered Precambrian basement features which became active from time to time.

4.2 MANIFESTATIONS OF THE CAMBRIAN TECTONIC EVENTS

4.2.1 Unconformity

A major plane of unconformity separates the early-middle Cambrian Kunzam *La* Formation from the Ordovician Thango Formation. This plane is possibly undulatory, suggesting a period of extensive erosion in pre-Thango time.

4.2.2 Pre-Ordovician tilt and folds

An angular discordance between the bedding dips of the rocks of the Kunzam *La* and the overlying Thango Formations is observed at Takche and in the Pin Valley (Fig.2.11). Recumbent folds, locally developed in upper part of the Kunzam *La* Formation, are absent in the Thango Formation. These folds are considered to have been formed during the Cambrian.

4.2.3 Physiographic features

The basinal highs deciphered during the Thango-Muth period (Bhargava *et al*, 1991) are relatable to the movement during the late Cambrian period.

4.3 MANIFESTATIONS OF THE EARLY CARBONIFEROUS TECTONIC EVENTS

4.3.1 Basinal physiography

The distribution of the Po Formation in the Spiti Valley suggests that an area between Po and Losar was uplifted during late to post-Lipak period to form a NW-SE trending subaerial high (Bhargava *et al*, 1991b). Another minor subaerial high trending in ENE-WSW direction emerged in the Guling area (Bhargava *et al*, 1991b). These highs, attributable to post—Po epeirogeny, contributed clasts to the Ganmachidam Formation. This event is also reflected in the granitoids of corresponding age.

These basinal highs constituted important features which not only controlled the depocentres of the Po and Ganmachidam Formations but also subsequent Tertiary deformation, as at the sites of these interpreted physiographic highs, occur the main TF_1 and TF_2 (F_4 and F_5 folds of Bhargava *et al*,1991b)

4.4 MANIFESTATIONS OF THE CRETACEOUS TECTONIC EVENTS

4.4.1 Secondary Planar Structures

Foliation is rather universally developed in the Batal rocks. It is also developed in the Lipak Formation in the Phiphuk and Yangthang areas and in the Po Formation in the More Plain section, hence of post-Carboniferous age. These foliations are sub-parallel to parallel to the bedding and should indicate beds to be isoclinally folded. Since no regional isoclinal folds showing over-turning or recumbency can be established *vis-a-vis* overlying fossiliferous sequence, this foliation has been interpreted due to horizontal deformation (Klerkx *et al*, 1987).

The foliation cleavage developed in the rocks of the Po Formation at Tabo (Fig.4.11) is at steeper angle and difficult to relate with the axial plane of the fold in that area. In this small outcrop, it varies from N20°W-S20°E/90° to N30° W-S30°E/40° NE and N30° W-S30°E/10° NE and shows anomalous relationship with folds. This anomalous relationship could be due to basement control on the deformation (Wilkinson and Smith, 1988) in this area.

4.4.2 Folds

Three generations of folds are present in the Palaeozoic-Mesozoic rocks of Spiti, corresponding to F_3, F_4 and F_5 folds of the Vaikrita Group. However, only two fold episodes are present in the Tertiary rocks of the Himachal Pradesh indicating that the first of the folds referred to above is pre-Tertiary, and possibly of late Cretaceous age.

The direct evidence of Cretaceous folding is available at Khab where a 108 ± 17 Ma (Kwatra *et al*, 1987) granitoid body cuts across a series of folds (Fig. 4.13). The NW-SE trending folds of this generation are recumbent and coaxial with the second fold. Comparable folds are present in the Giumal and Chikkim Formations (Figs.4.12) at the Chichim Peak, in Kioto-Spiti and Giumal Formations in the Sakti Syncline. At the Chichim Peak, the fold shows several digitations with axial planes trending in NW-SE direction with 30°-40° inclination towards SE. This fold may be designated MF_1. Except for the highest fold, the closures of other folds have been sheared. The closure of the MF_1 fold is refolded along a fold of the Tertiary age (TF_1).

Folds related to this age are, perhaps, present in the Lilang Group also (Fig.4.14). However, it is difficult to distinguish them from the de'collement folds which are extensively present in the rocks of the Sanglung Formation.

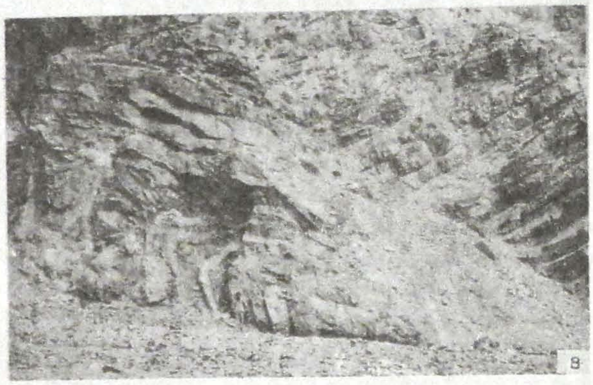
These folds mark the commencement of the Himalayan Orogeny which culminated in the folding of the Siwalik-Indus molasse. The MF_1 folds could be diachronous, as indicated by the age of 108 ± 17 Ma granitoid and the late Cretaceous age of the Shale Member (Chikkim Formation), which is also involved in this folding.

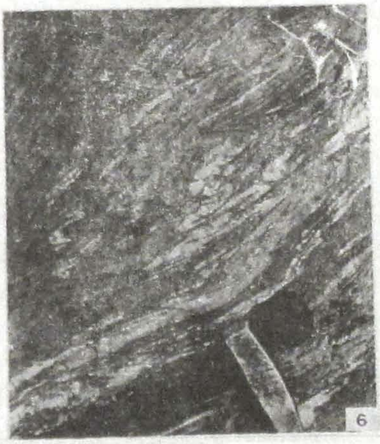
4.5 MANIFESTATIONS OF THE TERTIARY TECTONIC EVENTS

4.5.1 Folds

The folds in the Tethyan sediments are de'collement as well as harmonious with the regional structure.

Figs. 4.3 – 4.9





Explanation of Figs. 4.3 - 4.9

Figs. 3-6. F_1 and F_2 folds in the multiple deformed crystallines of the Vaikrita Group. Loc. 3 and 5: 200m towards Naggar from Jagatsukh-Hamta road junction, 4: Lipak Gad-Spiti confluence, Leo. **Fig. 7.** Raft of schist in lower Palaeozoic Rakcham granitoid (495 Ma). Loc. Tirung, Tidong Valley. **Fig. 8.** Upright folds in the Lipak Formation to the west of Kaurik Fault Complex. Loc. Lipak Gad. **Fig. 9.** Recumbent fold in the Lipak Formation to the east of Kaurik Fault Complex. Loc. Nako *Nala* bridge NH-22, Yangthang. (Bar scale is 10cm).

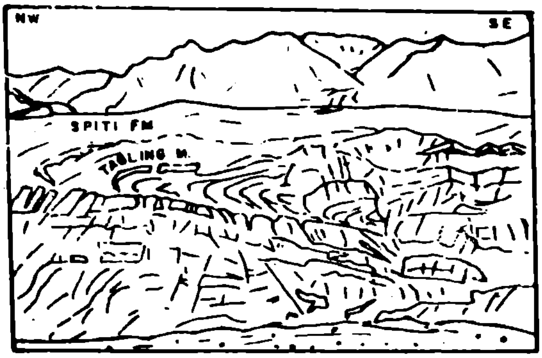


Fig. 4.10. Recumbent fold in the Kioto and Spiti Formations to the NE of the Syarma Fault Complex at Sakti (sketched from a photograph).

4.5.1.A *De'collement folds*

Large de'collement folds are observed in the Sanglung Formation which essentially comprises a sequence of limestone and shale alternations. The detachment along the bedding plane has occurred mainly along the contact of rocks of contrasting competence. These folds occur in various dimensions (Figs.4.15, 4.16). These décollement folds are more or less harmonious with the regional structures, thus indicating their genesis during the main folding episode.

4.5.1.B *Folds related to regional deformation*

These show a combination of parallel and similar folds with former dominating the pattern (Figs.4.17-4.26). Though, in general, the dips of the beds are of the order of 30°-50°, locally the outcrop pattern suggests a comparatively lower angle of inclination of the lithocontacts. This observation suggests that the dip of the enveloping surface is lower than the dips of the beds. As stated earlier, three generations of fold are present in the Palaeozoic and Mesozoic rocks, of which the earliest is of Cretaceous age (MF_1). Only the other two folds (TF_1 and TF_2) are discussed under Tertiary structure.

a. TF_1 folds : The TF_1 folds are coaxial with MF_1 fold of the Cretaceous age. These are the most prominent folds which have determined the outcrop pattern and, to a large extent, even the shape of the Spiti-Kinnaur Synclinoria. The TF_1 folds in the Spiti Valley between Losar and Schichling and in the Kinnaur area trend in NW-SE direction. East of Schichling they swing to E-W direction. The swing from NW-SE to E-W in the eastern part of the Himachal is a regional feature and is reflected in all the tectonic belts from the lowest Siwalik parautochthon to the highest crystalline nappes (Fig.2.7). This swing represents a re-entrant in the cover rocks, possibly as a response to the tectonic features of the Peninsular basement beneath the Himalaya (Swami Nath et al, 1964). The TF_1 folds have refolded the MF_1 folds in the Chichim, Sakti and Sumra areas (Fig.4.12).

The TF_1 folds are doubly plunging upright to gently overturned. Some of the folds have faulted limbs and crest. The largest TF_1 fold along the Spiti River, between Hal and Schichling, is located at the site of an interpreted basinal high which came into existence in post-Lipak period (Bhargava *et al*, 1991b). This basinal structure could have exercised a control over the formation of this fold. The TF_1 folds have consistent trend and extensive spread; hence regarded to represent slow and steady deformation.

The main TF_1 folds are labelled in Fig.4.27 (in pouch).

b. TF_2 folds : The TF_2 folds are cross-folds which have provided plunge to MF_1 and TF_1 folds besides folding their limbs (Fig.4.12). These are broad warps with axial traces trending in NE-SW direction in the area between Losar and Schichling and in N-S direction in the area east of Schichling. These folds are also of plunging nature. Most of these folds have limited extent. However, the TF_2 fold, from Guling in the Pin-Parahio Valley to Kebri in the Lingti Valley, extends for about 30km before getting truncated by the Syarma Fault Complex. This fold is sited over the interpreted cross-basinal high, formed during the late-Lipak times (Bhargava et al, 1991b). This basinal structure might have controlled the formation of this fold. The TF_2 folds are listed in Fig.4.27 (in pouch).

4.5.2 Faults

Faults of various pattern and dimensions are present in the Spiti-Kinnaur region. These can be classified as (a) Deep seated basement fault (b) Strike fault and (c) Cross-fault.

4.5.2.A ***Deep seated basinal to intrabasinal fault***

The More plain-Phirse Phu, Syarma, Kaurik and Pin Fault Complexes, as discussed earlier, are interpreted as the deep seated faults which constituted the intra-basinal features. These faults (Fig.4.28) affect the Tertiary fold pattern and are regarded to have been reactivated during the Tertiary Orogeny.

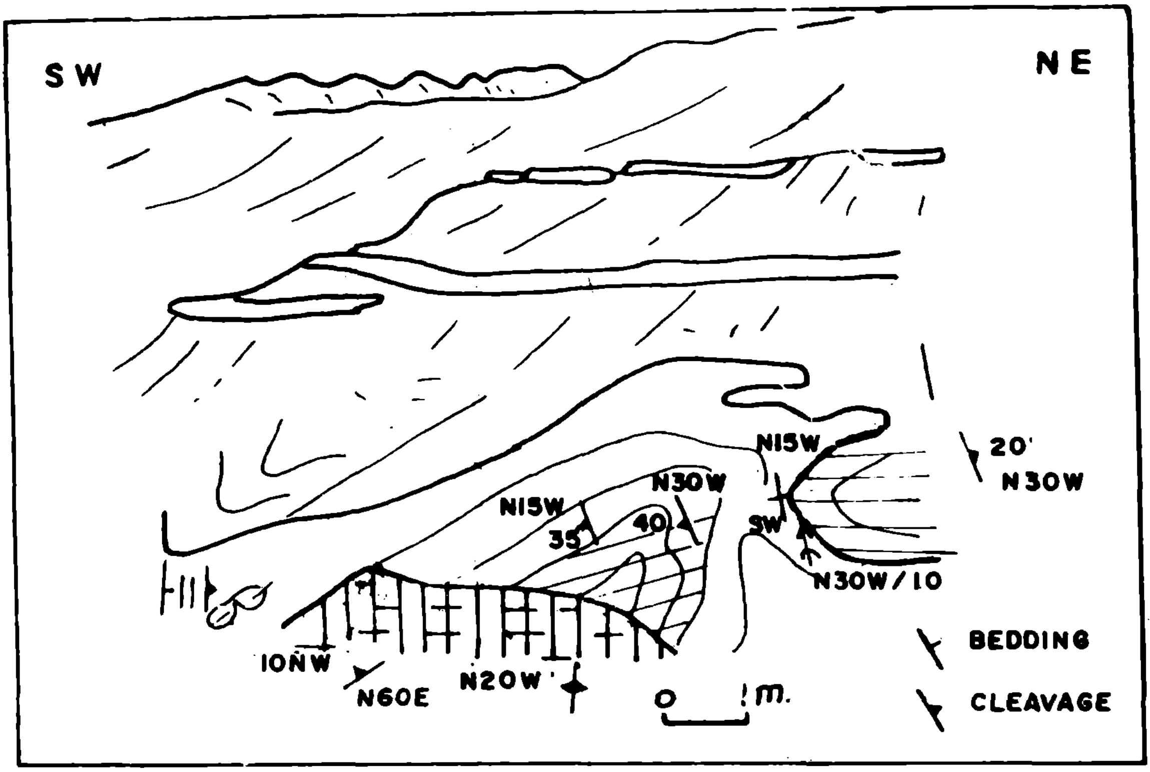


Fig. 4.11. Fold at Tabo (along road) showing aberrant and variable bedding-cleavage relationship in a single outcrop. Continuous straight lines represent cleavage (sketched from a photograph).

4.5.2.B *Strike Faults* :The NW-SE trending Spiti-Gyundi, Domal, Kaga and Na Faults belong to this category. Of these, the Spiti Fault, located along the course of the Spiti River, is the most important. It is a high angled fault along which the crest of the Spiti Anticline has been fractured. The Spiti Fault juxtaposes Ganmachidam Formation, Kuling Group and Mikin, Kaga and Chomule Formations against the Sanglung Formation on the downthrown SE block. Besides these, there are several other strike faults.

4.5.2.C *Cross Faults* : Several normal high angled cross faults, viz. Ratang, Chorgad, etc. have affected the limbs of the folds. The faults are of local extent and of variable orientation.

The NW-SE trending faults, which are parallel to the axial trace of the TF_1 folds, may be syn-TF_1 folding. The cross-faults are the youngest Tertiary structural elements in the area.

4.6 MANIFESTATIONS OF THE NEOTECTONIC EVENTS

Evidences of the neotectonic movements in Spiti-Kinnaur can be grouped under direct and indirect evidenecs as below:

4.6.1 Direct Evidences

4.6.1.A ***Earthquake*** : The Kinnaur Earthquake of 19th January, 1975 was found to have been triggered due to reactivation of the KFC in Kaurik area (Bhargava et al, 1978). This earthquake caused faulting of the alluviated ground (Fig. 4.29). The after-shocks of this earthquake continued for about one year after the main shock (Bhargava et al, 1978).

4.6.1.B ***Folds and Faults in the Quaternary sediments*** : East of Sumdo, on the left bank of the Pare Chu, the Quaternary lacustrine sediments have been juxtaposed against the Proterozoic Morang Formation along a high angle fault (Fig.4.30). In Lahaul,

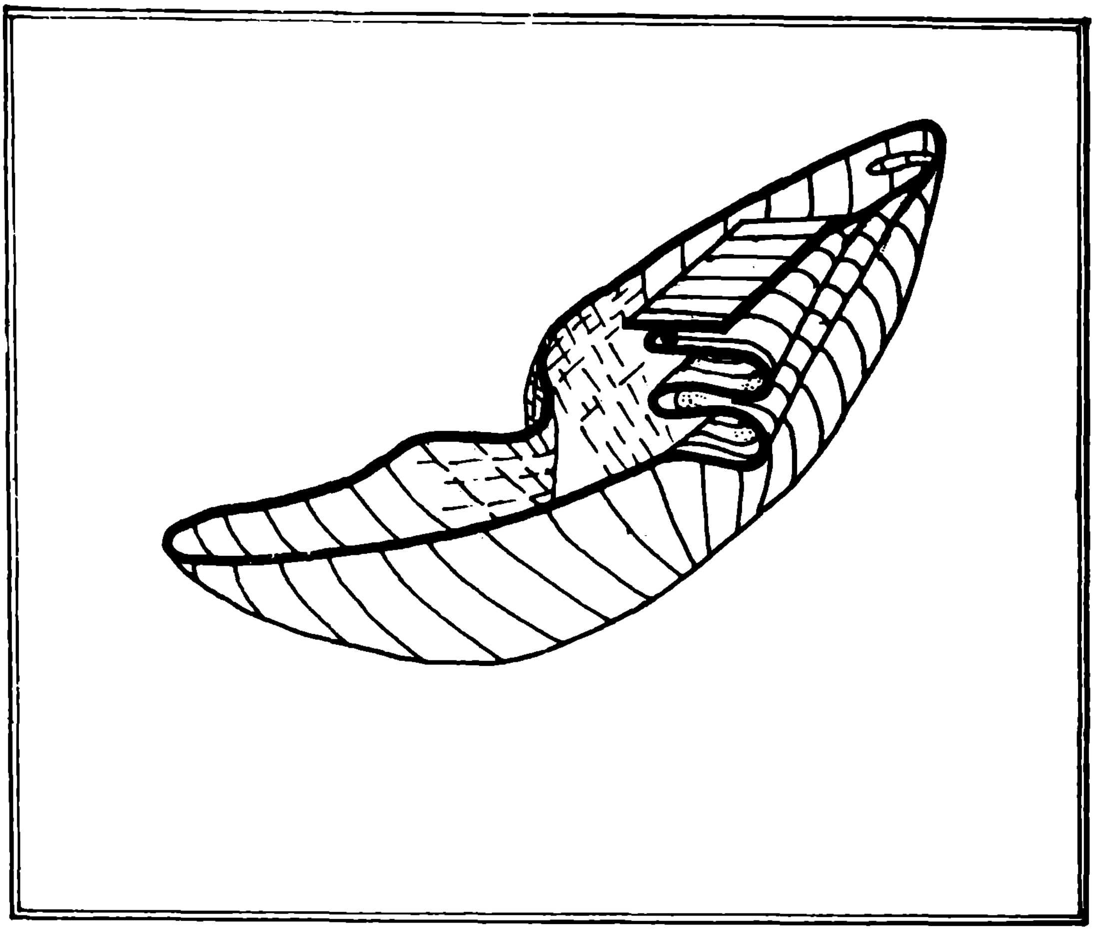


Fig. 4.12. Schematic sketch to show the structure of the Chikkim Syncline.

the Holocene sediments **have not only been tilted (Fig.4.31), but also folded (Bhargava, 1990).**

4.6.2 Indirect evidences

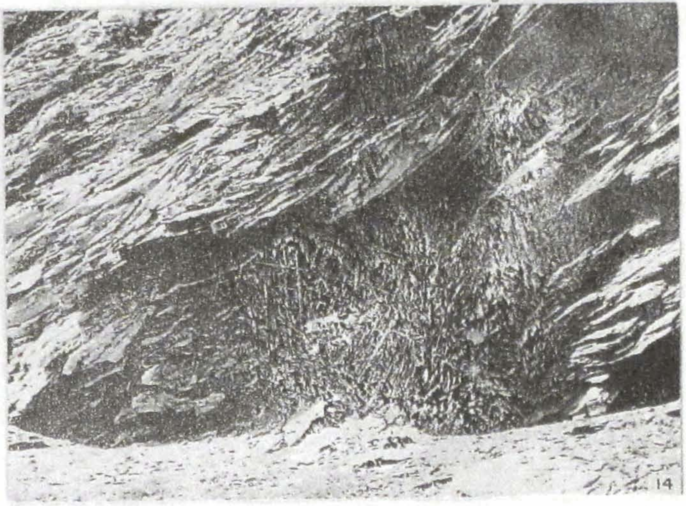
4.6.2.A *Scarplet :* A scarplet constituted of the Mikin Formation is exposed along the wide Spiti Valley south of Atargoo (Fig. 4.32). The scarplet bordering the fault plane is situated on the upthrown block of the Spiti Fault. Being surrounded on all sides by alluvium, it is conspicuous even from a distance.

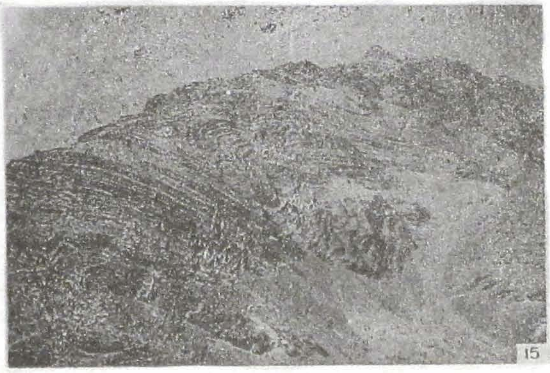
4.6.2.B ***Fluvial changes :*** Major changes in the courses of the Spiti, Puri Lungpa and Phirse *Phu* are noticeable in the form of (a) change in gradient (b) lateral shifting of the river and (c) drainage reversal.

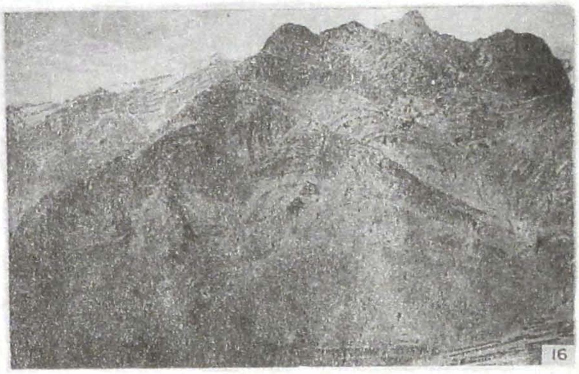
(a) Change in gradient : The Spiti river, upstream of Hal, is a straight single channel river between Hal and Schichling, where it flows along the trace of the Spiti Fault. It is braided and a broad channelled stream. Further downstream of Schichling, the Spiti River broadly meanders. The aforementioned scarplet is situated in the braided part of the river course.

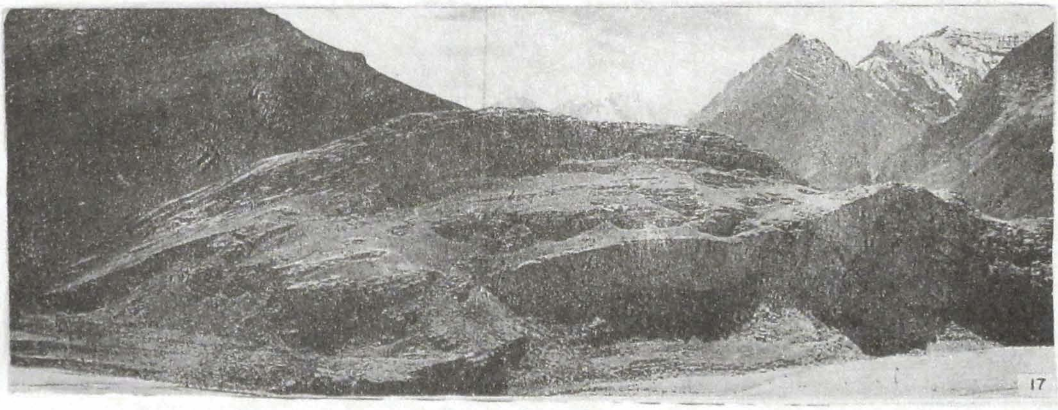
The change from straight to braided pattern in the river course is regarded to indicate a change in the gradient of the river (Schumm, 1985). The change in gradient in Hal-Schichling stretch,traversed by a fault, may be attributed to the Holocene reactivation of a part of the Spiti Fault, possibly in the vicinity of the scarplet described above.

Figs. 4.13 — 4.17





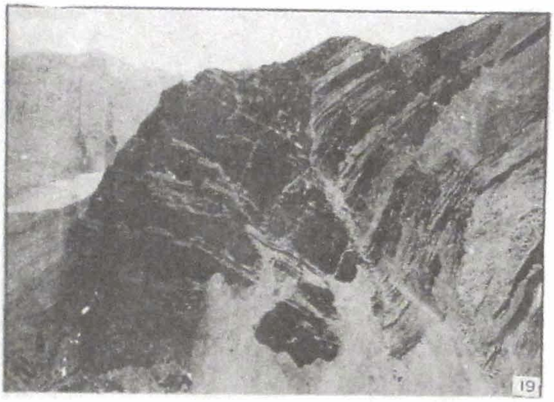


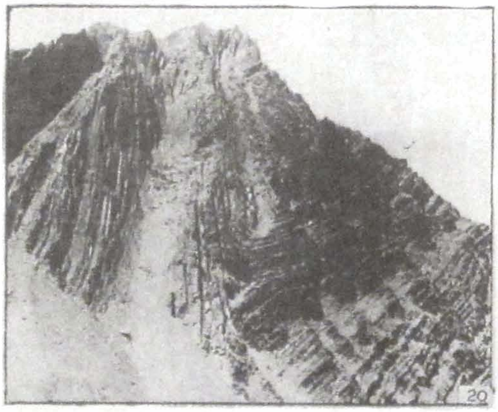


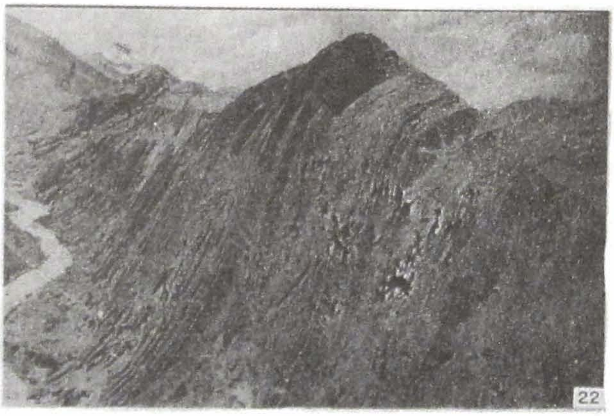
Explanation of Figs. 4.13 - 4.17

Fig. 13. Nako granitoid (108 ± 17 Ma) cutting across F_3 folds of the Morang Formation, Loc. Khab (numbered with respect to earliest fold observed in the Vaikrita rocks). **Fig. 14.** F_1 and F_2 (F_3 and F_4 with respect to earliest folds of the Vaikrita rock) in the Chomule Formation near More Plain Fault at Chumik. **Figs. 15-16.** De'collement folds in the Sanglung Formation comprising shale-limestone alternations. Loc. North of Kaza (15), Parahio Valley, near Chidang (16). **Fig. 17.** Broad F_2 (F4 when numbered with respect to the earliest fold of the Vaikrita rock) anticlinal warp at Khar. It plunges away from the viewer due to F_3 (F_5) cross folding. (Bar scale is 40 cms).

Figs. 4.18 – 4.22







Explanation of Figs. 4.18 - 4.22

Fig. 18. An open symmetrical anticline showing intraformational drag folds due to slippage of beds, with thickening of the hinge. Loc. Perang *Nala*. **Fig. 19.** A broad almost symmetrical syncline and an anticline (left bottom corner) with little or no thickening at the hinge in the Alaror and Kioto Formations. Loc. N bank of Ratang *Nala*, 3km SW of Rangring. **Fig. 20.** An asymmetrical syncline, a fault has developed along the attenuated left limb, which has a considerable extension (Kukoli Fault), Lilang Group. Loc. In Kukoli *Khad*, near its confluence with the Pin River. **Figs. 21-22.** Monoclinal flexures in the Lilang Group. Loc. Near terminus of the Ghunsarang glacier,.Kioto Formation (21), Ratang *Nala*, Hangrang (H) and underlying Sanglung Formation.

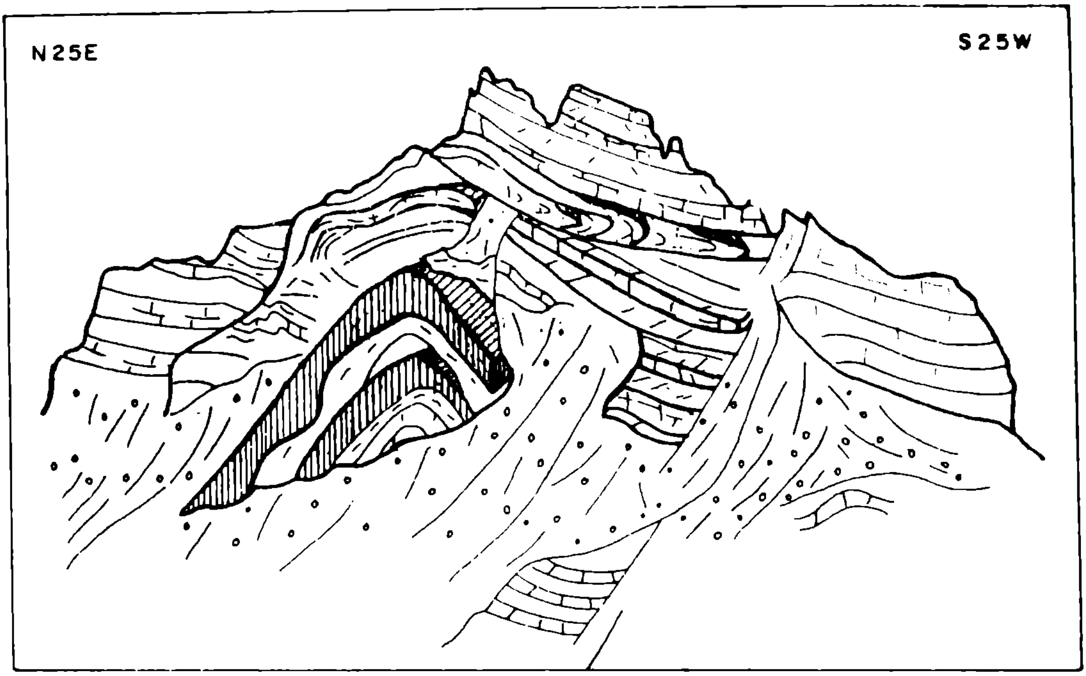


Fig. 4.23. Folding in Alaror-Kioto Formations in hill east of Kiomo. Besides open fold, some recumbent décollement fold are also noticed.

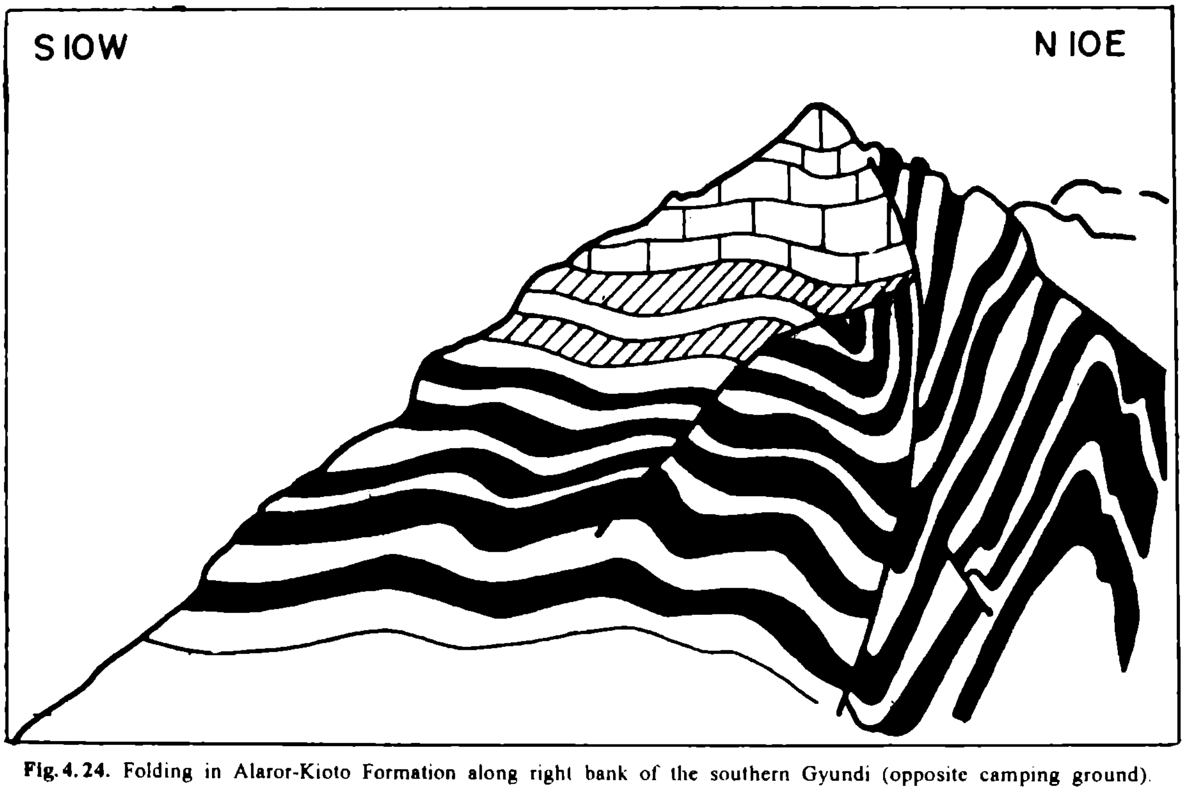


Fig. 4.24. Folding in Alaror-Kioto Formation along right bank of the southern Gyundi (opposite camping ground).

(b) Lateral shifting in the River: The fluvial terrace near Rama in the Lingti Valley shows pebbles of red sandstone of the Thango Formation. As no Thango rocks are exposed in the Lingti catchment, the red quartzite pebbles could not have been brought by the Lingti River. The fluvial terrace at Rama extends southward upto Atargoo in the Spiti Valley at a level higher than the present Spiti River bed. Downstream, this terrace continues upto Dankar-Schichling. This alluvial outcrop clearly suggests that the Spiti River originally looped through Rama and Dhankar. Such a course of the Spiti may also explain presence of red sandstone pebbles in the terraces at Rama.

The reactivation of the Spiti Fault, as deduced above, perhaps raised the Rama block, causing the Spiti River to flow along the downthrown block. The raising of the upthrown block, aided by landslides, dammed the river channel at Schichling. This damming caused a vast lake between Atargoo and Dankar.

(c) Drainage reversal : The Phirse Phu from the Telecon Pass flows southeast-ward and takes an abrupt turn towards north and through rills cuts its own fan and joins the Tso Morari lake (Fig.4.33).

The earlier course of the Phirse *Phu*, as documented by the spread of its Valley and oldest terrace, was towards the Pare *Chu*. A part of water of the Phirse *Phu* from the top of the fan still spills into the Pare *Chu*.

The point where the Sumkhel has deflected from its earlier course is located along the trace of the MPF. The activation of this fault possibly caused the Phirse *Phu* to swing towards NE, thereby diverting it into the Tso Morari.

There is yet another facet of the geomorphological history of the Phirse *Phu*. The divide between the Sumkhel and Phirse streams, three kilometre east of Telecon Pass, is situated on alluvial and fluvioglacial terraces indicating that a stream had flown through this stretch as well. The existence of wide valleys of the Sumkhel and Phirse right upto the Telecon Pass suggests that these together formed one continuous stream which joined the Pare *Chu*. The reactivation of fault located along the western margin of the Tso Kar upto the Telecon Pass, possibly tilted the upthrown western block towards northwest thereby truncating this river and reversing the course of the Sumkhel part of the stream (Bhargava, 1990). The uplift of this block is also supported by the occurrence of coarser clastics in the upper catchment of the Sumkhel and their comparative paucity in the Phirse *Phu* Valley.

Various tectonic elements of the Spiti-Kinnaur area are depicted in Fig.4.27 (in pouch).

4.7 SEE-SAW TECTONICS

The phenomenon of interchange in a relative movement of upthrown and downthrown blocks of the given fault in time has been described in the geological literature as 'Inversion Tectonics' (Williams *et al*, 1989). In the Spiti Valley, such inversions have repeatedly occurred along the MPF, SFC and KFC during the geological history of the basin. Such changes in relative direction of movement of blocks on either side of the fault with SFC as a typical example are recounted below :

1. The SFC restricted the post-Eocambrian basin to the SW. The NE block thus formed the upthrown side.
2. A deeper facies of the Tournaisian Lipak Formation occurs NE of the SFC over the Eocambrian. The NE block, therefore, formed the downthrown block.
3. The Visean to Norian basin was restricted to the SW. block. The NE block formed the upthrown side to delimit this basin.
4. (a) Rhaetic-Cretaceous rocks occur NE of this fault; (b) the Carboniferous rocks are more metamorphosed showing greater depth of burial and (c) rocks show semiductile recumbent folds. The NE block, thus, once again, became the downthrown side and remains so till this day.

Similar switching of direction of relative movement along MPFC and KFC are also decipherable. The periods when such inversion and reversion can be deduced are presented in table 4.1. It is suggested that the tectonic cycle, which involves repeated change in relative directions of movement along a fault in time, may be termed as 'See-Saw or

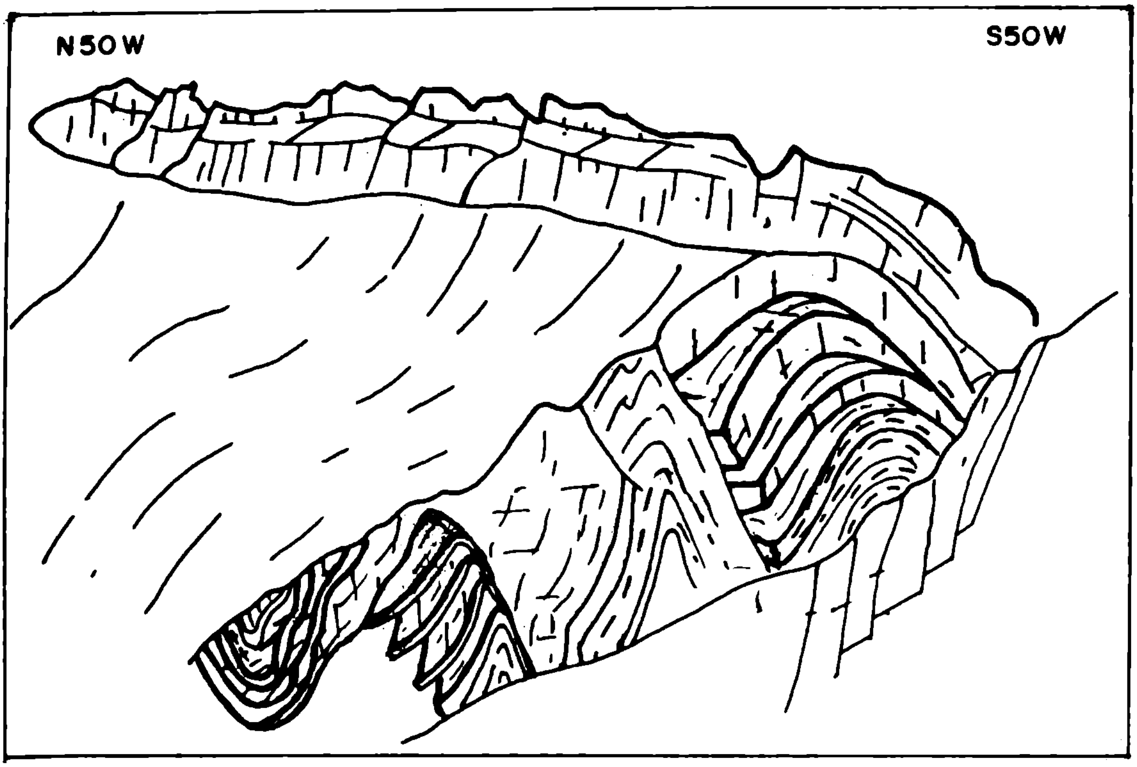


Fig. 4. 25. A view towards NE of Kenlung (Ullah *Nala*) showing folding in Alaror-Kioto Formations. Folding is mainly confined to Alaror Formation.

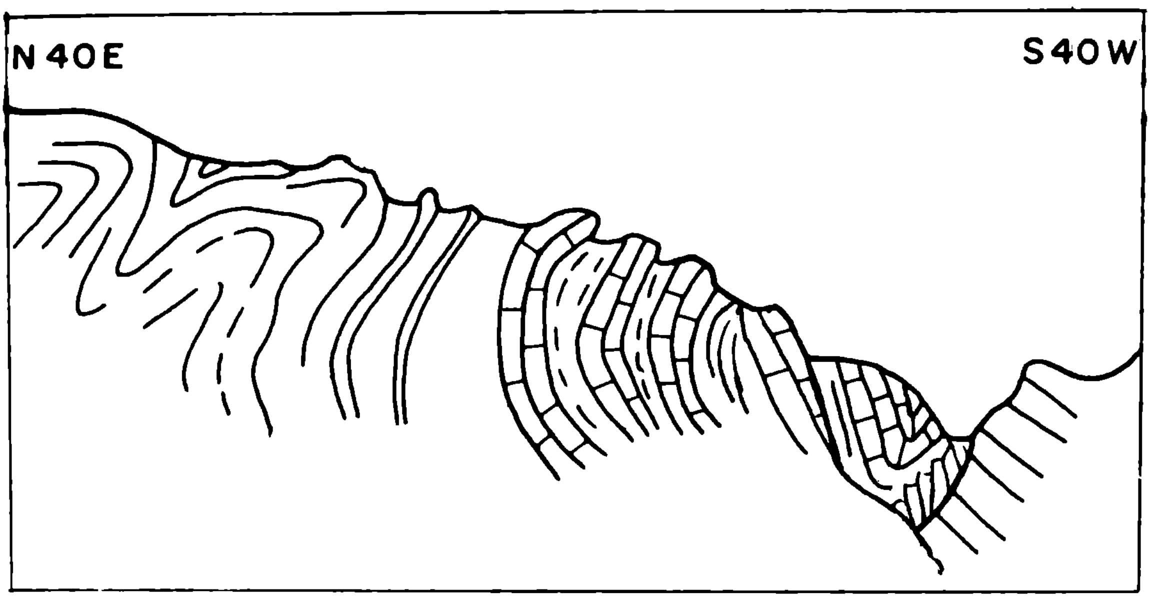
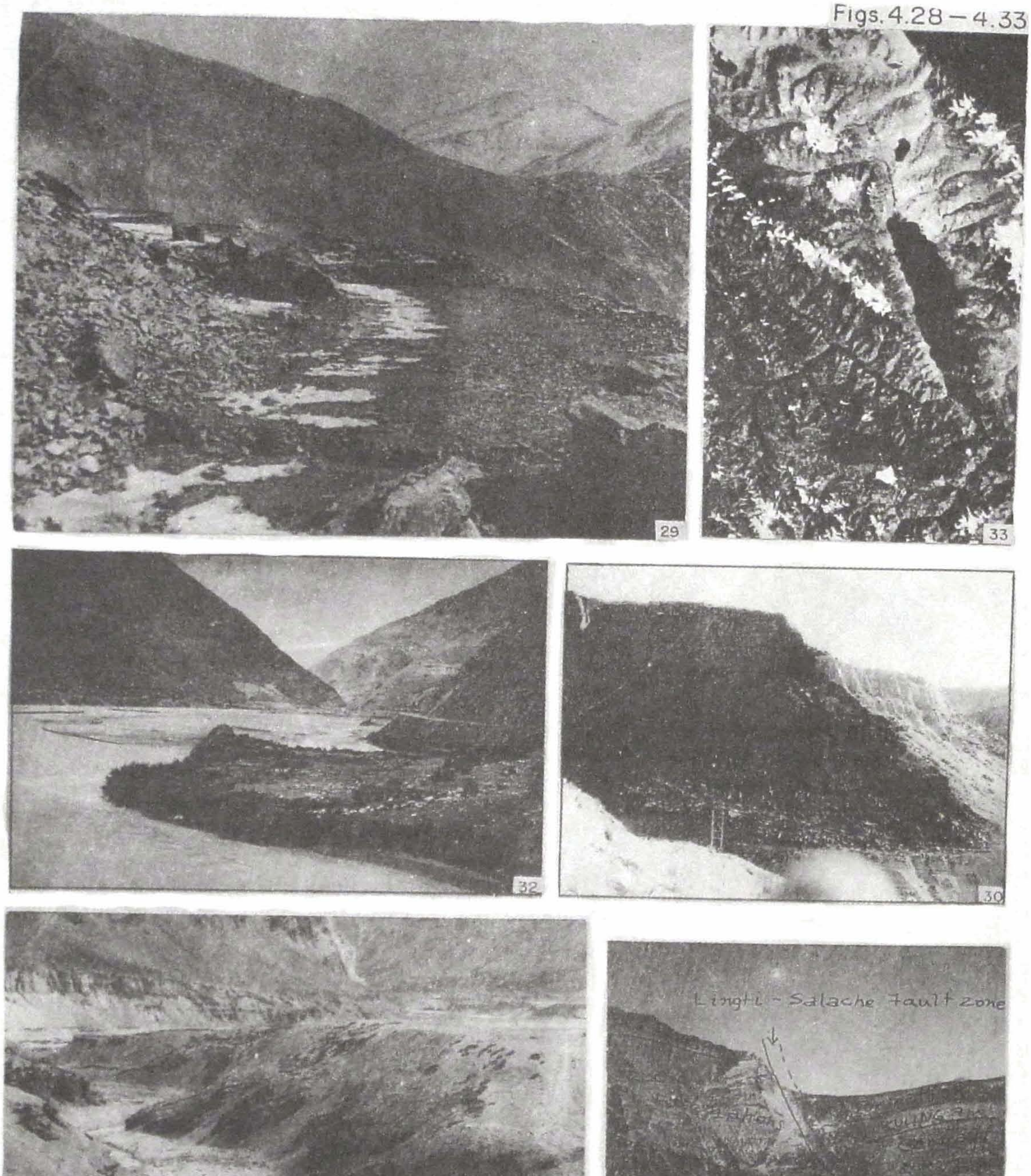


Fig. 4. 26. Folded Lilang Group near Nyungpur.

Figs. 4.28 – 4.33



Explanation of Figs. 4.28 - 4.33

Fig. 28. Salache Fault between Palaeozoic-Scythian rocks on downthrow side and upper Triassic. rocks on upthrow side. Fault hades towards downthrow side, it is steeper at top and shows a tendency to flatten at depth. **Fig. 29.** Series of step faults developed along road between Sumdo and Kaurik during 19th January earthquake of 1975, with southern block forming the downthrow side. **Fig. 30.** Fault between Quaternary lacustrine deposit (light coloured) and the Precambrian crystallines. **Fig. 31.** Tilted Holocene fluvial bed along the Sarchu Nala, just below the old bridge. **Fig. 32.** Scarplet (s) along the upthrow side of the Spiti Fault downstream of the Lingti. **Fig. 33.** Straight edged (west) Tso Morari pull-apart basin (25 km x 6cm) and Phirse *Phu* debouching in it. Earlier this stream flowed towards south to meet the Pare *Chu*.

Table 4.1
Changing pattern of blocks on either side of MPFC, SFC and KCF in time

FAULT		MPFC		SFC		KFC	
Period	BLOCK	SW	NE	SW	NE	W	E
Present		D	U	D	U	D	U
Rhaetic		U	D	U	D	U	D
Visean		D	U	D	U	D	U
Tournaisian		U	D	U	D	U	D
Eocambrian		D	U	D	U	D	U

D = Downthrow U = Upthrow

4.8 CONSTRAINTS IN THE DATING OF THE STRUCTURAL ELEMENTS

As indicated earlier, the Tertiary deformation has largely obliterated the older structures. The evidences for the pre-Tertiary tectonic events are, thus, far and few and there exist certain ambiguities in the interpretations drawn in the present work. These ambiguities are listed below.

1. In some sections of Lahaul and Spiti an apparent gradation in metamorphic grade and tectonic style is reported from the rocks of the Vaikrita Group to the Batal Formation. However, as discussed earlier, in one section of Kinnaur (Bassi, 1988a), definite breaks in metamorphic and tectonic episodes between the rocks of the Vaikrita Group and the Batal Formation were established.

2. Though no unquestionable Pr.F_2 folds seem to be present in the Eocambrian - Palaeozoic - Mesozoic rocks, the rocks of the Batal Formation in a few sections and those of the Kunzam *La* Formation in the Lankapanug section show folds which are comparable in style to Pr F_2 folds. Due to paucity of such folds, the aforementioned relationship cannot be unequivocally ascertained. If the 'Pr F_2' folds are same as those of the Kunzam *La* Formation in the Lankapanug section, then the age of the M_2 metamorphism associated with these folds shall also be late-middle Cambrian (pre-Thango), coinciding with the age of the early Palaeozoic granitoids. Such an interpretation may also account for the reported gradual change in the tectonic style and the grade of metamorphism from the Vaikrita Group to the Batal Formation in certain sections of Lahaul.

3. Cretaceous age to the folds exposed between Khab and Yangthang has been assigned due to (i) 108 ± 17 Rb - Sr age of the Nako granite (Kwatra *et al*, 1987), which cuts through these folds and (ii) parallelism of these folds with overturned/ recumbent folds of the Chikkim syncline.

There are two distinct granitoid varieties in the Khab-Yangthang sector; both these granitoids cut the recumbent folds in the aforementioned sector. The granite varieties are : (i) biotite-rich foliated granite with yellowish stains and (ii) leucocratic tourmaline-bearing granite. The 108 ± 17 age (Kwatra *et al*, 1987) is of the leucocratic granite. The biotite granite, texturally, is comparable to the Rakcham Granite which is 495 Ma old (Sharma, 1983). Should the granite in Khab-Yangthang section also yield a similar Rb-Sr date, the folds referred as MF_1 in this section shall be correlatable with Pr F_2 folds (Proterozoic or middle-late Cambrian).

5. BASIN ANALYSIS

The following aspects of the basin analysis, viz. (1) Facies and palaeoenvironment of sedimentation, (2) Basin morphology, (3) Palaeocurrent directions, (4) Location of palaeo-shoreline, (5) Provenance and (6) Evolution of basin in space and time are discussed in this chapter. As stated earlier, very few sections are accessible in this mountainous terrain where detailed studies could be made. The conclusions derived thus are broad based. The palaeocurrent directions of each formation are meagre and, due to absence of marker beds within these formations, represent data from different stratigraphic levels. The palaeocurrent information contained here, therefore, is of limited use.

5.1 FACIES AND ENVIRONMENT OF SEDIMENTATION

A preliminary interpretation of environment of sedimentation for the Tethyan sequence of Kinnaur has been made by Bhargava *et al*, (1984) and that of Spiti by Narain (1975), Srikantia (1981) and Fuchs (1982). A more detailed account for the Spiti part is provided by Bhargava (1987), Bhargava *et al*, (1987, 1991b), Bagati (1990) and Bagati *et al*, (1991). These interpretations, especially of the Palaeozoic sequence, in the light of additional data collected, have been partially modified in the present work. In the present study the pre-Batal successions, which comprise metamorphic sequence, have been omitted.

5.1.1 Haimanta Group

5.1.1.A *Batal Formation*

The Batal Formation represents moderately to poorly sorted heterolithic facies varying from mud (Hc) to sand, arranged in numerous small fining - upward cycles. The thickness of cycles increases towards the stratigraphic top and in each succeeding cycle there is an increase in grain size. The lower part has an overall higher percentage of argillaceous and carbonaceous matter as compared to the upper part. The characteristic bedding features are lenticular bedding, mud drapes in between sandy layers and rhythmite showing subparallel laminations and low angle truncation surfaces. Basic lava flows are sporadically found in the basal part and matrix-rich conglomerates in basal and middle parts.

The above lithological assemblage and bedding features suggest a broad peritidal setting mainly in subtidal lower shore face zone and partly in the intertidal zone environments. The fining—upward cycles possibly indicate subtle changes in coastline reflecting change in relative depth. These changes in earlier history of the Batal Formation were in deeper part of subtidal areas and were also quite frequent resulting in thin cycles. Towards the upper part, as indicated by predominance of sand and increased thickness of cycles, there was an overall shallowing. In upper part, the change in depth within the depositional cycles seems to be mainly between deeper part of upper shore face to shallower part of the lower shore face in a tidal setting. The matrix—rich conglomerates represent tidal channel (Friedman and Sanders, 1978) or the coarser material flushed from coastal part due to shifting strand lines. The hurricanes possibly produced the graded rhythmites. The basin in earlier part had poor circulation thus preserving the carbonaceous material. During the sedimentation of the upper part of the Batal Formation, the area of sedimentation became shallower.

In the Batal Formation, a few ripple marks present in its upper most part in the Batal-Kunzam *La* and Debsa sections indicate palaeocurrent directions varying from SW to NE through NW quadrant. In all, ten palaeocurrent readings were recorded.

5.1.1.B *Kunzam La Formation*

In better developed sections this formation shows five units. The lowest unit, heterolithic mud mixed (Hc) facies is poorly to moderately sorted siltstone, shale with subordinate medium grained sandston and sandy rhythmites (Fig.5.1) showing parallel bedding. The typical bedding features are wavy ripple (Fig.5.2) and lenticular beddings, low angle truncations (Fig.5.3), ripple marks (Fig.5.4), channel fills of sands (Fig.5.5) and syndepositional slumps. Rippled sand layers show grading. No apparent cyclicity is noticed and various units occur randomly, often separated by low angle discordance surfaces. The sequence is characterised by the *Cruziana* facies of trace fossils. There is no perceptible change in environment of deposition along the Batal-Kunzam *La* contact. The trace fossil assemblage of *Cruzina* facies, ripple, wavy and lenticular beddings suggest deposition mainly in subtidal environment. Absence of *Cruzina* and presence of *Diplichnites* (Bhargava *et al*, 1982) indicate, in general, low energy conditions, though presence of local bottom currents are indicated by parallel alignment of *Rusophycus* (Bhargava and Srikantia, 1985) (Fig.5.6). Bar and channel conditions are also indicated by low angle dipping laminated sand rippled layers and lenticular units, which are thicker at the point of pinch out. Influence of mild hurricane/storm is reflected by graded rhythmites.

The next higher unit is also represented by mud-mixed heterolithic facies (Hc) but shows graded rhythmites, sand packages with mud drapes, low angle truncation (Fig.5.7), local flute casts (Fig.5.8) and small scale ripples. No trace fossils were recorded though bioturbations are present. Numerous rhythmic units show sole markings, low angle lamination and current-ripple lamination capped by ripple bedding. Moderate sorting in sandy layers, however, indicates intermediate energy level. The deposition could be in lower to intermediate part of subtidal zone. The local conglomerate in the Pin Valley also belongs to this facies, which is broadly comparable to sublittoral sheet sandstone of Reading (1982), representing a transition intermediate storm deposit of high and low energy shelf of fluctuating wave intensity.

The third unit is sand dominated heterolithic facies (Ha) represented by matrix deficient cross-bedded sandstone showing ripple and lenticular bedding. This unit shows evidences of high energy in the area of deposition producing matrix-deficient and cross-bedded sandstone, indicating a shallowing toward middle to upper shore faces.

It is succeeded by another heterolithic facies represented by algal dolomite, silty shale, shaly siltsone and fine sandstone. The bedding features in this unit are algal mat and columns, low-angled cross-bedding in lenticular beds showing thicker ripple unit near pinching and less than one centimetre ripple layers with mud drapes, wavy bedding, herringbone cross-bedding (Fig.5.9) and mudcracks. This unit encloses trilobite, brachiopod and *Hyolithes* fossils. The carbonate beds in this facies have an erosional (*e.g.*, Bara Lacha *La* section) as well as gradational (*e.g.*, Kunzam *La* section) contact with the underlying sediments and a sharp contact with the overlying sandstone. The lithologic and fossil assemblages indicate shallowing and local sub-aerial exposure followed by erosion and deepening to cut off clastic input and deposition of carbonate over eroded edges. Further shallowing led to restoration of sandy sedimentation. Recurrence of such cycles gave rise to several levels of carbonate deposition. Presence of algal mat and *Epiphyton* built columns (Fig.3.9) and trilobite remains suggests deposition in restricted platform to low energy, possibly shallow lagoonal environment. Shallowing led to tidal flat conditions when herringbone cross-bedded and mudcracked sandy and silty beds were deposited. The uppermost unit shows facies variation from pink-maroon silty shale (Fig.5.10), fine siltstone and sandstone showing cross-bedding and ripple lamination in the Kunzam *La* section to greenish-pink, white, cross-bedded quartzarenite, shale and siltstone showing mudcracks and ripple marks in the Parahio section. The lithologic assemblage and bedding features indicate further shallowing and consequent increase in energy condition. Frequent subaerial exposures formed mudcracks and oxidising conditions imparted a maroon colour to the sediments.

The overall pattern of the Haimanta Group (Batal and Kunzam *La* Formations) indicates a gradual shallowing from subtidal to tidal and possibly supra-tidal environments along with gradual aeration of basin. Appearance of benthonic communities in early Cambrian coinciding with basal part of the Kunzam *La* Formation led to bioturbations which, in the beginning, mainly occur as horizontal burrows (Fig.5.11). Somewhat complex burrows appear in upper part of the Kunzam *La* Formation (Fig.5.12).

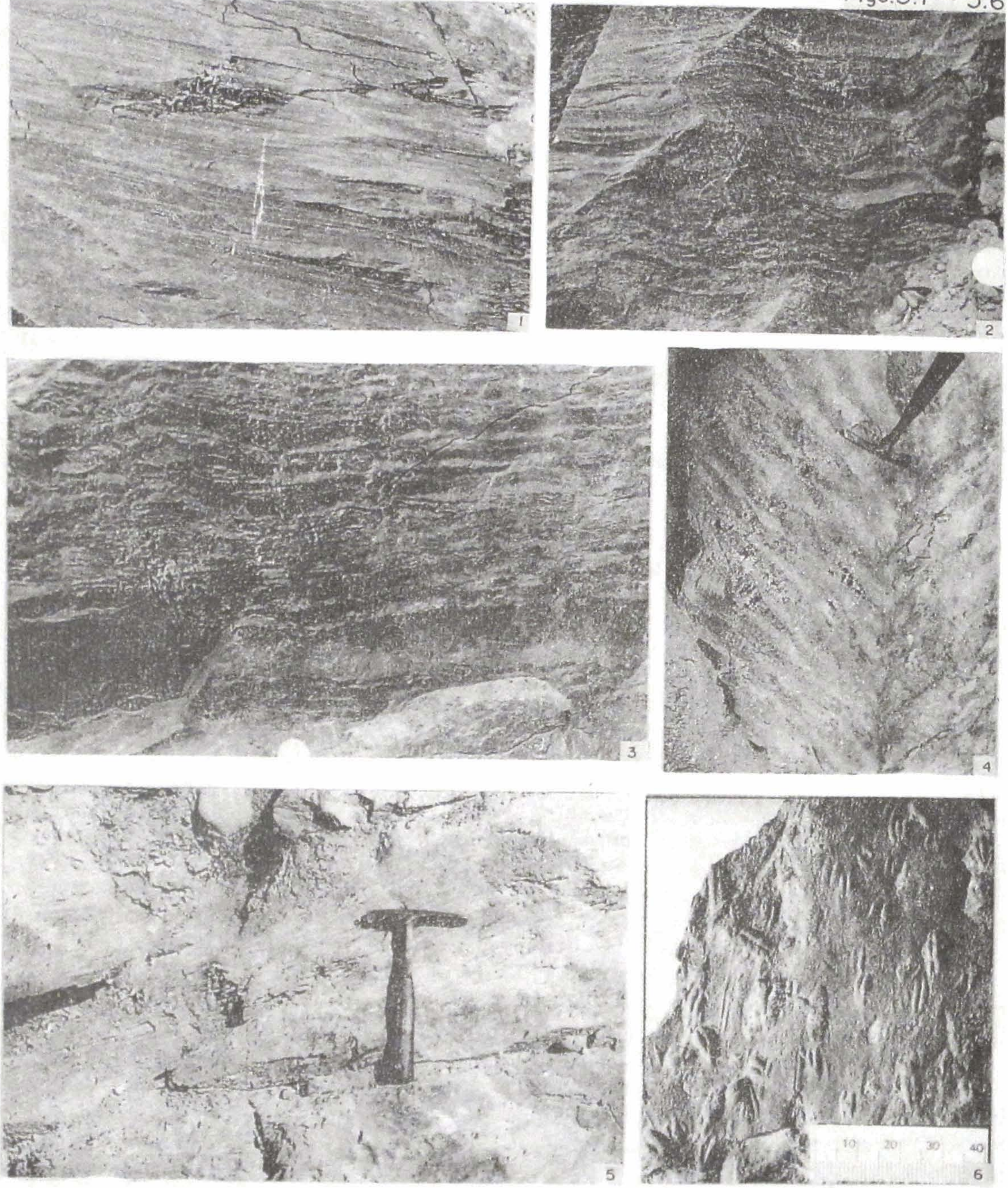
In all, about thirty palaeocurrent readings were recorded in the Kunzam *La*, Pin and Parahio sections, the vector mean direction being NNE.

5.1.2. Sanugba Group

5.1.2.A *Thango Formation*

The thickness of the Kunzam *La* Formation in general decreases from NW to SE and in the same direction older and still older sequences are preserved. The Thango Formation in the Kunzam *La*-Parahio section, thus, rests over the youngest unit of the Kunzam *La* Formation and over the oldest in the Gyamthing and other Kinnaur sections. This disposition of the Thango Formation over different stratigraphic units of the Kunzam *La* Formation could be due to an overlap or to erosion of the Kunzam *La* Formation in pre-Thango period. The latter interpretation is favoured as the clasts in the conglomerate of the Thango Formation have a distinct Kunzam *La* Formation affinity. The main lithologic

Figs.5.1 – 5.6



Explanation of Figs. 5.1 - 5.6

Fig. 1. Sandy rhythmites, Kunzam *La* Formation. Loc. Kunzam *La* section. **Fig. 2.** Wavy ripple bedding, Kunzam *La* Formation. Loc. Kunzam La section. **Fig. 3.** Low angle bedding truncation. Kunzam *La* Formation. Loc. Kunzam *La* section. **Fig. 4.** Ripple marks in the Kunzam *La* Formation. Loc. Kunzam *La* section. **Fig. 5.** Channel fill in the Kunzam *La* Formation. Loc. Kunzam *La* section. **Fig. 6.** Aligned Rusophycus, Kunzam *La* Formation. Loc. Four km N10^{0}W of Kunzam *La*.

assemblages in the fully developed Thango Formation are (a) both matrix-rich and matrix-poor conglomerate showing moderately sorted, fairly well rounded clasts with subordinate coarse grained tabular cross-bedded sandstone; (b) coarse medium and fine grained sandstone showing tabular, festoon, herringbone cross-beddings (Fig.5.13) and tidal bundle in the upper and ripple cross-bedding in basal part; (c) cross-bedded medium to fine grained, bioturbated, ripple bedded sandstone-shale with load casts, *Planolites, Rouaultia, Phycodes* etc. and (d) cross-bedded sandstone with oscillation and also current ripple marks at places with bifurcating (Fig. 2.16) and flat topped crests, mudcracks (Fig.5.14) and current crescents (Fig.5.15).

In the conglomerate facies, the basal most conglomerate contains clasts of the Kunzam *La* affinity and the ones higher, in addition, enclose those of the Thango affinity also indicating uplift in provenance during the deposition. This movement gave a gentle tilt to the Kunzam *La* beds resulting in local angular discordance with the overlying Thango Formation. The conglomerate showing a decrease in size of clasts towards stratigraphic top seems to be of fluvial origin, which were brought by torrential mountainous rivers. These could also be remnants of fans, largely reworked during marine transgression.

The cross-bedded sandstone facies (Sa) is the most predominant and indicates effect of tidal currents with minor influence of wave action in a shallow tidal sea. The sequence showing low angle cross-bedding (Fig.5.16), ripple bedding and mud draped ripple layers (Fig.5.17) indicate wave activity by migrating bars with minor tidal influence. The bifurcating linguoid wave ripples, flat crested ripples, current crescent and mudcracks reflect intratidal to possibly supratidal palaeoenvironment.

The shale-sandstone facies (Ha) with trace fossils in upper part indicates reduced energy, possibly in intertidal zone. Thicker shale components perhaps represent inter to subtidal palaeoenvironment.

The Visher's curves for Thango sediments (Bhargava *et al*, 1991b) suggest environments varying from fluvial component reworked on beach, tidal channel, wave zone, beach and possibly mixed environment in one case.

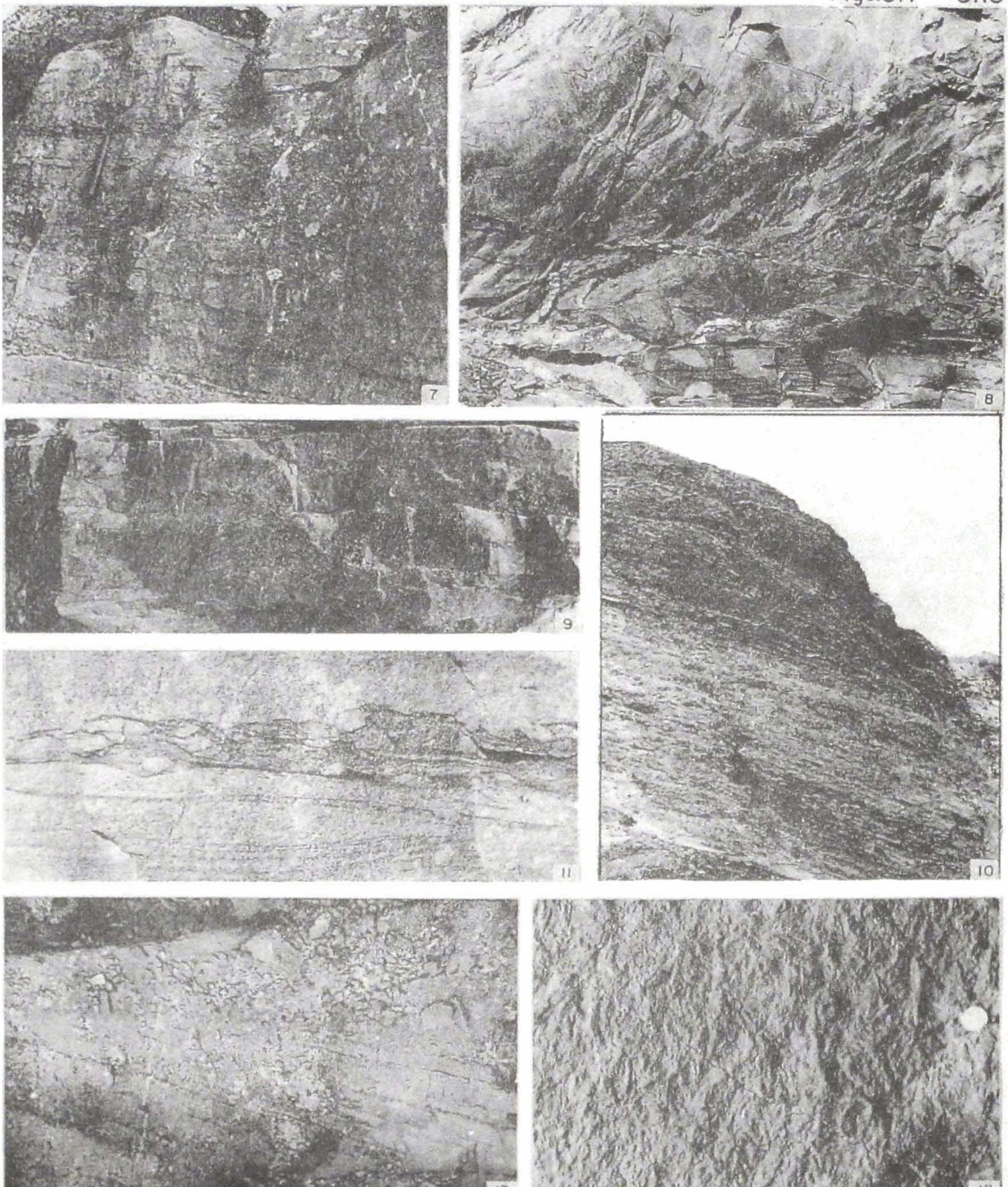
To summarise, the sedimentation of the Thango Formation commenced with fluvial material reworked on beach, and passed through essentially a tidal zone with storm episodes where wave action was prominent. During the later part, locally short lived supra-tidal/intertidal conditions were attained. Towards the terminal phase, by and large, there was decrease in energy level, possibly due to relative deepening. The entire sedimentation took place under oxidising conditions.

In the Thango Formation the palaeocurrent directions were determined by cross-beds. The directions are highly variable. The average mean direction is predominantly towards NE. In total 25 palaeocurrent directions were recorded from the Takche, Sanguba and Thango sections.

5.1.2.B *Takche Formation*

This formation shows two distinct composite facies. In western part of the basin, *i.e.* from Takche upto Ratang section, it has a considerable siliciclastic input, whereas, in the eastern part *i.e.* Pin, Parahio and Leo in Spiti basin and entire Kinnaur, the carbonate component is dominant. The change from arenaceous to calcareous is apparent between the Ratang and Parahio Valleys. In either case a number of cycles are recognisable in the Takche Formation. In the clastic dominated sequences, the cycles in basal and middle parts of the formation commence from bioturbated fine grained sediments or with fossiliferous beds. This passes into alternation of silty and fine to medium grained calcareous clastics, both showing parallel and low angle cross-beds. It ends up in fine-medium grained sandstone showing hummocky cross-stratification and low-angle discordance. Such cycles vary in number from two to eight. Some of these cycles are thick while others have limited thicknesses. Within some of the cycles occur minicycles *e.g.* bioturbated units and fossiliferous units as smaller interbedded units or hummocky cross-bedded unit interbedded with fine bioturbated units. The upper carbonate (mostly dolomite) part is generally rich in corals and brachiopods. In this part, the cycles commence with siltstone-coral/brachiopod/crinoidal carbonate and/or bioturbated beds interbedded with fossiliferous beds ending in cross-bedded or rippled sediments. These cycles broadly represent shoaling cycles, beginning in lower energy environment (middle-lower shore face ?)and

Figs.5.7 – 5.13



Explanation of Figs. 5.7 - 5.13

Fig. 7. Low angle bedding truncation in the middle part of the Kunzam *La* Formation. Loc. Kunzam *La* section. **Fig. 8.** Flute casts and other sole marks in the middle part of the Kunzam *La* Formation. Loc. Kunzam *La* section. **Fig. 9.** Herringbone cross-bedding, Kunzam *La* Formation. Loc. Shitikar (Kunzam *La* section). **Fig. 10.** Shale dominated upper part of the Kunzam *La* Formation. Loc. Shitikar (Kunzam *La* section). **Figs. 11-12.** Burrows in the Kunzam *La* Formation. Horizontal in basal part (11) and complicated in upper (12). Loc. Kunzam *La* section. **Fig. 13.** Herringbone cross-bedding, Thango Formation. Loc. Takche.

ending in upper shore face affected by storms of mild intensity. Towards the upper parts, the beds containing *Favosites, Halysites* and rugose corals possibly indicate deposition in near shore undathem (Facies Belt 7 of Wilson, 1975) or along subtidal-intertidal interface, where siliciclastic material was also deposited. In the carbonate dominated sequences of the Pin, Parahio, Gyamthing and Tidong Valleys, the cycles commence either with a sequence of bioturbated fine grained clastics or limestone-marls with shale partings passing through organic buildups and ending in cross-bedded clastics showing cuspate ripple marks. The cycles in the microfacies are not very clear, yet broad cycles commencing with packstone/ mudstone/ wackestone and end in breccia (rudstone) at top, can be identified.

Small coral, stromatoporoid, algal and bryozoal build-ups occur in the Takche Formation of the Parahio, Pin, Lipak and Tidong Valleys. The wackestone indicates quiet, protected, open to restricted platform (Facies Belts 7 and 8 of Wilson, 1975) to partly foreslope (Facies Belt 4) palaeo-environment. In the former, well segregated sandy and carbonate beds were deposited, whereas in the latter environment, whole fossil wackestone showing syndepositional deformation was laid. Both seem to represent low energy environment. The rudstone normally is regarded as a foreslope facies (Wilson, 1975).

The most predominant corals found in the Takche Formation are *Halysites* and *Favosites*. The former indicates high energy protected environment (Wilson, 1975) while the latter, especially basket-shaped (Fig.3.14) growth common in the Tidong Valley, suggests a basin with feeble current (Wilson, 1975). The bryozoa, which forms bafflestone, indicates low energy or protected high energy environments similar to that of *Halysites*. The high energy environments are indicated by laminar and low domal stromatoporoid (Kershaw and Riding, 1978). The occurrence of *Vermiporella* in rudstone facies suggests that it could thrive in high energy environment and also possibly form wave resistant structures (Bhargava and Bassi, 1986). Its colonies, however, within the *Halysites* chains are indicative of its preference to protected environment. The reef facies is symbolised by spherical and encrusting forms of *Girvanella* (Wray, 1977; Tsien and Dricot, 1977). The typical organic reefs are only selectively developed in the Spiti-Kinnaur area. The build-ups, having enough siliciclastic material, seem to have developed near shore and have been compared with fringing type (Bhargava and Bassi, 1986). Only in the Manchap *Thach* area, possibly back reef, partly organic reef and foreslope facies are developed. Overall, the organic build up and microfacies indicate protected low energy environment with local introduction of high energy. Each cycle mentioned above represents prograding event of varying magnitude.

In the Takche Formation, only the cross-bedding in the Takche and Parahio sections were utilised to determine the palaeocurrent directions. These indicate currents to vary between NW to NE quadrants, the latter being more prominent. Southeasterly palaeocurrent directions in the Takche Formation were noticed in the Pin Valley. In all about 20 readings were taken.

5.1.3 Kanawar Group

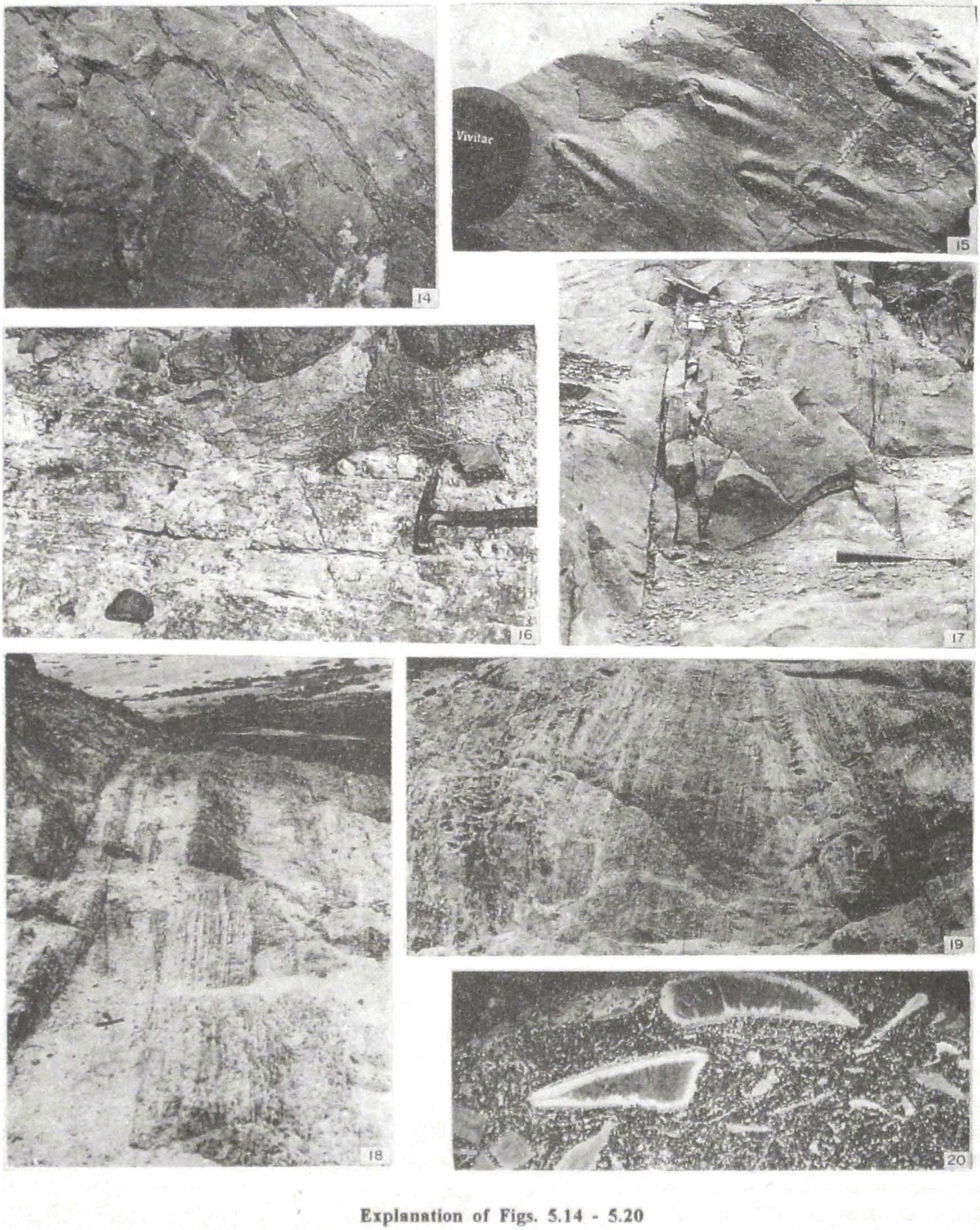
5.1.3.A *Muth Formation*

The clean sand in the Muth Formation, abruptly appearing just above the Takche Formation, indicates a probable sedimentologic break whose duration is difficult to determine. The Takche-Muth contact in the Takche and Gechang sections is undulatory. However, as stated earlier, it is difficult to conclude if these undulations represent erosional surfaces.

The Muth Formation is essentially represented by clean sandstone facies (S) which mainly shows low angle truncation surfaces (Sa) with subordinate low angle cross-bedding (Fig.5.18), alternating with low angle cross-bedded units with sub-ordinate sub-parallel low angle truncations (Fig.5.19). Locally minor trough and festoon cross-bedding, ripple bedding and channel fills are present. Herringbone cross-bedding, mudcracks and interference ripple marks are sporadic. Only in some isolated sections thin dolomitic beds (i.e. Pin section) and thin pebble beds are developed. The sandstone subfacies characterised by aforementioned bedding features are repeated in quick cycles. In between some of the cycles occur erosional surfaces. The Muth Formation, besides its lithology and bedding features, is characterised by total absence of fossils and even bioturbation. Only a few orthid impressions (Bassi, 1988b) and trace fossils referable to *Planolites, Palaeophycus tubularis, Arenicolites* and arthropod tracks are known from this formation.

The sediments of the Muth Formation, during

Figs.5.14 – 5.20



Explanation of Figs. 5.14 - 5.20

Fig. 14. Mud cracks in the Thango Formation. Loc. Takche section. **Fig. 15.** Current crescents in the Thango Formation. Loc. Lankapanug. **Fig. 16.** Low angle cross-bedding, Thango Formation. Loc. Takche section. **Fig. 17.** Mud drapes in the Thango Formation. Loc. Takche section. **Figs. 18-19.** Low angle cross-bedding, sub-parallel bedding and low angle truncation planes, Muth Formation. Loc. Takche section. **Fig. 20.** Cortoid of shells aligned parallel to the bedding (slide print), Gechang Formation, Loc. Liwa *Thach*. (Bar scale is 10cm for Fig.5.14 and 2mm for Fig.5.20)

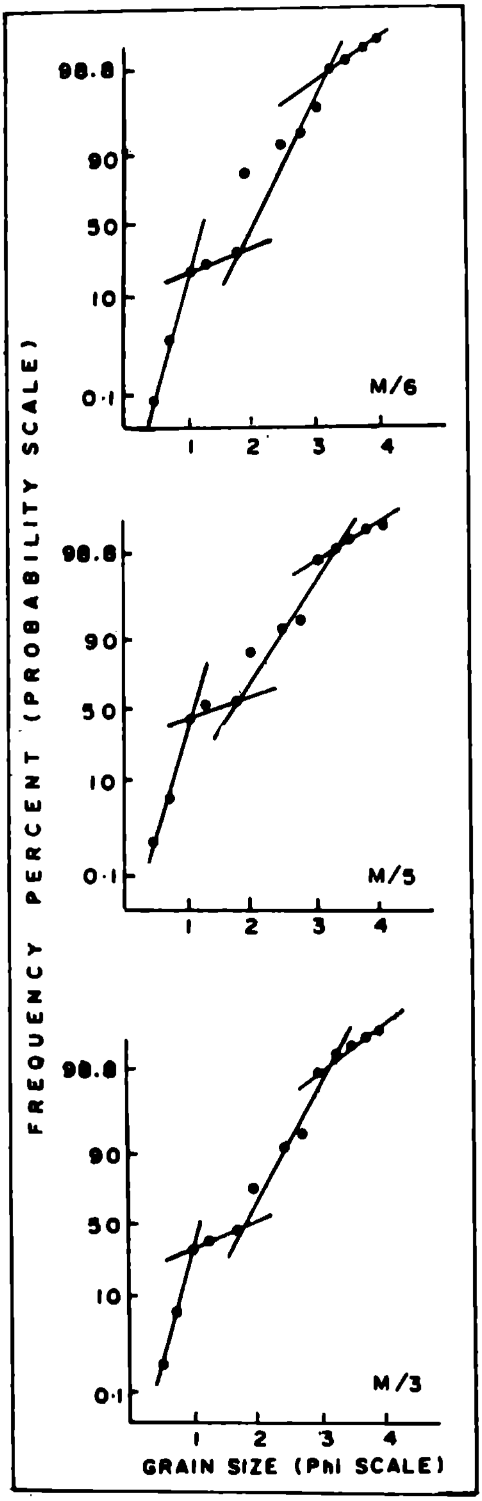


Fig. 5.21. Visher's curves for the Muth Formation. Measurements from sieving of friable sandstone.

a preliminary study in Kinnaur, were interpreted to be of intertidal palaeoenvironment (Bhargava *et al*, 1984a). Since the sandstones are largely very clean, this interpretation was revised and the beach to wave zone environment was favoured (Bhargava *et al*, 1991b). In this interpretation, sporadic herring-bone cross-bedding, mudcracks, interference ripple marks, frosted quartz grains and CM (Passega, 1964) and Visher's curves (Visher, 1969) were taken into consideration.

The fine-grained sand with planar, low angle bedding and some trough cross-lamination has been observed in the transgressive upper shore face to beach environment of Galveston Island, Texas (Davis *et al*, 1971). In this environment, cross-bedding of ripple origin, as reported from Gulf of Gaeta, Italy (Reineck and Singh, 1971, 1973), can also develop. The Muth sedimentation, however, pertains to high energy environment with fast rate of reworking to account for lack of trace fossils and bioturbation. Some shallow channels also existed to produce channel fills and parallel laminated sands, low angle cross-bedding and ripple laminations. Subaerial/ subaqueous exposure in this setting of the sediments produced mudcracks and also erosional surfaces. The frosted quartz grains could be wind blown from inland basins, but no desertic or any other inland environment (Das Gupta, 1971) is visualised.

The Visher's curves were drawn (Fig.5.21) for sequences showing (a) low angle festoon cross-beds, (b) low angle cross beds, (c) sub-parallel laminations, (d) cross-bedded unit above erosional surface, (e) channel filling and (f) ferruginous-calcareous sandstone showing sub-parallel to interbedded low angle cross-lamination. Each curve shows two saltation populations.

The palaeocurrents recorded in the Muth Formation are polymodal. In the Pin Valley, the mean direction is towards SE, whereas, in the rest of the basin it is mainly towards NW. In total about 30 readings were taken.

5.1.3.B *Lipak Formation*

The Lipak Formation, in most part of its sequence, represents heterogeneous facies comprising shale, sandstone, calcareous sandstone, limestone and dolomite. In certain parts, specially the middle, exclusive biohermal limestone facies and in upper part gypsum facies occur. The bedding features include ripple bedding, parallel laminations, low angle cross-bedding, local discordance surfaces with small channels, algal laminations and hard ground. The dominant fossils are brachiopod, coral and crinoid. The above mentioned facies are orderly arranged to form several cycles varying from 2 to 12 in number in different sections. These cycles of heterogeneous facies in the Takche section begin with (a) micrite/bioturbated sandy micrite-siltstone ending up in cross-bedded quartzarenite, (b) micrite-shell hash-coral build- up with local shale-argillaceous limestone, (c) hardground, shale-micrite-silty carbonate. In Pinglung, Mud and Lipak sections, the cycles commence with carbonate-carbonate+shale-siltstone-sandstone. In upper middle part, synaeresis mudcracks are recorded. These cycles reflect several shoaling events within the Lipak Formation.

The change from clean sands of the Muth Formation to heterogeneous carbonate dominated sequence of the Lipak Formation is regarded to indicate a relative deepening of the basin, where much of clastic supply was cut-off. This deepening may be related to transgression of the Lipak Sea in Phiphuk, Shalkar-Sumdo and Phirse *Phu* sectors.

The cyclicity in heterogeneous facies indicates changing from low to high energy environment (from terrigenous free to terrigenous dominated sediments) in subtidal to intertidal set-up. At the beginning of each cycle, subtidal or even below wave base conditions were acquired. In the latter environment, the hardground was formed which provided a suitable substrate for coral buildups.

In the carbonate dominated sequence, the microfacies, in order of increasing abundance, are boundstone, grainstone, wackestone, mudstone and packstone with cement varying from micrite to vuggy coarse sparite in open spaces. Clotted micrite and cortoids, though occur, are rare. These features indicate a setting varying from Facies Belt 5 of Wilson (1975) *i.e.* organic buildups to restricted platform (Facies Belt 8) with possible foreslope (Facies Belt 4) environment. These constitute shallowing-up sequence on minor scale also. Several of the cycles referred above are incomplete/truncated. Early cementation is characteristic of the facies. Lack of faunal diversity (especially coral) and presence of algal build-ups make the Lipak palaeoenvironment comparable to that of the Inshore Rocky Shore of Bahama (Bathrust, 1971) of somewhat moderate energy regime. The gypsum in upper part of the formation represents ultimate in shallowing cycle which produced platform evaporite facies (Facies Belt 9 of Wilson, 1975). One of the present authors (UKB), however, is of the opinion that since a typical evaporite cycle is not present, as suggested by Mallet (1865) also, the gypsum could be due to reaction between the limestone and the sulphuric acid produced from iron pyrite of the overlying Po Formation.

The palaeocurrent directions in the Lipak Formation were measured only in the Losar section. The cross-beds in the arenite and coquina beds of this formation show currents towards NW and NE.

5.1.3.C *Po Formation*

The Po Formation apparently comprises alternation of mud facies (Mb to Ma) and sandstone facies (Sa). However, a close examination reveals a gradual change from the former to the latter through heterolithic facies (Hb, He and Ha) forming a cycle. The lowermost unit, made up of dark grey to black shale with a few silty grains, is followed up by (a) silty shale with fine silty layers, (b) silty shale with fine sand layers, (c) siltstone with sand layers, (d) siltstone with rippled fine sand layers at places with herringbone cross-bedding and (e) cross-bedded sandstone with local herringbone cross-bedding. The intensity of bioturbation, which is of small size and moderate in basal part, increases towards top and is maximum in unit c. It again decreases in unit d and is rare in unit e. The basal part does not show sedimentary structures. Ripple bedding appears in unit d and low angled cross-bedding in unit e. The trace fossils (*e.g.* resting traces of star-fish) are mostly confined to black shale part and indicate low energy environment. In sandy facies *Skolithos* is rather common. Each cycle represents a progradation, possibly of low wave energy beach face comparable to Gulf of Gaeta (Reineck and Singh, 1973). The environment varied from mid-shelf to upper shore face. The bioturbated shale/siltstone with thin laminated silty or sandy layers represents transition to lower shore face zones, whereas, the siltstone with rippled sandstone layers indicates middle shore face and sandstone represents an upper shore face zone. At places, it even acquired beach-tidal inlet condition where herringbone cross-bedding was formed. The grain size plot in Visher's curve (Bhargava *et al*, 1991b) indicates surf zone environment for such sandstone. The amalgamated thicker sand beds showing internal erosional surface represent storm episodes. Such cycles are repeated between five (in Losar area) to eight times (in Tabo-

Po area), each succeeding cycle is shorter and coarser, indicating rapid progradation and shallowing of basin with increasing time.

The plant fossils in the basal part of the Po Formation have often been regarded to represent near land condition. In the low energy sea, however, the plant fragments could drift to somewhat longer distance without much damage to the leaf or stem.

In the Po Formation, the palaeocurrent directions, determined by the cross-beds in the arenaceous units, are towards north as well as south. Only 10 palaeocurrent directions were studied in the Losar and Po sections.

5.1.3.D *Ganmachidam Formation*

The sequence of the Ganmachidam Formation is developed only in areas where the Po Formation is developed. It is composed of heterogeneous facies comprising siltstone, sandstone, grit and diamictites forming following coarser cycles: (a) siltstone with a little sand and grit followed by cross-bedded fine sandstone with pebble beds, (b) pebbly gritty sandstone, followed by conglomerate. The bedding features are planar to trough cross-bedding in sandstone and low angled cross-bedding with ill-preserved ripple bedding in the siltstone. No fossils, except for a few lamellibranch impressions, could be found. Bioturbation is rare to absent.

The Ganmachidam conglomerate has been regarded a glacial deposit by several workers. None of the glacial features, however, are present. The grain size plot (Visher's curves) of the sandstone indicates a beach setting varying from delta/estuary, low tide, wave zone to foreshore (Bhargava *et al*, 1991b). The cyclicity of finer-coarser facies (No. of cycles 1-8) indicates a coarsening-up sequence from upper shore face to beach and perhaps upto delta in some case. The conglomerate possibly represents deposits of mountainous coastal streams or fans which ensued due to sharp rise of the provenance area. These were reworked in a marine environment to constitute a unit of coarsening-up cycle.

The palaeocurrent directions recorded in the Ganmachidam Formation are variable though majority of them fall in NE quadrant. About 35 readings were taken in Ganmachidam, Lingti, and Po sections.

5.1.4 KULING GROUP

5.1.4.A *Gechang Formation*

This formation commences either with a clast supported conglomerate (e.g. Parahio section) or shell rich zone (e.g. Ganmachidam), both occurring as lags. The bulk of the Gechang Formation is composed of weakly bioturbated cross-bedded, fine/medium to coarse and even gritty sandstone facies (Sa). Rarely micaceous sandstone (e.g. Ghunsarang section) or shale (e.g. section behind Po Rest House) is present. The fossils are mainly lamellibranchs and brachiopods (Fig.5.20). Ichnofossils *Skolithos*, *Laevicyclus* and *Zoophycos* have been recorded.

The lithounits are arranged in order of (a) shelly coarse/medium grained sandstone-gritty sandstone, (b) sandstone with pebble lag -cross-bedded sandstone, (c) sandstone with shell-lag- cross-bedded sandstone. These indicate shallowing-up cycles. A maximum of five generalised cycles have been identified at Ghunsarang Pass. In most of the sections, however, only one or two cycles are present. The pebble/shell lag is interpreted to represent commencement of transgressive cycle, when the finer clastics were winnowed and pebbles/shells were concentrated as lag. The cycle ended with deposition of cross-bedded sandstone. Cycles occurring in mid section of the Gechang Formation commence with shale/micaceous sandstone of subtidal zone and end up in sandstone of foreshore to upper shore face environment. Presence of mud cracks and ferruginous sandstone suggests subaerial exposures.

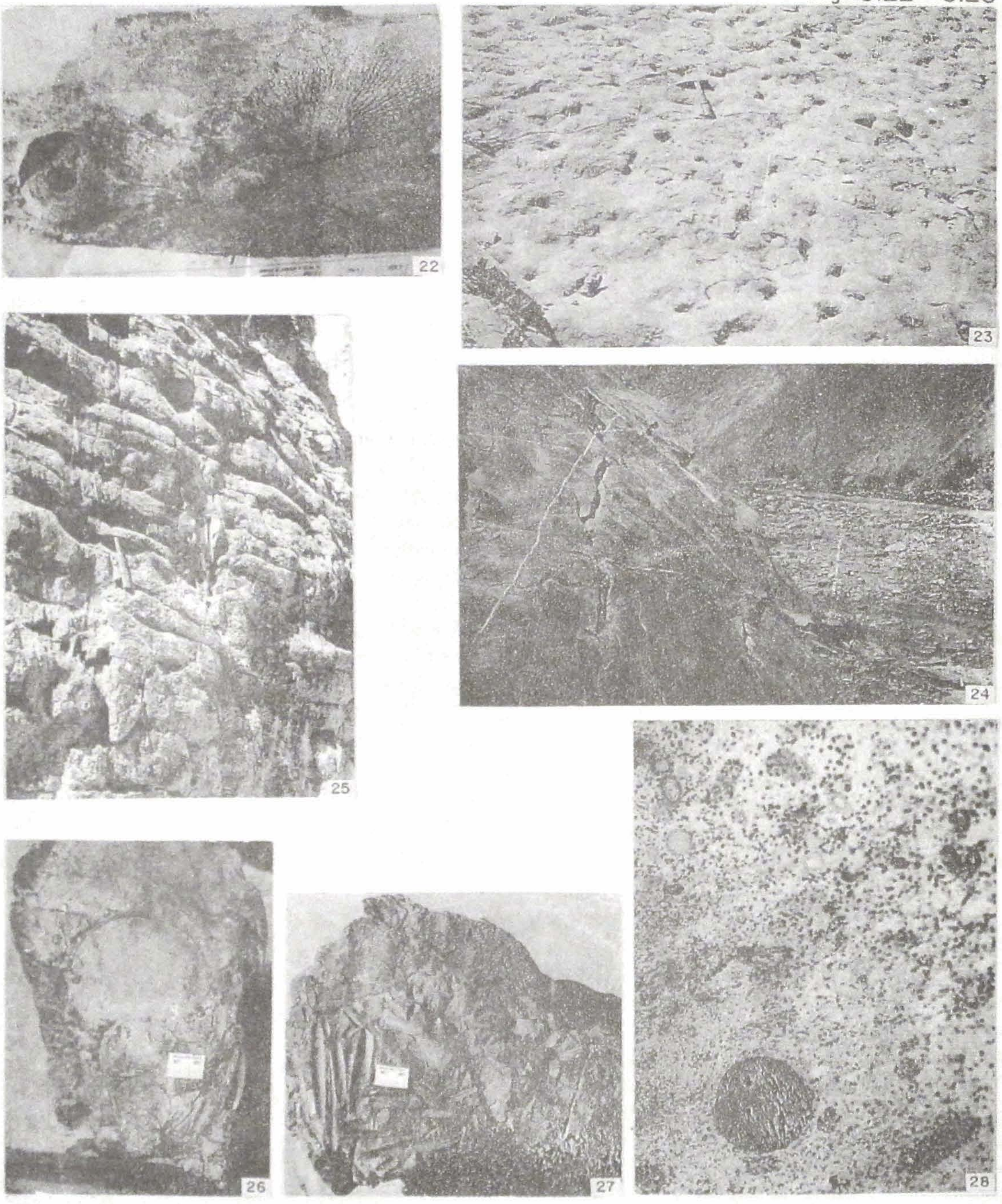
Eurydesma, occurring in the basal part, suggests shallow and high energy marine conditions (cf. Dickins, 1957). The top of the Gechang Formation in several sections is profusely bioturbated and may indicate an omission surface. The absence of Kungurian to Midian, and also possibly of the Artinskian fossils, is regarded to signify a break in deposition at the end of the Gechang sedimentation covering Kungurian-Midian.

The Gechang Formation shows vector mean of palaeocurrent directions in NW quadrant. 40 readings were collected in Losar, Pin, Parahio and Lingti sections.

5.1.4.B *Gungri Formation*

The Gungri Formation over the Gechang represents a transgression of Djulfian age. This formation represents a black/dark grey mud facies (Mb) with zones having silt/sand and/or shell rich layers

Figs.5.22 – 5.28



Explanation of Figs. 5.22-5.28

Fig. 22. *Protoretipora* with large sized crinoid. Gungri Formation. Loc. Tumtum Thanga. **Figs. 23-24.** Cuspate ripple marks in the dolomite of the Member A (Sanglung Formation). Loc. Gyundi *Nala*. **Fig. 25.** Parallel and wavy bedding in dolomite. Para Member (Kioto Formation). Loc. Kiomo. **Figs. 26-27.** Profusely burrowed cephalopod representing hard ground in the Spiti Formation. Loc. Sakti. **Fig. 28.** Ooids in the sandstone occurring in the basal part of the Giumal Formation. Loc. Tangpa Dok. (Bar scale is 1cm for Fig.22 and 2mm for Fig.28.).

(Ma). Broadly the shale in basal part is silty, towards middle-upper part it is fine grained. Along the transition from silty shale to shale in several sections occurs *Zoophycos* (Bhargava *et al*, 1985b). Within shale are found millimetre fine silty layers and cherty calcareous and phosphatic nodules. In certain sections also exist siltstone and medium to fine grained sandstone (e.g. Ghunsarang *Nala*). In basal part occurs *Productus*, whereas *Cyclolobus*, *Xenaspis*, bryozoa and crinoid (Fig.5.22) are found in upper part of the sequence.

The stratigraphic arrangement of different beds reflects cyclicity of sedimentation. These cycles are mainly of three types : (a) silty shale-shale (Ganmachidam section), (b) shale-shale with mm-fine siltstone beds (Lalung section), (c) shale-shale with silty lenses (Sumna section), (d) shale with spiriferids-shale with *Lamnimargus*-shale with nodule and brachiopod- siltstone sandstone (Chuktyanjan *Thach*, Ghunsarang).

This formation reflects sedimentation mainly on shelf mud under restricted circulation. Fine shells and silty bands within the sequence are regarded to be storm layers. The cycles enumerated above (two to five) represent shallowing-up events in a narrow environmental setting. Relative deepening of the basin is envisaged at the appearance of *Zoophycos* (Fig. 2.67).

5.1.5 Lilang Group

5.1.5.A *Mikin Formation*

The Mikin Formation comprises a carbonate sequence with local shale partings. These units are arranged in an orderly manner to constitute cycles commencing with pure to argillaceous lime mudstone, and ending up in a carbonate sequence with shale partings. The bedding features observed are nodular and wavy beddings and subaqueous slumps. The formation is rich in cephalopods.

The microfacies of the Mikin Formation are dominantly represented by different varieties of thin-shelled wacke/packstone in a homogeneous micritic matrix. The clasts are poorly to moderately sorted. The other microfacies is represented by lime mudstone.

These microfacies are considered characteristic of subtidal to bathyal facies (Wilson, 1975; Flugel, 1982). Peloids, radiolaria (though rare), nodular bedding and nodular conglomerate (Wilson, 1975) and subaqueous slumps (Wilson, 1975; Cook and Taylor, 1977) support a hemipelagic environment of sedimentation. Intact valves in several cases may indicate general absence of current, though irregular fabric recorded in filamentous limestone possibly points to the presence of occasional bottom currents.

The cyclic order of superposition of pure lime at bottom and lime-shale towards top of a cycle may be regarded to indicate shallowing-up sequence showing conditions of deposition varying from pure carbonate to minor influx of fine terrigenous material. It may also indicate depositional environment shifting from bathyal to subtidal and again reverting to bathyal; alternatively it may be due to increase and decrease of mud supply brought about by geomorphic changes in the provenance area. The second alternative is preferable.

5.1.5.B *Kaga Formation*

Overall, it constitutes a heterogeneous facies comprising alternation of shale and limestone in which shale predominates. The thickness of shale horizon in basal part is two metres. It increases to 25m in middle-upper part and again decreases to five metres in the upper part. The shale-carbonate alternation is represented by six cycles. The sequence is rich in cephalopods and *Daonella*.

The carbonate microfacies are (a) filamentous pack/wackestone, (b) packstone with organic dropstones and several levels of disconformities and (c) mudstone. These microfacies, like those of the Mikin Formation, indicate bathyal to subtidal conditions. Abundance of pelagic bivalve *Daonella* suggests deeper marine environment of sedimentation. The shale-carbonate mega-cycle indicates fluctuation in the supply of terrigenous material reflecting geomorphic/climatic changes in the provenance. Possibly, there were disruptions in sedimentation, within the bathyal environment, causing local disconformities, hard ground formation and filling of uneven surface by the next micro-cycle of sedimentation. Shallowing, perhaps due to change in the sea level, reverted sedimentation of shale. In the initial phase of deposition of the Kaga Formation, the period of shale sedimentation was brief, it became prolonged in middle-upper part and again reverted to shorter duration in upper part. The cephalopods flourished in bathyal basin conditions. The carcass of cephalopod occurring as "organic dropstones" (Fig. 2.71) indicates lack of current and deposition on a quiet shelf (Bhargava, 1987).

5.1.5.C *Chomule Formation*

It comprises even/uniform thin-bedded carbonate beds (Fig.2.72) with local and rhythmic calcareous shale and marl beds. Nodular and wavy beddings and large subaqueous slumps characterise the carbonates of this formation. The mega-heterolithic lithofacies show cyclic patterns (total cycles five) commencing with (a) fine grained dolomite to argillaceous dolomite, (b) fine grained dolomite to shale and (c) cherty limestone/ dolomite to non-cherty or argillaceous dolomite representing coarsening-up/shoaling-up cycles. *Daonella* and *Halobia* are the most dominant fossil remains. The microfacies include (a) mudstone, (b) filamentous lamellibranch wackestone/ packstone, (c) thin shelled wackestone with calcisphere and radiolaria and (d) calcitised radiolarian wackestone/ packstone. Bioturbation is rare.

The radiolarians (fairly abundant in a part of the sequence) and calcispheres (Fig.3.36-37) in the carbonate rocks of this formation indicate an environment transitional between open sea shelf and basin margin (Facies Belt 3 of Wilson=Deep shelf margin≡clinothem). Such an environment is characterised by lack of bioturbation and preponderance of subaqueous slides (Cook and Mullins, 1983). The thin shelled pelagic and deep water *Halobia* and *Daonella* provide additional support to the above interpretation.

Each cycle commencing from pure carbonate and leading to argillaceous carbonate-shale possibly indicates increase and decrease in supply of mud to the basin. Some of the cycles are incomplete.

5.1.5.D *Sanglung Formation*

5.1.5.D_1 **Member A** : It comprises a cyclic sequence of dolomite/limestone showing cuspate ripple marks (Fig.5.23-24), locally argillaceous siltstone and shale with lenticular bedding. Each complete cycle begins with dolomite passing into siltstone/shale or carbonate ending in an argillaceous carbonate. A few cycles commence with shale in basal part and end with siltstone in upper part. Twelve such cycles broadly represent shoaling and/or coarsening up events.

The main microfacies are (a) bioclastic/ lithoclastic wacke/packstone with clasts of bryozoa, echinoid spine, mollusc, sponge, (b) mudstone, (c) thin shelled stylobrecciated packstone, (d) sponge-spicule mudstone, (e) coral wackestone and (f) pelletoidal grainstone. The microfacies (b), (c) and (d) indicate a somewhat deeper environment, whereas, the (e) and (f) microfacies indicate shallower conditions. These microfacies indicate conditions fluctuating from upper foreslope - foreslope (Facies Belt 4 of Wilson, 1975) to basin margin (Facies Belt 3). The cycles beginning with siltstone and ending with pure carbonate are suggestive of deepening-up sequence, *i.e.* a shift from upper middle foreslope to lower foreslope-basin margin setting. In the Lingti Valley, nine full and one incomplete such cycles are decipherable.

5.1.5.D_2 **Member B** : It is made up of carbonate, shale and siltstone alternation in the basal and middle parts and carbonate and sandstone in the upper part in regular stratigraphic cycles. Each cycle commences with carbonate and ends in shale-siltstone or sandstone passing through argillaceous carbonate. The shale-silty sandstone part, being around 13m thick in first three cycles, decreases to 9 metres in 4th and 5th cycles and then to 2 metres (sandstone) in upper cycle. The thickness of carbonate units also decreases upward only to increase abruptly in the last incomplete cycle. In other wards, each younging cycle is thinner and has clastics coarser than those of the preceding cycle. The bedding features in the sandstone beds are tabular and herringbone cross-beddings.

The carbonate microfacies are (a) mudstone/ wackestone, (b) lamellibranch wackestone and (c) grainstone which suggest moderate to high energy environment. The sedimentation mainly took place in subtidal to intertidal, varying from middle to upper foreslope environments. The herringbone cross-bedding indicates influence of tidal currents in the terminal phase of its sedimentation.

The stratigraphic arrangement of sediments indicates coarsening-up cycles. Six complete and one incomplete cycles are present in the Lingti section.

5.1.5.D_3 **Member C** : It comprises a sequence of carbonate rocks, shale, siltstone and sandstone. Sporadically shale encloses boulder and cobble size fragments. In lower part, the cycles are of carbonate rock and shale, while in the upper part, these are of carbonate and sandstone (including siltstone). There are seventeen such cycles. The sedimentary structures in the sequence are rippled bedding and low angle cross-bedding. *Rhizocorallium* occurs in shale, whereas, *Skolithos* occurs in sandstone beds of the upper part of the sequence. The carbonate microfacies are (a) lamellibranch grainstone, (b) lithoclastic quartzose wackestone, (c) micritic to sparitic rocks and (d) hydrozoan bindstone.

The microfacies indicate low to moderate energy conditions. Occasional high energy and near shore conditions are indicated by grainstone and quartzose wackestone. *Rhizocorallium* and hydrozoan bindstone suggest low to moderate energy basin. The sedimentation is thus interpreted along foreslope (Facies Belt 4) mostly in subtidal to intertidal setting. The angular cobbles and boulders represent slided material along the foreslope. The cyclicity of sediments suggests about 17 coarsening-up cycles representing shifting sedimentation from middle foreslope to upper foreslope, possibly even in littoral to circa-littoral zone.

5.1.5.E *Hangrang Formation*

This formation, mainly comprising dolomite with subordinate shale and limestone, represents reefoid build-ups. There seem to be organic cycles within the Hangrang Formation. At the Hangrang Pass, in section A, the cycle commences with oolitic, ooidal dolomite, followed by dolomite with stromatoporoid and solitary coral and culminates in dolomite with *Thecosmilia* colonies. In section B also there are two cycles, the lower one beginning with shell hash, followed by ooidal limestone and ending in *Thecosmilia* framestone. The second cycle begins with solitary coral zone and ends in *Thecosmilia* framestone. These cycles represent superimposed reefs (James, 1979).

The carbonate microfacies are (a) sponge bafflestone, (b) chain coral-sponge bafflestone, (c) sponge-hydrozoan bafflestone, (d) tabulozoan framestone, (e) *Thecosmilia* framestone, (f) hydrozoa framestone, (g) algal bindstone, (h) packstone/wackestone, (i) packstone/grainstone and (j) poorly sorted floatstone.

The organic build-ups mostly are of small to medium size. These are referable to knoll-type of reefs which flourish on a platform.

Except for *Thecosmilia* framestone (under boundstone facies) and grainstone, all other carbonate microfacies indicate low to moderate energy environment. Various boundstone facies of low energy, in fact, are found in the protected niches of bushy colonies of *Thecosmilia*. The carbonate microfacies, as stated above, show stratigraphic cyclicity. Each cycle begins with low to moderate energy facies and ends up with moderate to high energy *Thecosmilia* framestone facies (Fig.2.80). These are normal stages in reef growth beginning with pioneer (stabilisation) stage to colonisation and diversification which are known from all over the globe (James, 1979). These indicate an increase in energy conditions and may correspond to shallowing-up cycles due to combined effect of eustatic changes and vertical growth of the reef knobs. The hydrozoan, sponges and tabulozoa, besides occurring within *Thecosmilia* colonies, occur exclusively and independently at places associated with solitary corals (e.g. Rangring). These localities represent low energy areas, possibly of back reef setting or lower part of the slope as is also suggested by the occurrence of floatstone facies in these build-ups. The Lalung, Pin-Spiti to Hangrang areas dominated by *Thecosmilia* represent a wide reef area of moderate energy with protected parts to provide niches to low energy boundstone facies.

The Kiomo reef with mainly solitary corals and rare hydrozoa seems to represent lagoonal environment.

5.1.5.F *Alaror Formation*

This formation shows the sedimentary cycles from carbonate to shale mudfacies (Mb) through a heterolithic shale-carbonate or argillaceous carbonate facies along the Guling-Atargoo road. These cycles are capped by cross-bedded sandstone (Sa)-cross-bedded limestone. The dominant body fossil is *Monotis* and trace fossil is *Rhizocorallium*.

The carbonate microfacies are (a) sandy ooidal grainstone/packstone, (b) layered mudstone with tempestite layers and (c) bivalve ooidal grainstone/packstone. The ooidal grainstone facies indicates a winnowed platform edge sand (Facies Belt 6 of Wilson, 1975). The layered mudstone with tempestite layers near platform edge sand could be formed in a shallow shelf lagoon (Facies Belt 7). The sedimentation thus seems to shift from platform edge sand to lagoon. During this palaeoenvironmental variation, possibly due to eustatic changes, the shale and sandstone were cyclically deposited.

5.1.5.G *Nunuluka Formation*

It shows a sequence of sandstone, limestone and shale. Three fining-upward sedimentary cycles, each beginning with carbonate dominated unit and ending with clastics (basal cycle with sandstone and upper with shale), occurs along the Atargoo-Guling road. The sandstone facies is characterised by tabular cross-bedding and herringbone cross-bedding. The microfacies is highly sandy ooidal-algal packstone.

The herringbone cross-bedding in sandstone indicates an influence of tidal currents. It was followed by rise in sea level to cause sedimentation of carbonate. This site, however, could not be far from the coast and also not deeper as is indicated by the sandy nature of the carbonates. The second cycle possibly commenced from mudflat and ended in carbonate sedimentation in zone overlapping or adjoining the tidal flat/coastal area (Bhargava, 1987).

5.1.5.H *Kioto Formation*

5.1.5.H$_1$ Para Member : The sedimentary cycles in this member begin with cross-bedded dolomite/ooidal gritty dolomite and end up in subparallel bedded (Fig.5.25) to massive bedded grey dolomite. The bedding features, besides cross-bedding, are sharpstone conglomerate and channel fills. The microfacies are (a) bioclastic wackestone/packstone (b) foraminiferal peloidal grainstone and (c) peloidal aggregate bio/lithoclastic floatstone/packstone. Small to medium sized megalodontids are the most dominant fossil remains.

In view of preponderance of oolites, quinqueloculinids and megalodontids, a winnowed shelf edge sand area with tidal channels was suggested as site of deposition (Bhargava, 1987). Presence of rare aggregate grains and oncoids, together with packstone and floatstone, may suggest sedimentation partly in subtidal area of a protected lagoon. The cycle from ooidal to bedded dolomite indicates a change from intertidal to subtidal palaeoenvironment. This sedimentary cycle in the Para Member is comparable with late Triassic Lofer Cyclothem (Fisher, 1964; 1975). The palaeoenvironmental setting of the Para Member is relatively deeper and away from coast/beach area, as compared to that of the Nunuluka Formation. The Para Member is thus interpreted to represent a transgression over the Nunuluka Formation. This transgression caused deposition of the Para Formation over the Lipak Formation in the Phiphuk area.

5.1.5.H$_2$ Tagling Member : It comprises dolomitic limestone with lenticular conglomerate. The sedimentary features include wavy and sub-parallel beddings, low angle cross-bedding, large cavities filled with arenaceous material and local coral knobs. The microfacies are (a) peloidal grainstone, (b) nerinid grainstone, (c) shell-hash packstone, (d) bioclastic and ooidal grainstone, (e) *Thecosmilia* framestone and (f) glauconitised distorted ooidal foraminiferal packstone.

The microfacies, large arenaceous material-filled cavities and low diversity of fauna suggest a winnowed shelf edge (Facies Belt 6 of Wilson, 1975) to restricted platform edge (Facies Belt 8), where corals formed small and scattered reefs. The glauconitised ooids and foraminiferal tests symbolise hard ground formation suggesting a sudden deepening of the shelf resulting in cutting of the terrigenous supply, a prolong sediment-water contact and consequent hard ground formation. The top of the Kioto Formation, thus, is interpreted to represent a submarine hiatus.

5.1.6 Lagudarsi Group

5.1.6.A *Spiti Formation*

It belongs to mud facies (Ma) represented by black shale with cherty flakes and local fine, weakly graded silt layers/streaks, fossil shell layers and local sandstone and conglomerate interbeds. The sequence is characterised by horizontal burrows, *Zoophycos*, pelagic nektonic body fossils (*Belemnites* and other cephalopods) and prolific presence of hard ground (Fig.5.26-27). The lithologic and fossil assemblages suggest deposition on a shelf with slow rate of sedimentation as suggested by commonly preserved hard grounds. The Visher's curves for weakly graded and poorly sorted sandstone are akin to turbidite and subtidal deposits. These, together with silty layers/streaks, are interpreted to represent storm events, which not only brought silty material, but also reworked part of the sediments to impart it a weak grading. It is difficult to provide a satisfactory genesis of the boulder conglomerate. It may be due to limited mud flows from shallower part. The nodules with fossils as nucleus possibly formed diagentically due to change in pH values of the pore water. A slight change in pH could also lead to precipitation of chert and phosphate. Since the fossils in the nodules are undeformed, the latter are considered to have formed around the fossil as protective layer prior to compaction.

5.1.6.B *Giumal Formation*

This formation represents essentially a quartzarenite and glauconitic sandstone facies. Locally occur glauconitic shale, gritty beds (in upper part) containing siltstone and black shale pebbles in basal

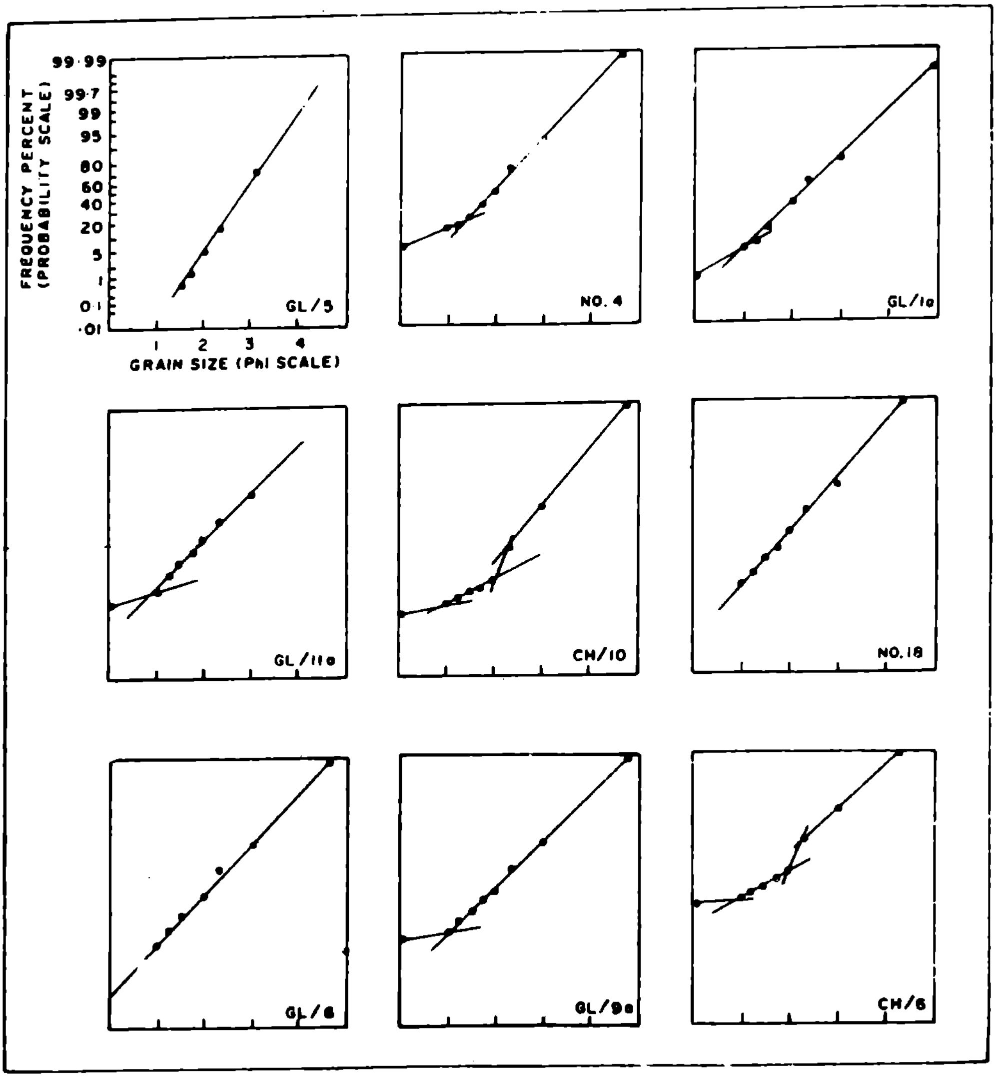


Fig. 5.29. Visher's curves for the Giumal Formation. Measurements made of thin section.

part of black shale interbeds. The sequence is characterised by weak graded bedding and poorly to moderately sorted coarse to fine grained sandstone. Horizontal burrows, branched and unbranched, together with a few ooids (Fig.5.28), are mainly confined to basal part of the formation. The basal part (50cm to 2.5m) is mostly represented by fine grained siltstone with or without black shale beds. The overlying succession shows a sequence of coarse grained sandstone-fine grained sandstone-silty sandstone with shale-shale representing an upward-fining cycle of about 59m thickness. Next fining-upward cycle is represented by sandstone-shale (135m) and the uppermost by pebbly/gritty sandstone-glauconitic limonitic sandstone - fine sandstone with local gritty bands (about 50m).

The black shale and fine silt/sand in basal part indicate extension of palaeoenvironmental setting of the Spiti Formation with gradual aeration of the basin. The three upward-fining cycles are possibly related to major waning phases during the sedimentation. Most of the Visher's curves drawn for about 30 samples of the Giumal Formation are in the form of straight lines (Fig.5.29), which are comparable to those of the turbidite deposits. These curves, however, reflect a sorting better than those of typical turbidite deposits. Visher's curves of a few sandstone samples in basal and middle parts also show two minor saltation populations. If the site of deposition of the Giumal Formation is considered in deeper water setting, then the sandstones seem to have retained shallow-water characters despite their transport by density currents. Alternatively, the Giumal Formation may represent shallower environment.

5.1.6.C *Chikkim Formation*

5.1.6.C_1 Limestone Member : In the basal part it comprises limestone, while in the upper exists an alternation of marl, limestone, and shale. The carbonate beds contain sporadic siliciclastic and dark grey pyritous limestone bands. The fossils include globorotalids, *Globotruncana* and radiolaria. The carbonate microfacies are mudstone and *Globotruncana*- globorotalid- radiolarian wackestone.

The carbonate microfacies and lithologic assemblage are typical of shelf to off-basinal environment (Wilson, 1975). There were occasional periods of restricted circulation when dark grey pyritous limestone was deposited. The silt and broken shells could be transported from the upper part of the shelf. The alternation of marly limestone and shale possibly indicates alternating periods of increased and decreased mud supply on the shelf area.

5.1.6.C_2 Shale Member : It represents mainly a mud facies (Mb) with silty and marly layers. The bedding features are weak, grading to parallel lamination. The characteristic fossils are globorotalids and *Globotruncana*. The Shale Member is considered by the present authors to represent deposit of outer shelf environment.

5.1.7 Quaternary

5.1.7.A *Glacial*

The glacial cycle seems to be the earliest identifiable Quaternary sedimentary cycle. In the area, however, no true fossilised glacial deposits could be located. The evidences for glaciation are (a) wide 'U'-shaped valleys which subsequently have been filled by fluvial-lacustrine sediments and (b) huge erratics found along higher reaches (*e.g.* right flank of the Pattan Valley).

The erratics and morphological features bear testimony to widespread glaciation. As the glaciers melted, the streams ensuing out of these reworked the morainic material. The reworking resulted in (a) removal of finer material leaving large cobble and boulder erratics as remnants and (b) where streams were turbulent the glacial material was thoroughly reworked and redeposited as glacio-fluvial sediment. Presently the glacial deposits are being formed as various kinds of moraines in the existing glaciers. These, like older glacial deposits, have little chance of preservation as the mighty stream which shall be produced on melting of the glaciers shall either remove this material to distant sites or, if streams are weaker, these may rework and redeposit sediments at nearby sites after removing the finer material.

5.1.7.B *Fluvial*

The fluvial deposits occur (a) along the flanks of the present rivers and also (b) in the fossil valleys. The former occur in terraces occupying different levels. The fluvial sedimentation represents (i) fine material carried by the river in suspension, (ii) medium size material by saltation and (iii) coarser material during its most turbulent stage by rolling. On decrease in velocity of the stream the coarser clastics are deposited first, interspace of which is filled by sand-silt size material. Local ponding results in deposition of silt and clay.

Maximum coarser material to the rivers is, however, provided by avalanches, fans and slides. Only a part of the material has been redistributed by the axial drainage, whereas, most of it has remained stacked along the banks and over-banks. During severe melting of snow and glaciers, the increase in stream level deprives the slides/avalanches/fans of clasts smaller than pebbles. The removal of material creates voids and coarser material readjusts to reduce interspaces. When the flood wanes, the stream deposits clay, silt and sand in these interspaces form a conglomerate bed. Such conglomerates do not show pebble imbrications. In areas where a sequence of fan deposit is preserved, each subsequent fan avalanche, in general, has a lesser extent. This could be due to increasing aridity as well as acquisition of greater tectonic stability.

The fluvial deposits mainly show facies of braided streams. The main channel deposits are rare, though channel cut and fill of overbank or bank type are observed.

5.1.7.C *Lacustrine*

The lacustrine sedimentation, though ephemeral, has played an important role in modifying the geomorphology of the terrain. All terraces which constitute wide valleys (Fig.1.12) at Kioto, Phaldhar, Rangring, Atargoo, Hurling, Sumdo, Shalkar, Chango, Shiasu and Kupa are formed by the lacustrine deposits. An excellent study of lake sedimentation can be made between Atargoo-Pin-Spiti confluence, Sumdo-Kaurik and Sumdo-Hurling sections due to road cutting. At the first mentioned locality, a prism shaped coarse material occurs as a slide. The lacustrine beds rest above it indicating the genesis of lake due to damming of the river by a slide. In fact all the lake sediments mentioned above occur along the river valleys, which were dammed due to landslides. The Sumdo lake sediments show clastic material mainly coming from NE in the form of a coarser material fan. The grain size of clastics decreases away from the source area. Vertically the sediments show cyclicity from grit-coarse sand-medium sand-silt. This represents dispersion of one fan slide. The subsequent cycle, commencing with coarser material, has invariably cut and filled the underlying finer unit. Dewatering of sediments caused syndepositional deformation and squeezing. The cross-bedding and climbing ripples show presence of currents in the shore-line area. Thin clay layers occur within different cycles. After several cycles, the sequence is terminated by coarser clastics capped by mud, indicating filling up of the basin. As the blockade of the river at Sumdo was removed and its flow restored, it cut the lacustrine bed. The restoration of the river flow has resulted in partial reworking of the lake sediments. Each cycle beginning with coarser clastic could reflect a neotectonic impulse in the provenance area to trigger new slides. Alternatively, it may be a climatic manifestation, the coarser material indicating commencement of snow melting and finer of onset of winter.

All the lake basins show evidences of neotectonism indicating that the damming of the rivers was possibly caused by structural disturbances.

5.2 SHORE LINE OF THE SPITI BASIN

The study of the facies of the coeval Batal and Manjir Formations and Tandi, Kuling and Lilang Groups provides broad clues to the location of the shore line and the craton.

The Manjir Formation in the Chamba area, the western most limit of this formation, is rich in large size clasts varying in size from pebble to boulder. Towards east, this formation shows gradual reduction in the frequency and size of the clasts. In Lahaul and Spiti, the pebble horizons are very thin and rare. The distribution of coarser clastics vis-a-vis finer ones suggests the depositional dip towards east.

The Tandi Group represents an age range between late Permian and middle Jurassic (Srikantia and Bhargava, 1979; Prashra and Des Raj, 1990). Though of much less thickness, the Tandi Group is, thus, a broad time equivalent of the Gungri Formation, Lilang Group and possibly the Spiti Formation. The Permian part of the Tandi Group, represented by the Kukti Formation, is too much arenaceous and shows sedimentation in intertidal setting with deepening to subtidal environment towards upper part. Its equivalent, the Gungri Formation, belongs to shelf mud environment. Similarly, the early and middle Triassic parts of the Tandi Group (Gushal Formation) shows shallow subtidal setting, whereas, its equivalents, the Mikkin, Kaga and Chomule, show shelf edge environment. The Dilburi Formation of the Tandi Group is a deposit of coastal zone, while the Spiti Formation shows a shelf mud environment.

The facies distribution of the late Permian-Triassic and middle Jurassic rocks, thus, also indicates presence of deeper facies of the basin towards east. Based on the above observations, it is concluded that shore line possibly existed to the west of the Spiti basin. However, it is difficult to define the coastal facies in various formations for precise demarcation of the shore line.

During the Batal period, the coast line seems to be much west of Spiti. It was perhaps located west of Chamba, where the Manjir Formation is well developed. However, along strike direction towards SE, as the pebble contents decrease, the coast line seems to be far from the limit of the Manjir Formation. In other words, the coast line was not parallel to the present strike of the beds.

Thicknes of the Kunzam *La* Formation decreases towards the southeastern-end of the Spiti Synclinorium. Towards Kinnaur, older and still older horizons of this sequence are exposed. These areas, therefore, seem to have formed the highest topographic levels in post-Kunzam *La* period which were eroded in the pre-Thango period. Such an interpretation is also borne out by the Thango conglomerates, which have a Kunzam *La* provenance, and show maximum thickness in these very areas. It is likely that the SE Spiti and eastern Kinnaur areas formed the shallowest parts of the basin, which even on minor fall in sea level, were bared and eroded. If so, then the coast line during this period probably was located nearest to these areas.

During the Thango period, as revealed by current crescents, the coast line seems to be near Lankapanug (SE corner) of the Spiti basin. These areas, as stated above, have thick conglomerate sequence, indicating them to be the shallowest part of the basin, *i.e.* nearest to the coast line.

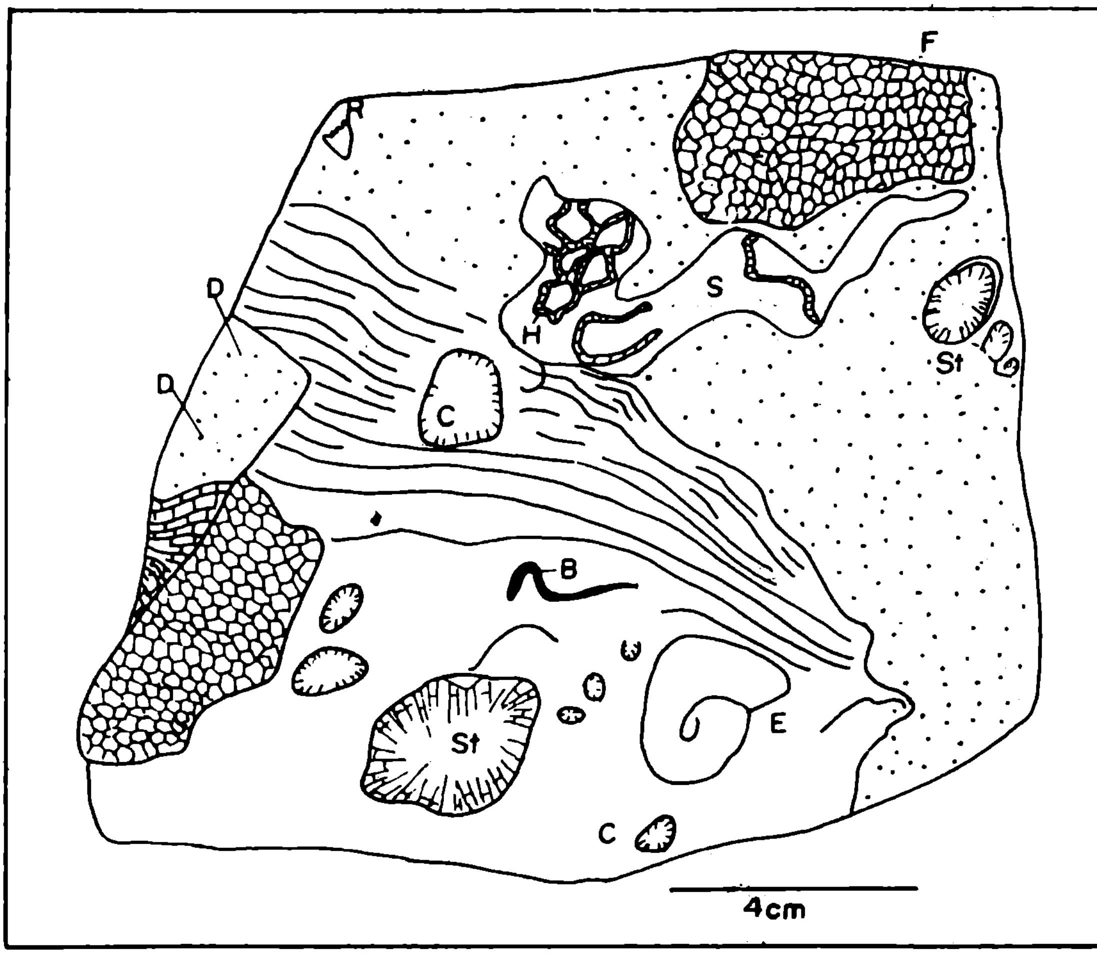


Fig. 5.30. Takche reef in hand specimen. Loc. Leo.
Explanations : R - Rhynchonellid, F - *Favosites*, S - Stromatoporoid, H - *Halysites*, St - Strepteplasmid, B - Brachiopod, E - ?*Euomphalus* C - Coral, D - Debris.

In the Takche Formation, maximum siliciclastic sequences are developed in Losar-Ratang and Tariya (Upper Pin Valley) with a few flat topped ripple marks. These areas, thus, could be in proximity of the coast line.

No distinct facies changes are seen in the sequence of the Muth Formation. But, if the Muth Formation entirely represents the beach deposit, the coast line could not be far from the present limit of the outcrops.

In Hurling-Shalkar and Phirse *Phu* sections, the Lipak Formation rests over the Precambrian sequence, indicating Carboniferous transgression in these areas, *i.e.* these areas were near to the coast line. Similar interpretation can also be made from the occurrence of the gypsum (if evaporite) at Losar, Hurling-Shalkar and in the Yulang Valley suggesting that these areas were nearest to the coast line.

During deposition of the Po Formation, there are evidences to suggest frequent shifting of the coast line. During black shale deposition, it was quite far from the present limit of the outcrops in a westerly direction and near the present day outcrops during the deposition of quartzite. However, with the passage of time the coast line shifted nearer to the Spiti Valley. It seems to be nearest to Kaurik, where the sequence is not only predominantly arenaceous but also contains conglomerate beds.

During the deposition of the Ganmachidam Formation the coast line had a configuration similar

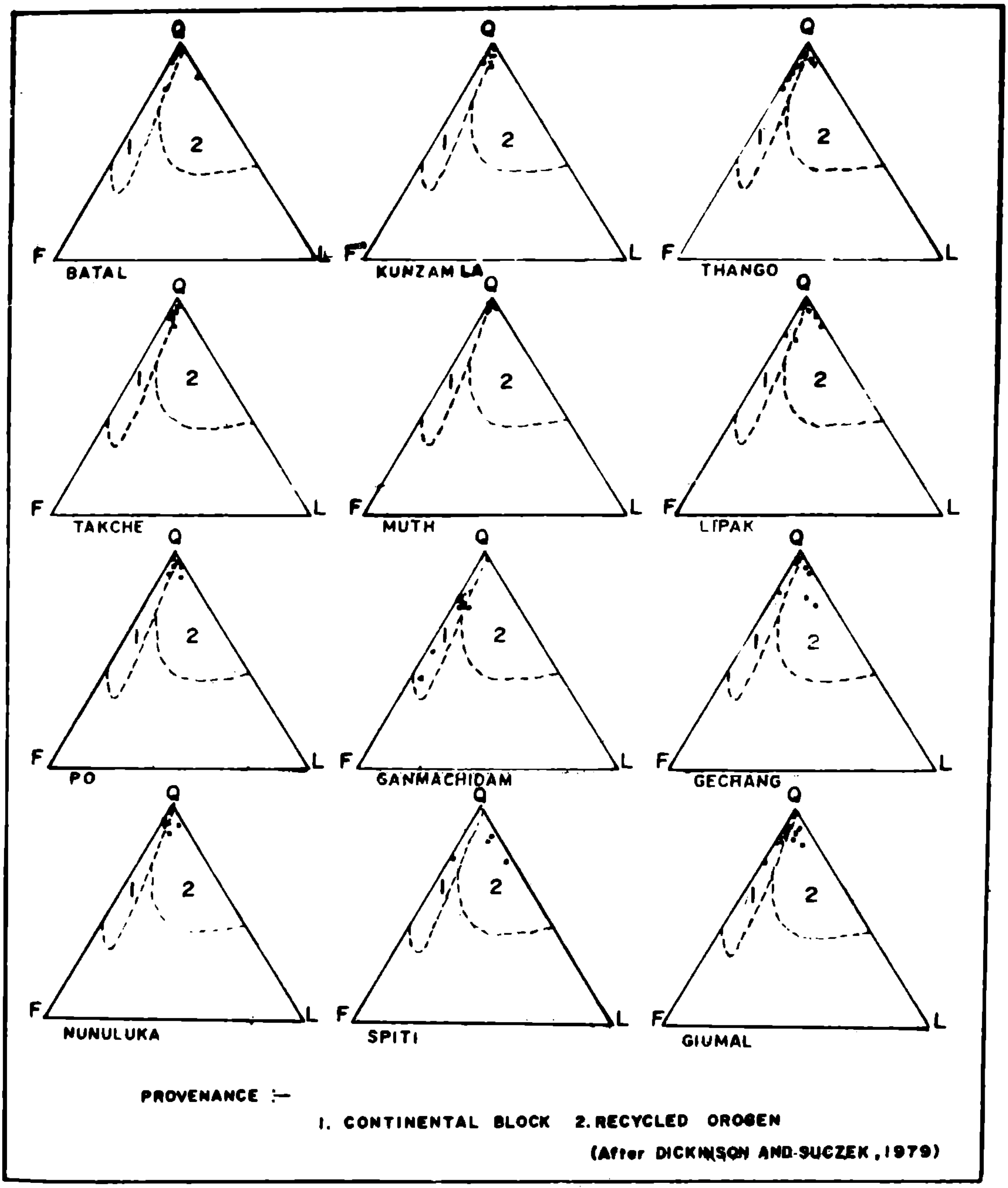


Fig. 5.31. Q-F-L diagram for the clastic sequences.

to that of the Po Sea. Due to rise of an intrabasinal high between Losar in NW and Po in SE, the basinal area seems to have shrunk in this part.

The Gechang Formation shows shallow marine high energy conditions indicating the proximity of its basin to the coast line.

Shallow water time equivalent of the Gungri Formation are known from the Salooni Formation and Kukti Formation (Tandi Group). The facies in these formations are also not coastal. Thus, the coastline was located even further west of the Salooni outcrops. The isolated pattern of the Salooni Formation, besides due to post folding erosion, may also be due to its deposition in embayments suggesting a highly irregular coastline during the deposition of the Salooni-Gungri sediments of late Permian age.

Similar distribution of the sea and land seems to have extended during early-middle Triassic time, as suggested by shallower facies in the Gushal Formation (Tandi Group), in contrast to the Mikin-Chomule facies. A shallowing sequence of the remaining part of the Lilang Group suggests migration of the coast line towards east.

Such interpretations are not possible for the Spiti, Giumal and Chikkim Formations. However, as they are generally deeper water deposits (mostly open shelf), the coast lines of their respective basins have to be much west of the present day outcrop limit.

5.3 BASIN MORPHOLOGY

Generalised basin morphology for the Palaeozoic sequences of the Spiti basins was proposed by Bhargava *et al*, (1991b).

The equivalent of the Batal Formation shows coarser clastics in the Chamba-Manjir sector, thereafter along strike, the frequency of clasts shows a gradual decrease, whereas, across the strike towards east, the number and size of clasts rapidly decrease. This may indicate a sharp change from a gently sloping coast sand area to subtidal zone and shallow inner-shelf area (Fig.7.1). The Batal Formation regionally shows uniform lithologic characters suggesting no major variation in the basin topography.

During the deposition of the Kunzam *La* Formation, the basin upsloped towards SE and Kinnaur parts. Being shallowest, these areas on slight regression were exposed to erosion. The deepest part of the basin possibly was in Zanskar from where turbidites have been reported (Fig.7.2). This deduction is also possibly supported by predominant development of the carbonate facies in Baralacha-Zanskar sector. As, by and large, there is a gradual or little change in the sedimentary facies, the basin is interpreted to have a gentle slope.

The shallowest part of the Thango basin, as is evidenced by the conglomerate facies, lay towards SE part of the Spiti and eastern Kinnaur (Fig.7.3). This basinal profile is broadly relatable to the basinal highs proposed in Gyundi and SE part of the Spiti Synclinorium (Bhargava *et al*, 1991b). The litho- and biomicrofacies of the Takche Formation suggest location of the Lahaul-Ladakh-Takche in NW and Tariya in SE as the shallowest parts of the basin (Fig.7.4). The presence of back reef facies (Fig.5.30) is indicated in the Parahio and back reef to partly reef and fore reef areas in the Pin and Tidong Valleys respectively. The 'main organic area' of this reef, possibly was towards the Kumaon basin, where robust stromatoporoid colonies are reported (Khanna *et al*, 1985).

During the deposition of the Muth sediments, a remarkably identical facies was developed in the Spiti-Zanskar-Kinnaur-Kumaon sector. A uniform basinal geomorphology is, therefore, visualised. The thickness of the Muth Formation from Spiti towards Zanskar gets gradually reduced, perhaps, reflecting upsloping direction of the basin. A minor basinal high has been propounded in the Spiti part during the deposition of the Muth sediments (Bhargava *et al*, 1991b).

In eastern Kinnaur and a part of Spiti, no Lipak Formation exists. This could be due to non-deposition or else owing to active and rapid erosion during post-Lipak and pre-Kuling period. This region of Kinnaur and Spiti, lacking the Lipak sediments, coincides with the sub-basinal high, interpreted during the deposition of the Muth Formation. It is likely that this high persisted and over which only a limited thickness of the Lipak Formation could be accommodated which was easily eroded. As a contrast to this basinal high, a relatively deeper part existed north of the Syarma Fault Complex where predominantly a crinoidal carbonate mudstone facies is developed. The basin profile changed during Lipak mid-way, forming certain deeper parts at Takche, Parahio, Pin and Lipak *Gad*, where hard ground and algal-coral build-ups were formed (Fig.7.5). During the terminal phase, the proposed basinal high possibly became more pronounced causing formation of 'Sabkha' like lagoons at Losar, Yulang-Hurling-Shalkar-Chango-Yangthang.

During the deposition of the Po Formation, the basin was considered to have been confined to the two corners of the Spiti basin (Bhargava *et al*, 1991b). Since the overall facies and thickness of the Po Formation at Losar and Po are identical, it is proposed that the basin might have been somewhat continuous through the Syarma part of the Spiti basin as well (Fig.7.6). Southeastern Kinnaur possibly remained a positive area during the deposition of the Po

Formation. The Po Formation towards Zanskar also shows gradual reduction in thickness. Beyond Thidsi, it is not developed showing shallowing and presence of positive area in the basin in that direction.

There is no Ganmachidam Formation in most parts of eastern Kinnaur, the central part of Spiti and beyond Thidsi in Zanskar. This area in Spiti coincides with the basinal high which persisted since the deposition of the Muth. It is suggested that this high became pronounced and subaerial and provided clasts of the Muth, Lipak and Po sediments to the Ganmachidam conglomerate (Fig.7.7). The Ganmachidam basin seems to be highly variable as is revealed by frequent facies changes in this formation. These facies were possibly controlled by sub-basinal transverse highs which came into existence during this time. The Guling and Kidul transverse highs were most prominent during this period (Bhargava *et al*, 1991b).

The transgression during the deposition of the Gechang Formation covered the entire Spiti basin. In Zanskar, it is mainly developed where the volcanics are absent. The basinal highs persisted during this time also, though much of undulations seem to have been levelled. The basinal highs are somewhat decipherable in the basin of the Gungri Formation as well.

During the deposition of the Mikin and Chomule Formations (Fig.7.9), the basin showed rapid deepening with identical facies from Kinnaur to Zanskar. It suggests uniform conditions in the basin during this time. The Sanglung Formation shows rapid facies variation pointing to uneven basin conditions. No data, however, exist to interpret its exact physiography.

The Hangrang Formation shows coral build-ups. The build-ups are conspicuous around the basinal ridge identified in the Carboniferous-Permian time. May be this sub-basinal high formed favourable locale for organic growth (Fig.7.10).

Not enough details exist for the facies and thickness variations in the Alaror and Nunuluka Formations from Zanskar or Kinnaur for any palaeophysiographic reconstruction. During the deposition of the Po to Nunuluka Formations, the area NE of Syarma Fault Complex seems to have formed a high and as a result, no deposition of these formations took place in this area.

The Kioto and Spiti Formations show remarkably identical facies throughout the basin suggesting a uniformity in the basin physiography during this time.

During the beginning of Cretaceous, possibly tilting and deepening of the basin took place to generate turbidites (Fig.7.13).

5.4 PROVENANCE

The rock suites in the provenance area have been interpreted on the basis of heavy minerals and plot on Q-F-L diagrams (Fig.5.31) after Dickinson and Suczek (1979). These studies are mainly limited to clastic sequences. 15-20 slides of each formation were examined and on an average 50-100 grains were counted.

The Batal Formation shows a heavy mineral assemblage comprising chlorite, zircon, zoisite, sporadic staurolite, tourmaline and garnet (Kumar *et al*, 1984) indicating metasediments of green schist and amphibolite facies as the provenance rocks. In the Kunzam *La* Formation, the heavy mineral suite comprises brown tourmaline, purple zircon, epidote, chlorite, limonite and haematite. This suite is characteristic of granite to low grade metamorphic rock terrain (Tonita, 1954; Fedo-Colecìdo, 1956; Beveridge, 1960).

The heavy mineral assemblage of the Thango Formation is similar to the one found in the Kunzam *La* Formation. The clasts in the Thango diamictites are distinctly from the Kunzam *La* and basal part of the Thango Formations. The sedimentary, low grade metamorphic and granitic terrain thus formed the Thango provenance. The heavy minerals recorded in the Takche Formation are akin to those of the Kunzam *La* and Thango Formations, and thus, likewise indicate low grade metamorphic, granitic and partly sedimentary rocks in the provenance area. The heavy mineral suite of the Muth Formation are constituted of pink and purple zircon, brown tourmaline, limonite and haematite, which also point to low grade metamorphic and granitic rocks as provenance. The Muth Formation comprises well washed, multicyclic quartz indicating sedimentary arenaceous rocks also in the provenance area.

In addition to the polycyclic quartz, turbid quartz and sodic plagioclase, the heavy mineral yield in the Po Formation, though poor, is similar to that of the Muth Formation (*i.e.* zircon, tourmaline, haematite). Thus, a sedimentary to low grade metamorphic terrain with granitic body possibly formed the source area. The clasts in the Ganmachidam Formation have an unmistakable Kunzam La, Thango, Takche, Muth and Lipak and occasional granitic parentage. The heavy mineral suite comprising chlorite, zircon, zoisite, tourmaline and epidote, in addition, indicates mainly low grade metamorphic source.

The Thango to Ganmachidam rock sequences show continental block source (Fig.5.31).

The heavy mineral suite (chlorite, zircon, epidote) of the Gechang Formation (Fig. 5.31) also indicates arenaceous sedimentary and low grade metamorphic rocks as provenance "in a recycled orogen" (Dickinson and Suczek, 1979), suggesting at least a pronounced epeirogenic event. Fine grained sedimentary quartz and mica in the silty bands of the Gungri Formation indicate a low grade metasedimentary sequence in the provenance area.

The heavy mineral data on carbonate dominated Mesozoic rocks were not collected. The late Triassic Nunuluka sandstone, besides sporadic tourmaline, contains turbid quartz and plagioclase which are suggestive of sedimentary and acid igneous rocks in the provenance area. The Q-F-L diagram indicates a continental block setting (Fig. 5.31).

The thin sandstone bands in the Spiti Formation are mica rich with occasional K-felspar indicating a low grade metamorphic to acid igneous provenance. The Giumal sandstone has turbid and non-undulatory quartz which often shows rhombic zircon and iron oxide as inclusions. These, along with the presence of microcline, sodic plagioclase and muscovite, point to an acid igneous derivation. The Q-F-L diagrams (5.31) for these two formations show scatter of points, possibly indicating a mixed continental block and recycled orogen setting.

5.5 PALAEOCLIMATE

Only a few unequivocal evidences at a few stratigraphic levels are available for broadly interpreting the palaeoclimate for the Spiti-Kumaon region during the Palaeozoic and Mesozoic (Fig. 7.16).

5.5.1 Palaeozoic

5.5.1.1 ***Ordovician (Thango) Time :*** The Thango Formation, besides having red coloured clastics, also shows scales of gypsum in the Kinnaur area. The association indicates a warm arid climate during this period.

5.5.1.2 ***Ordovician-Silurian (Takche) Time :*** Small but extensive presence of algal-coral build-ups, especially in the SE Kinnaur and SE Spiti parts, indicates a warm sub-tropical climate.

5.5.1.3 ***Early Carboniferous (Tournaisian Lipak) Time :*** Local occurrence of coral-algal build-ups and extensive development of carbonate and gypsum in the upper part of the Lipak Formation are suggestive of an arid and warm climate.

5.5.1.4 ***Asselian-Sakmarian (Gechang) Time :*** *Eurydesma* signifies cold climate in peri-Gondwana region (Dickins, 1957). Its presence in the Gechang Formation thus points to a cold climate.

No direct evidence is available to decipher the palaeoclimate of the early-middle Cambrian (Kunzam *La*), Silurian-Devonian (Muth), Visean (Po), late Carboniferous-early Permian (Ganmachidam) and late Permian (Gungri). However, on the basis of frosted quartz grains present in the Muth, an arid to semiarid climate could be inferred for this period. Plant fossils in the Po suggest a change from warm arid to warm-humid climate during the Visean period. The conglomerate of the Ganmachidam, though mainly of tectonic origin, could also signify partial reworking of morainic material, thereby indicating a cold climate. The late Permian time in Spiti-Kinnaur, identical to the Peninsular part, might have witnessed a change towards a warmer climate.

5.5.2 Mesozoic

5.5.2.1 ***Triassic-early Jurassic (Lilang Group) Time :*** Extensive development of carbonate in almost the entire Lilang Group and prolific occurrence of knoll reefs throughout the basin during the Norian and sporadically in the early Jurassic time suggest warm tropical climate.

5.5.2.2 ***Late Cretaceous (Chikkim) Time :*** Though no clues are available for the late Jurassic-early Cretaceous time, by virtue of reliable palaeogeographic reconstruction, an extension of early Jurassic climate, *i.e.* warm-tropical, is visualised during this period also.

6. TETHYAN SEQUENCES OF SPITI-ZANSKAR, KINNAUR-KUMAON AND KASHMIR-CHAMBA-TANDI : A COMPARISON AND CORRELATION

The Spiti part of the Tethyan sequence is physically traceable into Zanskar constituting one major synclinorium. The Zanskar succession, north of the Suru Antiform closure, links up with the Kashmir Synclinorium, which, in turn, extends towards south into the Chamba-Bhaderwah Synclinorium (Fig.4.1). These synclinoria thus formed one continuous basin. The Kinnaur Synclinorium, likewise, links up with the Kumaon Synclinorium. The Kashmir-Spiti-Zanskar and Kinnaur-Kumaon successions, presently separated by the crystallines, in view of highly comparable litho and biofacies, are envisioned to form one large continuous basin. The present configuration is attributed to erosion combined with the effect of structural deformation. Within this unified basin existed subtle differences which exercised control on lithology of different parts. In the following pages a comparison and correlation of various sequences are presented.

The nomenclature used for the Kumaon part (Table 6.1) here is after Kumar *et al*, (1977). For Kashmir two sets of nomenclature exist, *viz.* (i) by Srikantia and Bhargava (1983) and (ii) by Kumar *et al*, (1987). The classification by Kumar *et al*, (1987) uses certain names which were also used by Srikantia and Bhargava (1983) but altogether in a different sense, thereby creating confusion. The classification of Kumar *et al*, (1987) though post dates that of Srikantia and Bhargava (1983), was used by Shanker *et al*, (1989) by referring to an unpublished work without justifying the reason to ignore or even refer to a pre-existing classification which had found roots in international publications (*e.g.* Talent *et al*, 1989). In the present synthesis, in view of priority, the nomenclature of Srikantia and Bhargava (1983) is mainly used with minor modifications. Spatial thickness variations of various formations in Kashmir-Tandi, Zanskar-Spiti, and Kinnaur-Kumaon are depicted in Figs.6.1 and 6.2.

The continuous Tethyan sequence with minor sedimentological breaks begins in all the aforementioned areas with the Eocambrian rocks, designated as the Batal Formation in Spiti-Zanskar, Machhal Formation (Kumar *et al*, 1987) in Kashmir and Ralam Formation in Kumaon. The extensions of Machhal and Batal in Bhaderwah, Chamba, Kullu have been designated as the Manjir and Katarigali Formations. The Batal, Machhal, Ralam and Katarigali sequences represent subtidal sedimentation. The Ralam and Manjir diamictites seem to represent fluvial/coastal fan material reworked in a marine environment. The Manjir diamictites, down depositional dip, show reduction in size and frequency of clasts. Its finer facies and time equivalent in Spiti and Kashmir are the Batal and Machhal Formations respectively (Fig. 7.1). The Batal Formation in the Pin-Parahio and Kargil sections includes thin interstratified basic flows.

The sequence resting conformably over the Batal Formation is referred to in the Spiti-Zanskar and Kinnaur sections as the Kunzam *La* Formation, which has maximum thickness in the Spiti-Zanskar areas. Towards southeastern Spiti and Kinnaur, as stated earlier, its thickness decreases and progressively older levels are exposed in this direction. The carbonate facies, though observed in Parahio-Takche also, becomes prominent in the Baralacha *La* section and in the Zanskar area. From the Member C of the Martoli Formation of Kumar *et al*, (1977) fragments of trilobite body and trace fossils have been recently found (Mamgain and Misra, 1989), suggesting its equivalence with the Kunzam *La* Formation in Kumaon. The carbonate rich part in Kinnaur and Kumaon seems to have been eroded. The equivalents of the Kunzam *La* Formation in Kashmir is the Shumahal Formation and perhaps also the Rangmal Formation, the latter may be an enlarged version of the carbonate rich sequence of Spiti-Zanskar. Equivalent of the Kunzam *La* Formation does not occur in the Chamba, Bhaderwah and Kullu areas where it was possibly not deposited (Fig. 7.2). These sequences by and large represent a subtidal sedimentation in low energy regime with occasional storm episodes and upward shallowing to supratidal environment. It is only in the upper part (middle Cambrian) that a relative deepening of the basin seems to have taken place giving rise to carbonate sedimentation. This cycle too passed into a shallowing phase when cross-bedded arenites were deposited in the Kashmir (Member C of the Rangmal Formation) and Spiti-Zanskar areas.

In the Spiti-Zanskar and Kinnaur areas, the Kunzam *La* Formation and its equivalents are overlain unconformably by the Thango Formation (Fig.7.3). The

AGE / AREA	KASHMIR AFTER MIDDLEMISS (1910) SRIKANTIA & BHARGAVA (1983) KUMAR ET AL (1987)	BHADARWAH - CHAMBA - TANDI AFTER DUTTA & BHATTACHARYA (1975) SRIKANTIA & BHARGAVA (1979)	ZANSKAR-SPITI AFTER HAYDEN (1904) SRIKANTIA (1981) BHARGAVA (1987)	KINNAUR AFTER BASSI (1989a)	KUMAON AFTER KUMAR ET AL (1977)
Late Cretaceous			CHIKKIM Fm.		JHANGU Fm
Early Cretaceous			GIUMAL Fm	GIUMAL Fm	GIUMAL Fm
Late Jurassic			SPITI Fm	SPITI Fm	SPITI Fm
Early Jurassic		DILBURI Fm	KIOTO Fm		FERRUGINOUS OOLITE BED
Norian Late			NUNULUKA Fm		KIOTO Fm
Norian Middle			ALAROR Fm		PASSAGE Fm
Norian Early			HANGRANG Fm		KUTI SHALE
Late Carnian	SONAMARG GROUP	GUSHAL Fm (TANDI GROUP)	SANGLUNG Fm	LILANG GROUP	
Early Carnian			CHOMULE Fm		KALAPANI Lst
Ladinian			KAGA Fm		
Scythian - Anisian			MIKIN Fm		CHOCOLATE Fm
Late Permian	ZEWAN Fm	KUKTI Fm	GUNGRI Fm	GUNGRI Fm	KULING SHALE
Middle Permian					
Early Permian	MAMAL, PANJAL VOL.		GECHANG Fm PHE Vol.	GECHANG Fm	
Late Carboniferous	AGGLOMERATIC		GANMACHIDAM Fm		
Visean	FENESTELLA SHALE		PO Fm		
Tournaisian	SYRINGOTHYRIS Lst		LIPAK Fm		
Devonian	WAZURA Fm MUTH Fm		MUTH Fm	MUTH Fm	MUTH Fm
Silurian	RISHKOBAL B		TAKCHE Fm	TAKCHE Fm	VARIEGATED Fm
Ordovician	RISHKOBAL A		THANGO Fm	THANGO Fm	SHIALA Fm
Late Cambrian					
Middle Cambrian	SHUMAHAL Fm		KUNZAMLA Fm	KUNZAMLA Fm	GARBYANG Fm
Early Cambrian	RANGMAL Fm				
Eocambrian	MACHHAL Fm	KATARIGALI Fm MANJIR Fm	BATAL Fm	BATAL Fm	RALAM Fm
Early Middle Proterozoic	VAIKRITA / SALKHALA CRYSTALLINES				MARTOLI Fm
MAIN CENTRAL THRUST					

Table 6.1. Broad correlation of the Eocambrian, Palaeozoic and Mesozoic sequences in the Western Himalaya.

clasts in the Thango conglomerates in the Spiti and Kinnaur areas are mainly of the arenites of the Kunzam *La* and the Thango Formations. In the Zanskar area, the clasts are prominently from the carbonate rocks of the Kunzam *La* Formation. The conglomerates are lacking in the NW part of Zanskar. The Thango Formation shows variation in thickness, least being in the Tanze-Yongma section. This Formation in the Jadhganga Valley (Kumaon) links up with the conglomeratic horizon mapped earlier as the 'Ralam conglomerate' (Bassi and Dutta, 1987). Subsequently, Mamgain and Misra (1989), even in some sections of Kumaon, found early Ordovician fossils in the sequence immediately above the 'Ralam' conglomerate. It is likely that in Kumaon, too, equivalents of the Manjir and Thango Conglomerates exist and both of them possibly have been mapped as the Ralam Conglomerate. The equivalent of the Thango Formation in Kashmir is Member A of the Rishkobal Formation which has been partly rendered phyllitic.

The overlying Takche Formation (= Manchap Formation) is mostly calcareous in SE Spiti and Kinnaur. Its calcareous contents and also thickness decrease in NW direction. In the Zanskar area, it shows erratic development and is by and large absent. The erratic thickness of the Takche Formation is attributable to post-Takche erosion, signifying a pre-Muth Formational break. The lithological equivalent of the Takche Formation in Kashmir is Member B of the Rishkobal Formation and in Kumaon, the Shiala and Variegated Formations. Probably the Muth A and Muth B of Kumar *et al*, (1977) are also equivalents of the Takche Formation. The thickness of the equivalent of the Takche Formation is maximum in Kumaon. These sequences show coral-algal-stromatoporoid-bryozoal build-ups, which are most prominent in Kumaon (Yong Limestone of Khanna *et al*, 1985) and Kinnaur (Bhargava and Bassi, 1986) (Fig. 7.4). Minor coral-algal build-ups are also observed in the Kashmir area. The environment of deposition varies from transitional zone shelf mud area to subtidal-coastal area for the Shiala Formation; organic reef to back reef area for the Yong Limestone (= Variegated Formation); shallow coastal area to foreslope, back reef and restricted platform for the Takche and shallow carbonate to subtidal complex for the Member B of the Rishkobal Formation.

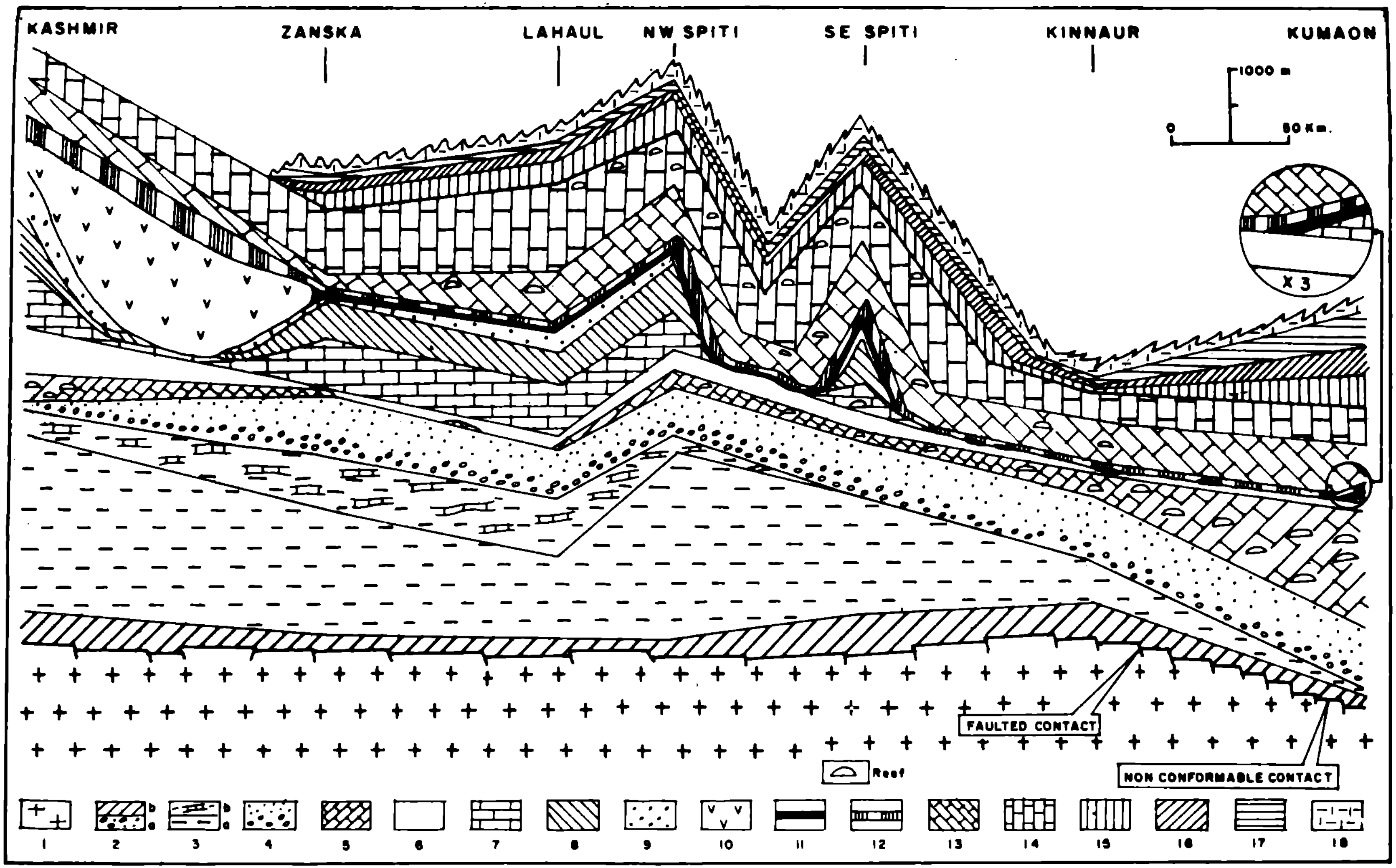


Fig. 6.1. Thickness variation of the Eocambrian-Palaeozoic-Mesozoic sequences in Kashmir, Zanskar, Lahaul, Spiti, Kinnaur and Kumaon. Expl. Equivalents of 1. Vaikrita Group. 2a. Manjir Formation. b. Salooni Formation. Batal Formation in Spiti. 3. Kunzam *La* Formation. a. areno-argillaceous basal and middle parts. b. carbonate dominated upper part. 4. Thango Formation, with conglomerate at base. 5. Takche Formation. 6. Muth Formation. 7. Lipak Formation. 8. Po Formation. 9. Ganmachidam Formation. 10. Panjal Volcanics. 11. Gechang Formation. 12. Gungri Formation. 13. Lilang Group minus Kioto Formation. 14. Kioto Formation. 15. Spiti Formation. 16. Giumal Formation and 17-18. Chikkim Formation. 17. Limestone Member. 18. Shale Member.

The remarkably uniform and conspicuous sequence of white supermatured quartzarenite referred to as the Muth Formation in all the areas (Muth C of Kumar *et al*, 1977, in Kumaon) rests abruptly over the Takche and its equivalent formations. The Muth Formation mostly has uniform thickness. Only in the Ropa-Hango sector, Lahaul and Zanskar areas, where the Takche Formation is also feebly developed, the Muth Formation is either absent or hardly a few metres thick. The contact between these two is interpreted to mark a depositional break. The limited thickness of the Muth Formation in Lahaul may be due to a pre-Lipak erosion, as may be suggested by a sharp contact between the Muth and Lipak Formations in these sections. The palaeoenvironment of the Muth Formation all over the Kumaon-Kashmir stretch is regarded to vary from sandy tidal flat, sandbar, mixed tidal flat, sandbar shoal in Kumaon to tidal beach in Kinnaur-Spiti-Zanskar and possibly also in Kashmir.

In Spiti, the Muth Formation is conformably succeeded by the Lipak Formation. The passage sequence between the Muth and Lipak Formations, made of limestone, dolomite, shale and sandstone, is of limited thickness in Spiti, hence classified with the Lipak Formation; in Zanskar, it is still thinner or not developed. In Kashmir, the passage bed, on the contrary, is a mappable unit of considerable thickness and was named as the Wazura Formation. The Wazura Formation and Syringothyris Limestone (≡Aishmuqam Formation) together form equivalent of the Lipak Formation. The Lipak Formation in Sumdo-Shalkar, Phiphuk and Phirse *Phu* sections rests directly over the Vaikrita Group. In Zanskar, about two kilometres NW of Tanze, this formation rests over the Kunzam *La* Formation after overlapping the Thango and Muth Formations,. No equivalent of the Lipak Formation is known in eastern Kinnaur. In the Kali Valley (Kumaon), the Kali Formation (Mamgain and Misra, 1989) is a possible equivalent of a part of the passage sequence in between the Muth and the Lipak Formations *i.e.* part of the Wazura Formation. The Lipak Formation and its equivalent mostly represent sedimentation in medium to high energy coastal reefal subtidal areas with Sabkha-like evaporite basins in Spiti (Fig.7.5). Proximity to land in Kashmir is indicated by fairly well preserved plant remains in the Members A and B of the Syringothyris Limestone (≡ Aishmuqam Formation).

The Lipak Formation only in fully developed sequences, exposed in SE and NW parts of Spiti, is followed by the sandstone-shale sequence of the Po Formation. From Spiti to Zanskar, the Po Formation shows too much of thickness variation with reduction in thickness towards NW. In central Spiti, Kinnaur and large parts of Kumaon it is absent (Fig.7.6). In Kashmir, its equivalent with more or less identical lithologic assemblage is the Fenestella Shale (≡Ganeshpur Formation). These sequences represent several shallowing-up cycles from mid-shelf to shore face and even tidal flat. Several cycles end up in diamictites. Both these formations contain doleritic to dioritic transgressive sills.

The Po and the Ganeshpur Formations are conformably succeeded by conglomeratic horizons referred to as the Ganmachidam Formation and Pindabol Formation (Agglomeratic Slates) respectively. These sequences, like the Po and Ganeshpur Formations, represent upward shallowing cycles mostly from subtidal to beach environment, where possibly the alluvial fan/fluvial material was reworked by marine processes. The equivalent of the Po and Ganmachidam Formations are not known in eastern Kinnaur and Kumaon.

The Ganmachidam Formation in the NW part of Zanskar, west of Sarchu beyond the Gurlok Valley and the Pindabol Formation in Kashmir are in general succeeded by the Phe and Panjal Volcanics respectively (Fig.7.7). The volcanics comprise volcanogenic rocks in the basal part and andesitic to basaltic lava flows in the upper. These show ropy structure and are largely of subaerial origin.

The Phe Volcanics in the Thidsi sector overlap the Lipak Formation and, about two kilometres east of Tungri Tokpa, rest over the Batal Formation after overlapping the entire Palaeozoic sequence. Similarly, the Panjal Volcanics in Kashmir come to rest over early Palaeozoic sequence. The time span occupied by these volcanics, in the areas where they are absent, is perhaps represented by a hiatus in between the Ganmachidam and Gechang Formations.

The Gechang Formation and its equivalent Girthi Formation in the Girthi Valley (Mamgain and Misra, 1989), commencing in most of the sections with a lag and followed by arenites, marks a transgression in the Spiti and part of the Kumaon areas. It shows a great variation in thickness in Spiti, being thickest in the Lingti and Poh-Tabo sectors. In Zanskar, it has an uneven distribution. The Chumik Formation of Gaetani *et al*, (1990) is identical in lithology and fossil contents to the Gechang Formation with which it has also been correlated. The occurrence of the Phe volcanics in between the Chumik (≡ Gechang) and Gechang (*sensu stricto*) Formations could be due to tectonic complication as suggested by Gaetani *et al*, (1990). In Kashmir, the time equivalents of the Gechang could be the Mamal-Nishatbagh and part of the Panjal Volcanics sequences. The equivalent of the Gechang Formation is inconsistently developed in the Kinnaur area. This formation represents a subtidal to upper shore cycle of sedimentation.

The Gechang Formation is abruptly succeeded by the black shales of the Gungri Formation, which show more or less uniform thickness in Spiti. It is equally well developed in Zanskar, Kinnaur and Kumaon (Kuling Shale). Everywhere it represents sedimentation in inner to midshelf muddy region. In Kashmir its equivalent, the Zewan Formation which rests over the Mamal/Nishatbagh Formation, comprises alternation of sandy shale and calcareous sandstone in basal part and sandy limestone, calcareous sandstone, with thin shale partings in the upper part. This sequence commonly contains foraminifera, bryozoa, echinoid fragments, brachiopods, gastropod and lamellibranchs and is regarded to represent deposits of medium energy coastal intertidal-subtidal areas.

In the Chamba area, after a long hiatus, the Salooni Formation representing the time equivalent of the Gungri Formation occurs directly over the Katarigali (≡ Batal) Formation (Fig.7.8). In south Lahaul also its equivalent, the Kukti Formation, rests over the Batal and Chola *Thach* Formations. Both these represent deposits of subtidal-intertidal environment.

The Lilang Group, which succeeds the Gungri Formation in the Spiti Valley, has been subdivided into eight mappable formations. Though equivalents of the Lilang Group are present in all the sectors, lithological details similar to those available in the Spiti Valley are lacking. Therefore, only broad comparisons are possible.

The Mikin, Kaga and Chomule Formations are well-developed in Spiti. These represent sedimentation in subtidal zone of bathyal to basin margin (Wilson's Facies belt 3; last one mainly of the Chomule) environment (Fig.7.9) and indicate rapid deepening of the basin at the beginning of the Triassic (Bhargava, 1987).

Microfacies, similar to those found in the Mikin and Kaga Formations of Spiti, are also known from Kinnaur, Kumaon and Zanskar. The details of exact equivalents of the overlying Sanglung Formation representing foreslope to basin margin, tidal flat, littoral to circa-littoral environments from these areas are not known. However, a comparable palaeoenvironment of carbonate shoal sand bar to shelf mud is reported from Kumaon (Kumar *et al*, 1977). Equivalents of the reefoid Hangrang Formation are known from Kinnaur and Zanskar. No coral build-up so far has been reported from Kumaon. The Kuti Shale, which is a broad time equivalent of the Member C (Sanglung Formation) and Hangrang, Alaror (platform edge to shelf lagoon) and Nunuluka (tidal flat to coastal) Formations, represents sedimentation in shelf mud to transition subtidal zones (Fig.7.10). The lithologic and palaeoenvironmental details of the equivalent of these formations in Kashmir are not known.

In south Lahaul, the equivalents of the entire Mikin-Nunuluka succession seem to be represented by the Gushal Formation, interpreted as deposits of shallow subtidal-intertidal palaeoenvironment. In Chamba, the basal part of the Kalhel Formation may be equivalent of the above mentioned formations.

The predominantly oolitic carbonate Para Member (Kioto Formation), which marks a transgressive phase in the Spiti, is well developed in the Zanskar, Kinnaur and Kumaon areas (referred to as the Kioto). Its equivalents are possibly present in Kashmir also. The environment of deposition of the Para Member is uniformly shelf edge sand with tidal channel to local subtidal zone (Fig.7.11). The overlying Tagling Member, as defined in this publication, is a possible equivalent of the Laptal Formation of Kumaon. Both these members represent sedimentation in winnowed shelf edge to restricted platform edge. Its equivalent in Chamba is perhaps the upper part of the Kalhel Formation and, in south Lahaul, the Dilburi Formation, both representing tidal flat complex.

The black shale of the Spiti Formation, overlying the Tagling Member and Laptal Formation along a sub-marine sedimentological break, occurs in the Zanskar, Kinnaur and Kumaon areas (Fig.7.12). Everywhere it represents a shelf mud palaeo-environment, except in Kumaon, where due to presence of radiolaria bearing chert in upper part, the environment is interpreted to be deeper in the terminal part of the sedimentation of the Spiti Formation.

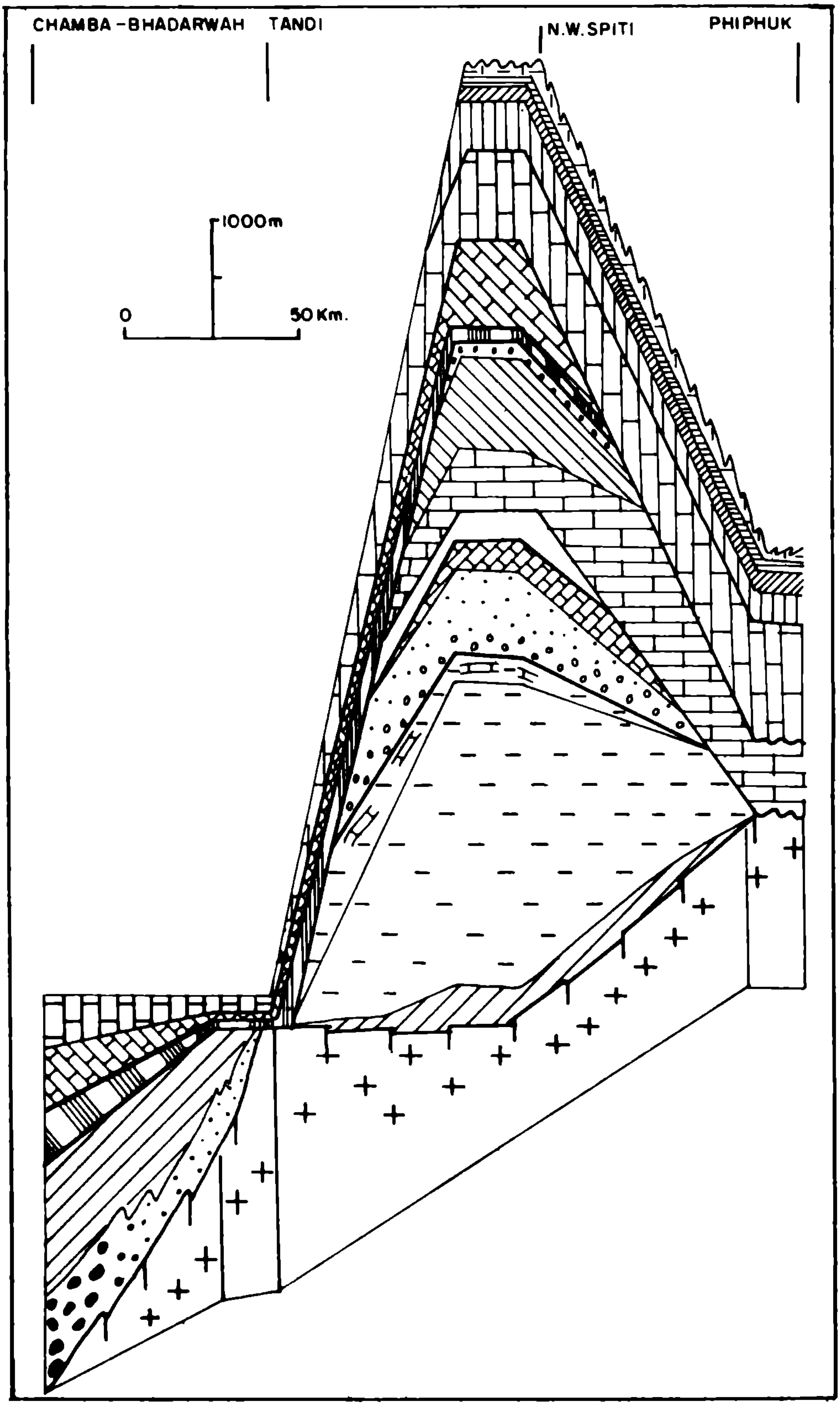


Fig. 6.2. Thickness variation of Eocambrian-Palaeozoic-Mesozoic sequences in Chamba-Tandi, Spiti and Lingti valley (Lalung *Nala*). Expl. As per Fig.6.1.

The Giumal Formation, succeeding the Spiti Formation, is uniformly calcareous in the basal and glauconitic in the middle and upper parts in Zanskar, Spiti and Kinnaur. In the Kumaon area, it is entirely made up of terrigenous clastics. It broadly represents proximal turbidites of continental slope to continental margin (Fig.7.13). Due to presence of coarser element in Spiti area, the Giumal Formation is interpreted to be of shallower environment as compared to other sectors.

The Chikkim Formation occurs in Spiti and Zanskar. The Kangi *La* Formation (Gaetani *et al*, 1983) may be equivalent of the Shale Member of the Chikkim Formation. Its equivalent in Kumaon has been designated as the Jhangu Formation (Kumar *et al*, 1977). All these comprise carbonate in lower and shale in upper parts and in general represent shelf to off basinal, lower to mid-shelf environments. In Kumaon, the Jhangu Formation is regarded as a deposit of continental slope (Kumar *et al*, 1977). Gaetani *et al*, (1983) consider Kangi *La* Formation to represent a distal turbidite (Fig.7.13).

No Cretaceous rocks are found in Kashmir, Chamba and south Lahaul. Terminal Cretaceous to Palaeocene and also possibly Eocene sequences in Zanskar are represented by Spanboth Formation and Chunglung *La* Slates respectively. The former represents infra-littoral to subtidal and the latter fresh water environment of sedimentation. These sequences in the Zanskar and Kumaon areas are overlain by the ophiolitic nappes. In the latter area also occur marine sequences as exotic blocks.

7. GEOLOGICAL HISTORY

The Eocambrian Batal Formation rests unconformably over a crystalline basement which shows pre-Batal deformation. The Tethyan sequences of the Kashmir, Chamba, Spiti-Zanskar and Kinnaur-Kumaon form part of a vast basin. After compensating for the crustal shortening, the size of the basin is likely to exceed 225 km x 900 km. Though sufficient data do not exist to comment categorically on the mechanism of formation of this basin yet, based on available observations, a tentative model may be proposed.

The Batal Formation in Spiti-Zanskar contains sporadic basic flows in the basal part and conglomerate in the upper part. The depositional updip rocks (Manjir) contain thick conglomerate in the Chamba area. The crystalline rocks, which form the floor for the Batal sequence, are of cratonic affinity.

The marine Tethyan basin sited over this crystalline sequence is, thus, visualised to have been formed due to rifting around 700-600 Ma (Singh, 1985), which coincides with the age of some granitoids. In view of clastics exceeding the volume of the volcanic rocks, it is suggested that the rifting was lithosphere-activated (Condie, 1982). The rifting caused block faulting and generated coarser clastics in the near-shore environment (Fig.7.1). In this block-faulted basin with poor circulation, the sediments could have two kinds of relationship *vis-a-vis* the basement, *viz.* (a) deposited over a block and (b) abutting against an upthrown block (Fig.7.1). This initial disposition is possibly responsible for different relationships observed between the cover and the basement, *i.e.* fault envisaged in Kumaon (Heim and Gansser, 1939; Kumar *et al*, 1972) and part of Zanskar (Gaetani *et al*, 1985) and conformable sequence in the Spiti-Zanskar (Srikantia, 1981). Some of the faults and perhaps even fault-bound blocks were reactivated from time to time. These exercised control over the sedimentation and also on late Tertiary tectonism.

The Eocambrian Batal basin extending in west upto Chamba area was of larger dimension. It shrank in area during the Cambrian, as suggested by a limited extent of the Kunzam *La* Formation. As a result, the Chamba-Kullu part became an area of non-deposition (Fig. 7.2) during the Cambrian time. Towards the late middle Cambrian, the basin witnessed some deepening only to revert to tidal flat-supratidal environment. At this juncture, possibly coinciding with the commencement of Pan-African suturing, there was a widespread regression in the Kashmir, Spiti-Zanskar and Kinnaur-Kumaon sectors. It raised the Kunzam *La* rocks to undergo erosion (Fig.7.3). Presence of trace elements of igneous suite (Bhandari and Sharma, 1984) and glass fragments in the sandstone of the Ordovician Thango Formation, may indicate a small magnitude rifting, resulting in a transgression during (?) late Cambrian to early Ordovician. The suturing-rifting occurred in pulses resulting in regression and transgression in quick cycles. Such cycles uplifted even the Thango sediments and exposed them to erosion. During these movements, sub-basinal highs having NW-SE and NE-SW trends were formed. It was during these movements that the 550-450 Ma granitoids were emplaced in the Vaikrita rocks.

Witnessing the warm climatic conditions, the basin somewhat deepened associated with the modification of basin profile, which promoted carbonate sedimentation and formation of small organic buildups (Fig. 7.4) during the Ordovician-Silurian (Takche) period. At the end of the Silurian/early Devonian period, the Zanskar, Spiti and part of the Kinnaur areas were exposed to erosion. The erosion seems to be maximum in the Lahaul-Zanskar area, where only a thin veneer of the Takche Formation is preserved. The late Devonian period (Muth Formation) witnessed another transgression in Spiti-Zanskar and Kumaon. Though from the Muth Formation to the Lipak Formation (late Devonian to early Carboniferous), in most sections, there is a passage sequence of different thicknesses, this contact is abrupt at Sarchu and part of Zanskar, while in Kumaon and eastern Kinnaur, the Muth Formation is succeeded by the Permian sediments. This relationship of the Muth Formation with the younger sequences seems to indicate a local post-Devonian sedimentological break in these areas. The cessation in sedimentation of the Muth Formation was followed by erosion also, which greatly reduced the thickness of the Muth Formation in the Lahaul and part of the Zanskar areas. The Lipak Formation, in several sections (Phiphuk, Shalkar-Sumdo, Tso Morari), rests over the Precambrian rocks indicating a late Devonian-early Carboniferous transgression. During this pe-

VENDIAN (MANJIR -BATAL FORMATION)

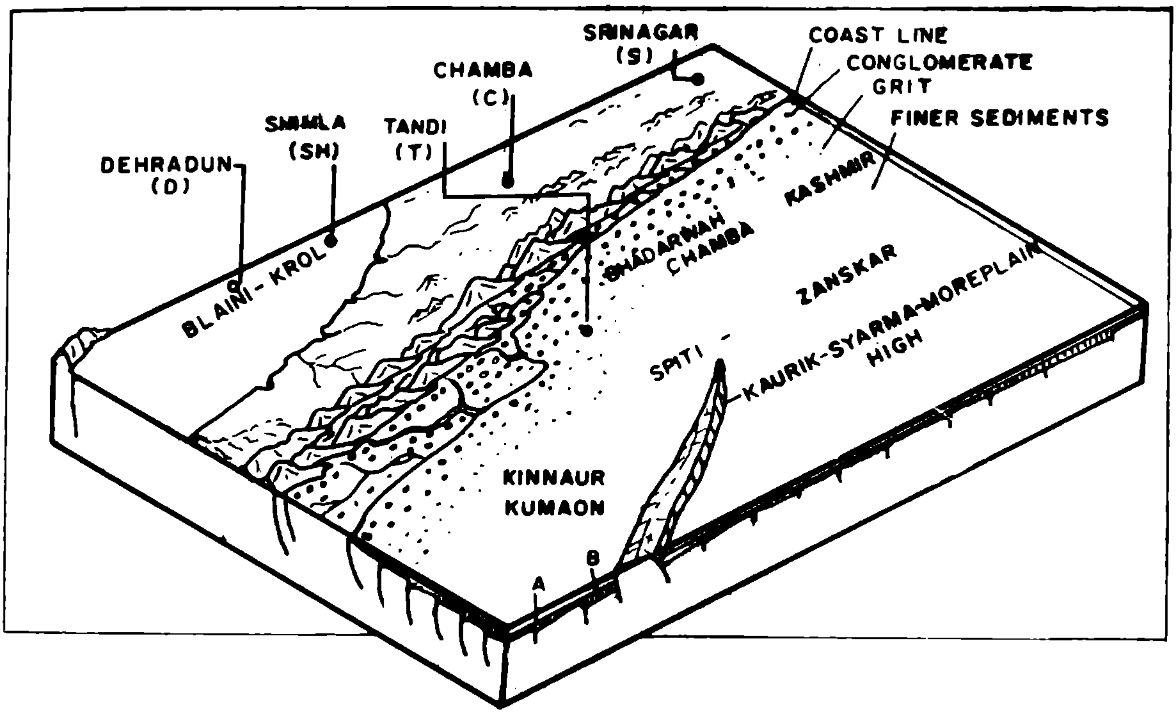


Fig. 7.1. A rifted basin formed site for the deposition of Eocambrian Manjir ,Katarigali, Batal and Ralam Formations. A- where sequence abuts against the basement, B - where non-conformable. The conglomerates were restricted mainly to the nearcoast areas. Dehra Dun, Shimla, Tandi,Chamba and Srinagar are plotted at their present geographical locations, whereas, the basin locations are shown after correcting for crustal shortening.

riod, even new stretches in the Lahaul-Zanskar areas were inundated by the sea. The Kinnaur-Kumaon sector, however, remained unaffected by this transgression. Several basement faults seem to have been reactivated during this movement; some like Syarma and Kaurik Fault Complexes, which had delimited th pre-Lipak Basin, allowed the basin to spill over the Precambrian basement in the Phiphuk and Shalkar sectors towards NE. In the Phiphuk area, the block NE of the Syarma Fault Complex possibly sank considerably to allow development of relatively deeper facies of the Lipak Formation in this area. This transgression was followed by shallowing which formed Sabkha-like basins in the Spiti part (Fig.7.5). The Syarma Complex once again became active and delimited the sedimentation to its SW.

During the Visean (Po-Fenestella Formations) time, the sedimentation took place in the siliciclastic sea. At this time, the highs, which were formed during the Ordovician (Thango period), became pronounced and the Phiphuk and Kinnaur-Kumaon areas did not receive any sedimentation (Fig.7.6)..During the late Carboniferous-early Permian (Ganmachidam) time, these highs in central Spiti became positive areas and sedimentation was confined to SE, NE and NW corners of Spiti and part of Zanskar. The clastic material to this basin was contributed by rapid erosion of the central raised part (Fig.7.7) which removed the whole of the Po Formation and a large part of the Lipak Formation. The accentuation of the sub-basinal high into a positive area was associated/followed by late Carboniferous- early (? late) Permian rifting which mainly occurred in the Kashmir and Zanskar parts. The rifting brought about a transgressive shallow sea in Spiti-Zanskar with a few embayments in Kinnaur-Kumaon in which the Gechang Formation and its equivalent were deposited. During this period, several lineaments were opened to provide early Permian sea in the Peninsular India and the Lesser Himalaya (Fig. 7.7).

This transgression was short lived as is evident from the absence of Kungurian to Kazanian elements in most of the Himalaya and even Midian in Spiti and Kumaon. A transgression during the Djulfian was more widespread. As a result, Chamba-

EARLY – MIDDLE CAMBRIAN (KUNZAM LA FORMATION)

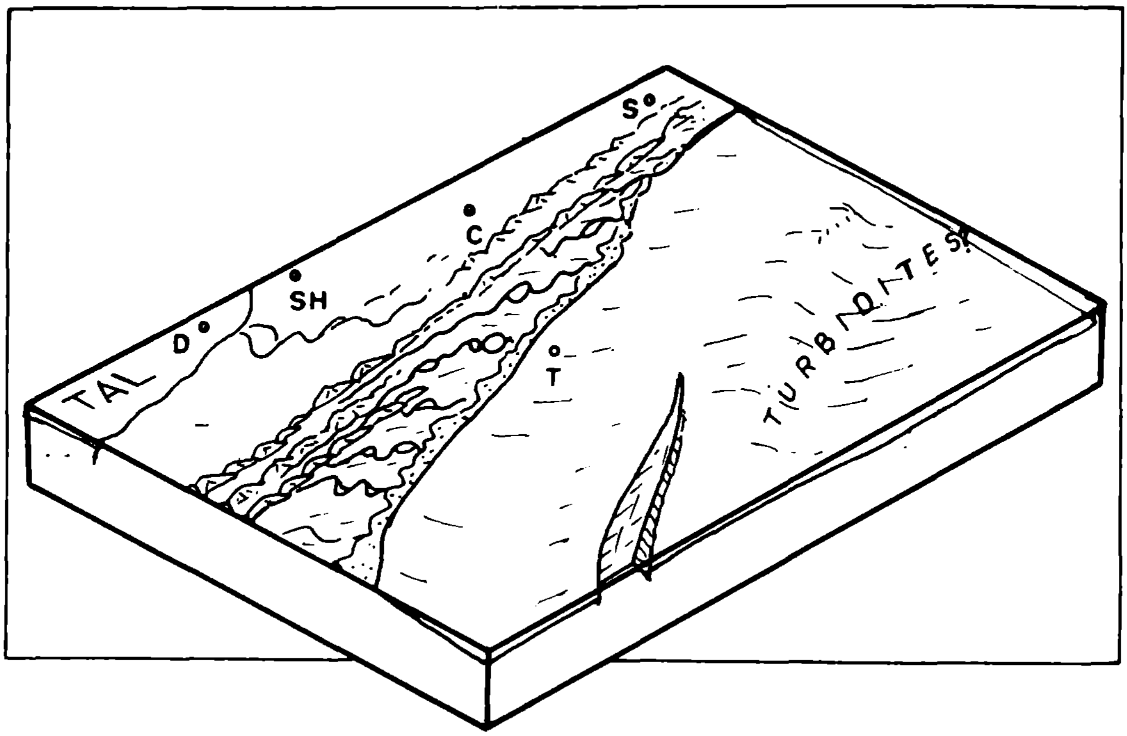


Fig. 7.2. During the Cambrian, the basin shrank, the provenance largely peneplained. The basin was mainly in subtidal setting during early Cambrian. Towards later part it became tidal.

Bhaderwah-Kullu and south Lahaul sectors, which had remained positive areas since earliest Cambrian time, were inundated by the sea. In these areas, shallower counterparts of the Gungri Formation of the shelf-mud-environment were deposited as the Salooni and Kukti Formations (Fig.7.8).

The advent of the Triassic witnessed rapid deepening of the basin upto early Carnic time (Fig. 7.9), followed by a gradual shallowing upto late Norian (i.e. upto Nunuluka Formation). Extensive development of coral knoll reefs took place during mid Norian. A Rhaetic - Liassic transgression associated with the rifting (Bhargava, 1987) took place. Once again the Syarma Fault Complex seems to have become active and allowed sedimentation of the Kioto Formation over the Lipak Formation in the Phiphuk area (Fig.7.11).

The shallower counterpart of the Kuling and Lilang sequences in the south Lahaul area is the Tandi Group. Several shallowing-up cycles during Triassic, recorded within various formations of the Lilang Group, might have resulted in repeated regressions in the south Lahaul and Chamba-Bhaderwah areas, which had formed the shallower parts of the basin. The Tandi Group, thus, may include several diastems, which possibly account for its smaller thickness, as compared to that of the Lilang Group.

At the end of the Callovian, the Kioto basin was submerged to the shelf mud depth in the Zanskar-Spiti and Kinnaur-Kumaon sectors (Fig.7.12), whereas, the Kashmir, Chamba-Bhaderwah and Tandi parts, perhaps due to sudden tilt of basin towards north east, became positive areas. In this basin ensued the sedimentation of the Spiti Formation. During early Cretaceous in the Spiti-Zanskar and Kinnaur Kumaon areas (Fig. 7.13), continental shelf and continental slope areas received sedimentation of the sandstone of the Giumal Formation. A deepening of the basin during late Cretaceous cut off the coarse clastic supply leading to the carbonate precipitation which, in turn, was followed by the sedimentation of the shale of the Chikkim Formation.

ORDOVICIAN (THANGO FORMATION)

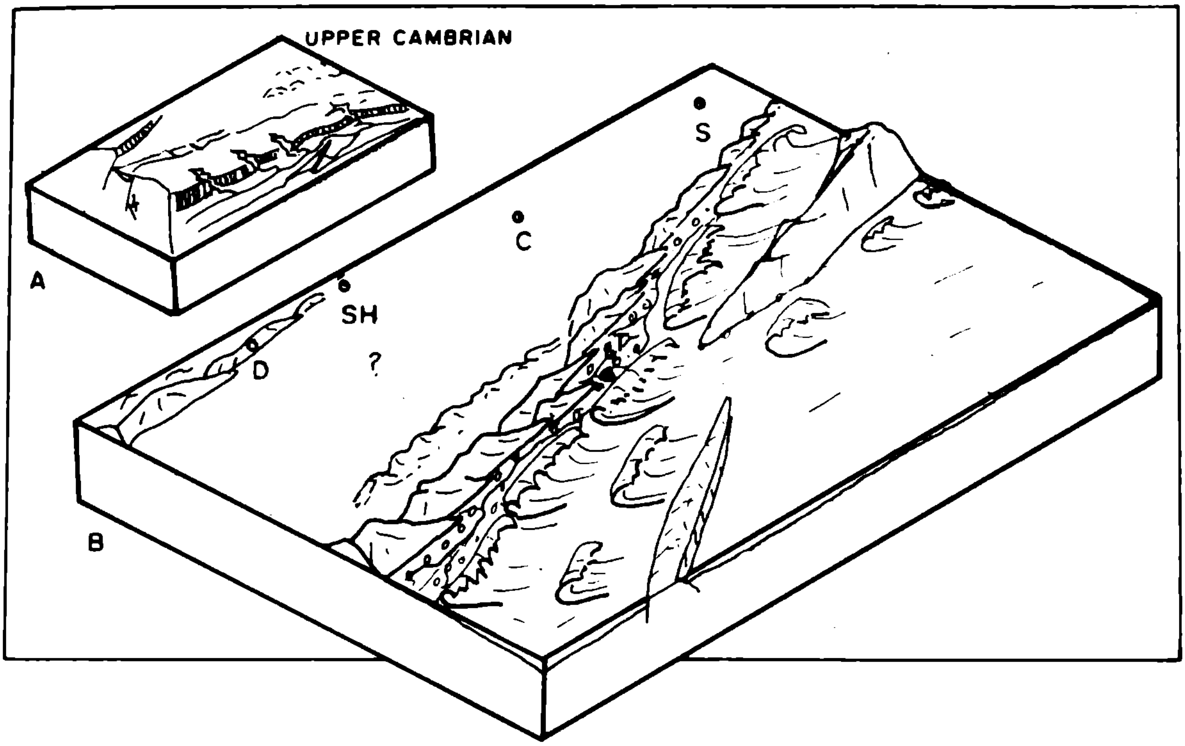


Fig. 7.3. During Ordovician (?late Cambrian), a swift rise in the provenance area,including the Kunzam *La* sequence,caused deposition of the conglomerate of the Thango Formation. The basin was mainly in a tidal sea.

SILURIAN (TAKCHE FORMATION)

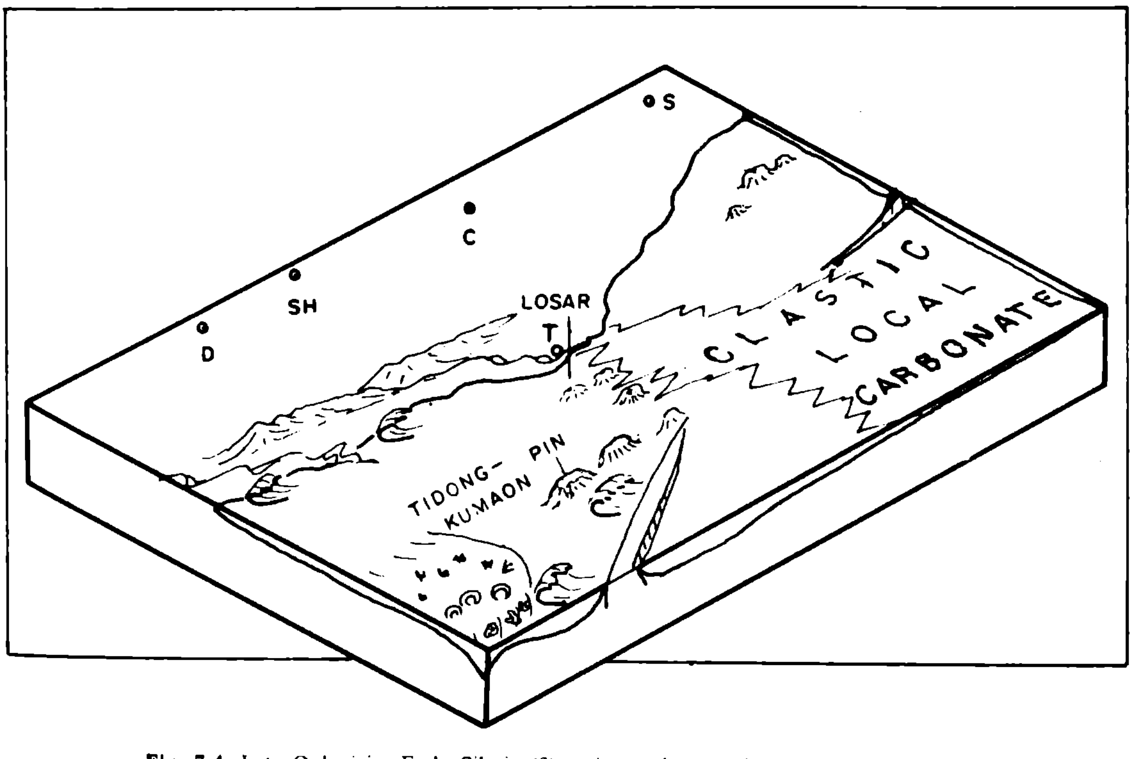


Fig. 7.4. Late Ordovician-Early Silurian(?) witnessed growth of organic build-ups.

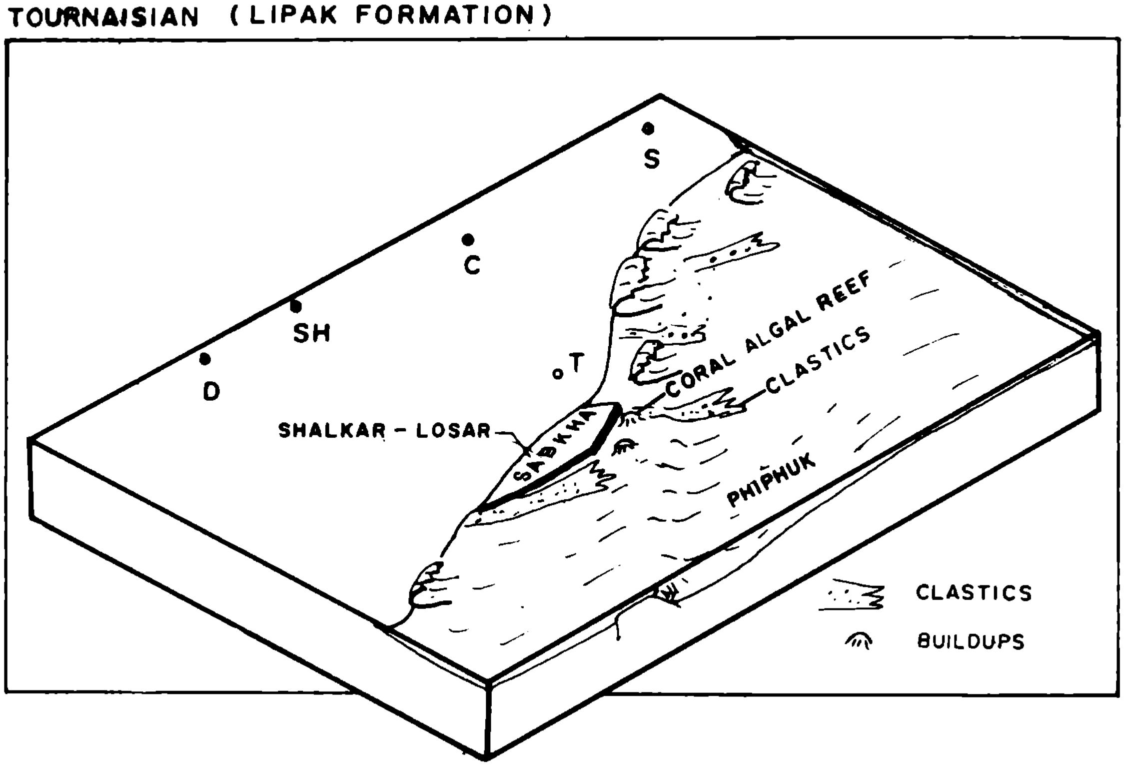


Fig. 7.5. During Tournaisian, hard ground, coral - algal build-ups and evaporite were formed. There was a limited transgression in Phiphuk and lower Spiti areas.

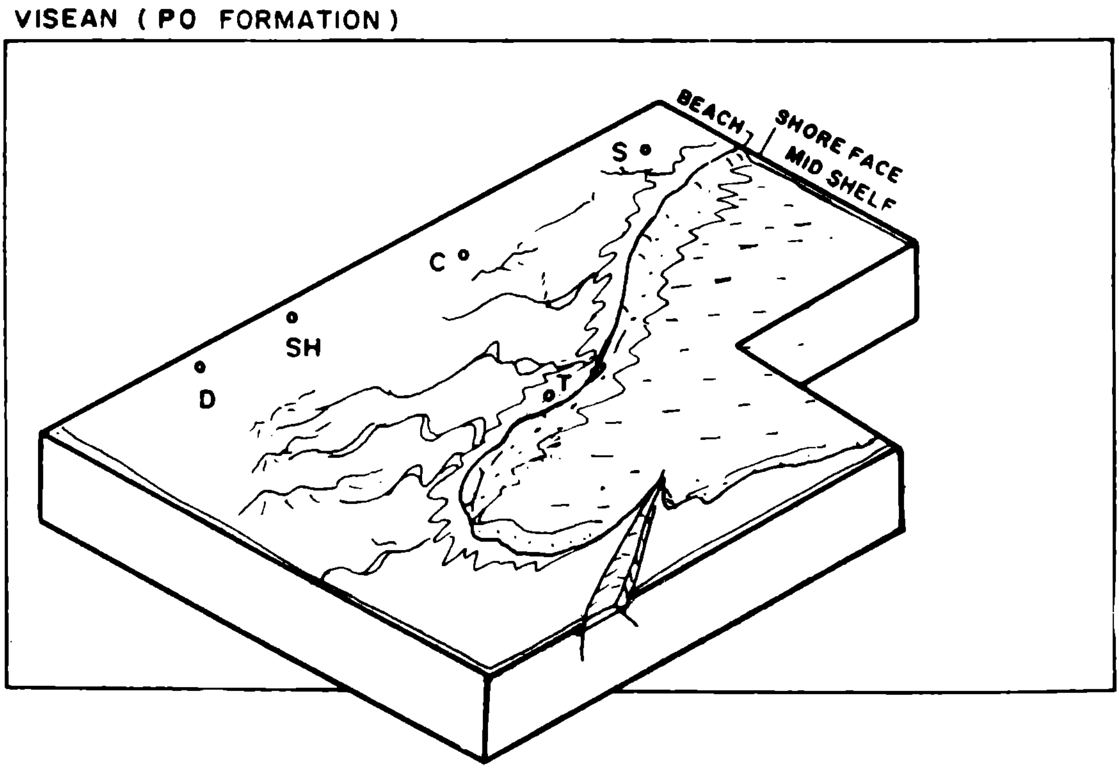


Fig. 7.6. During the Visean, the sea totally withdrew from Kumaon. It fluctuated from mid-shelf to tidal in Spiti - Zanskar.

LATE CARBONIFEROUS-EARLY PERMIAN (AGGLOMERATIC SLATE - GANMACHIDAM - GECHANG FORMATIONS, PANJAL - PHE VOLCANICS)

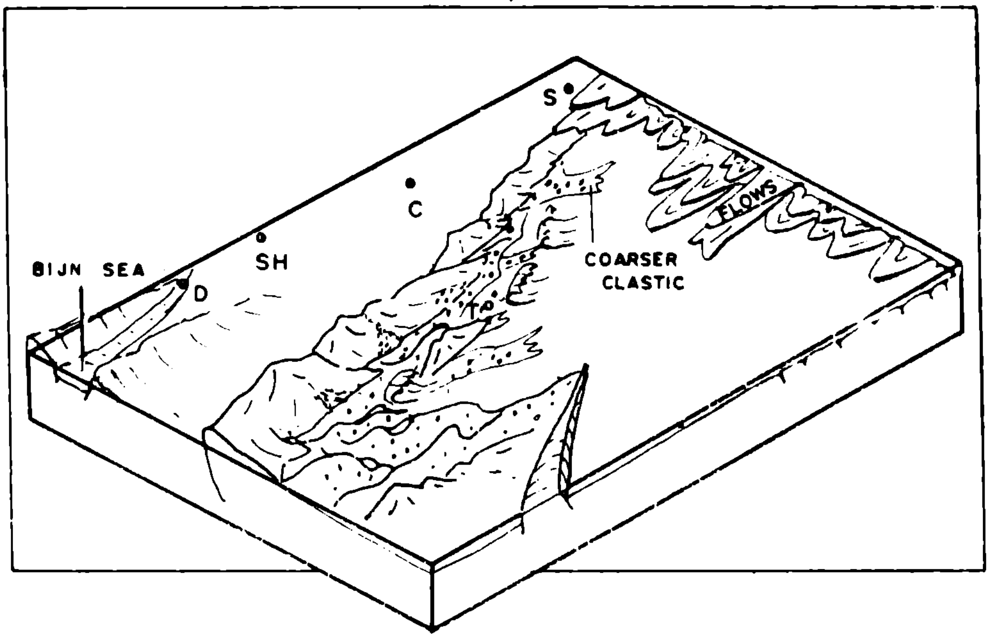


Fig. 7.7. During late Carboniferous, central part of the Spiti became a positive area and contributed clasts to the Ganmachidam Formation. Associated with rifting the Panjal and Phe Volcanics erupted in Kashmir- Zanskar.

LATE PERMIAN (KULING FORMATION)

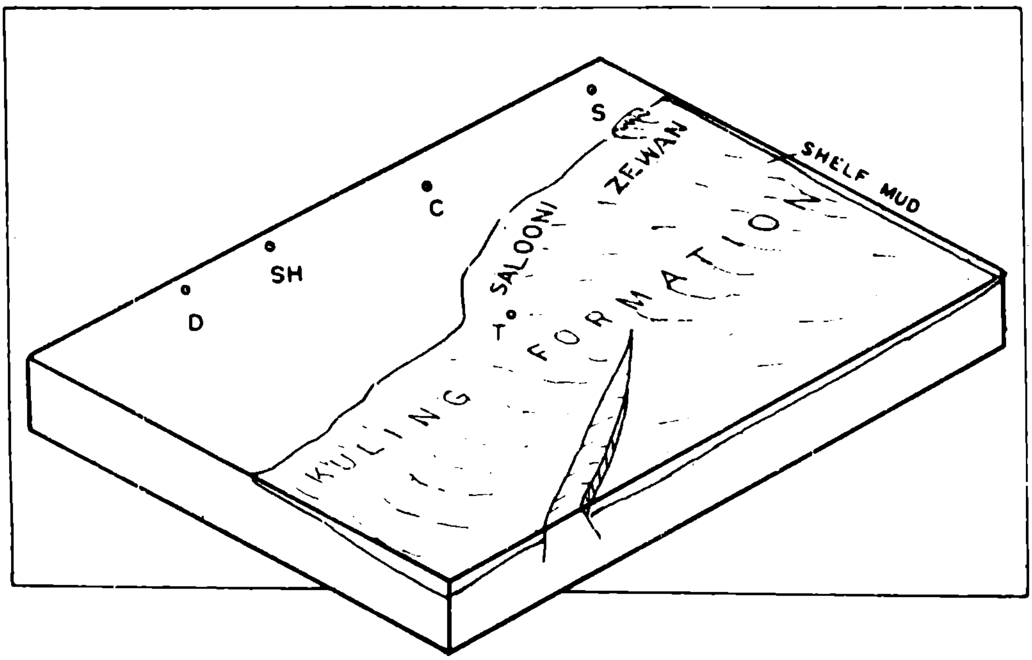


Fig. 7.8. During late Permian (Djulfian) wide spread transgression occurred in the Himalaya. The sea spread to Bhadarwah Chamba. The early Permian transgression, though of limited extent in the Himalaya was more regional; it inundated areas in the Lesser Himalaya, Rajasthan - Son - Narmada stretch.

SCYTHIAN - EARLY CARNIAN (MIKIN - CHOMULE FORMATIONS)

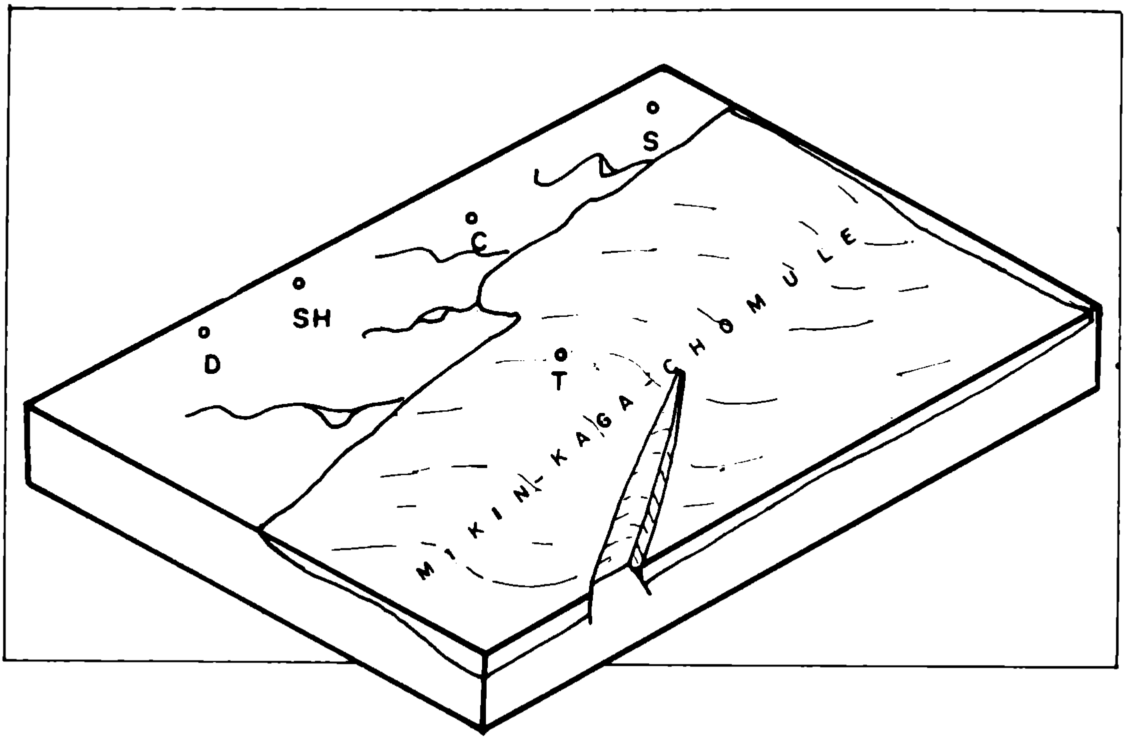


Fig. 7.9. Early Triassic witnessed a rapid deepening of the basin, a phenomenon which lasted upto early Carnian.

MID NORIAN (HANGRANG FORMATION)

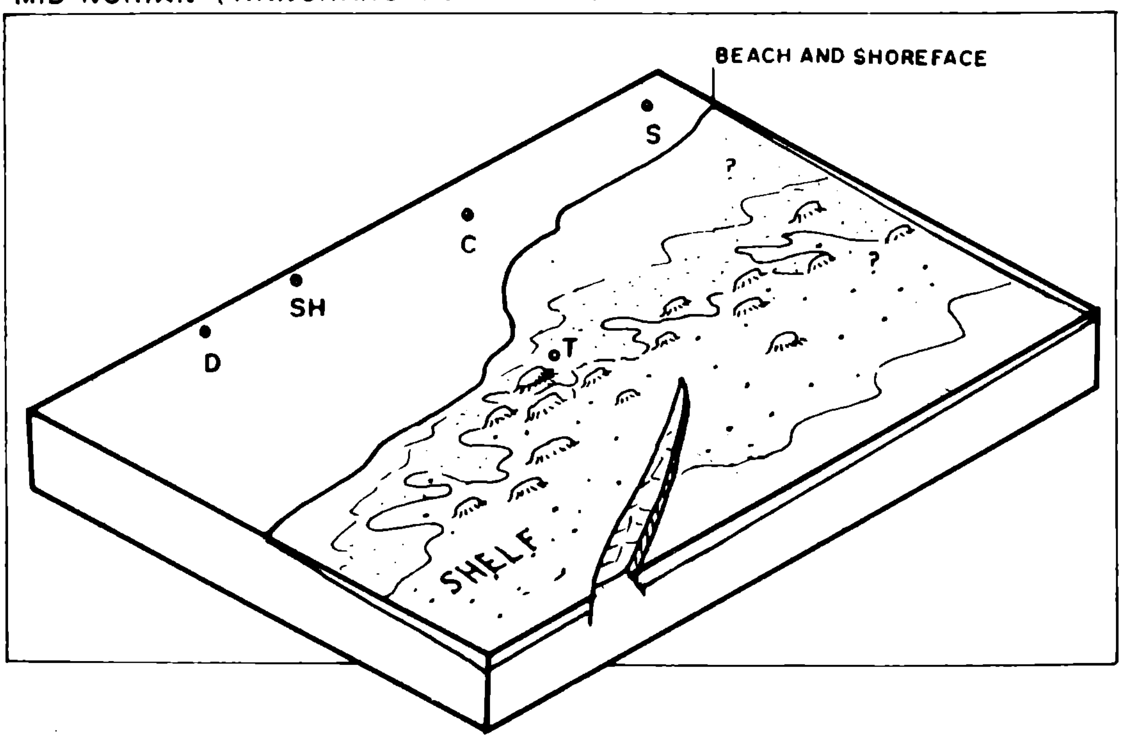


Fig. 7.10. Middle Norian was a period of extensive knoll- reef growth.

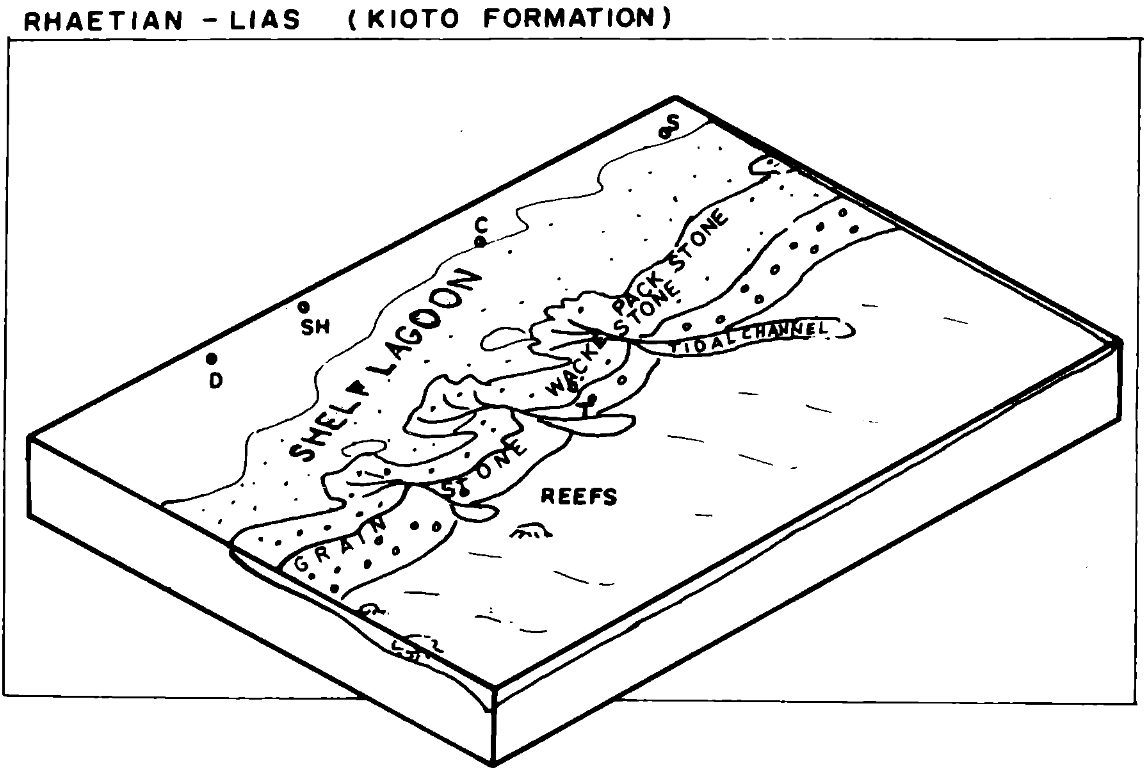


Fig. 7.11. Rhaetic - Liassic basin of shelf edge sand type with tidal channel to subtidal variations.

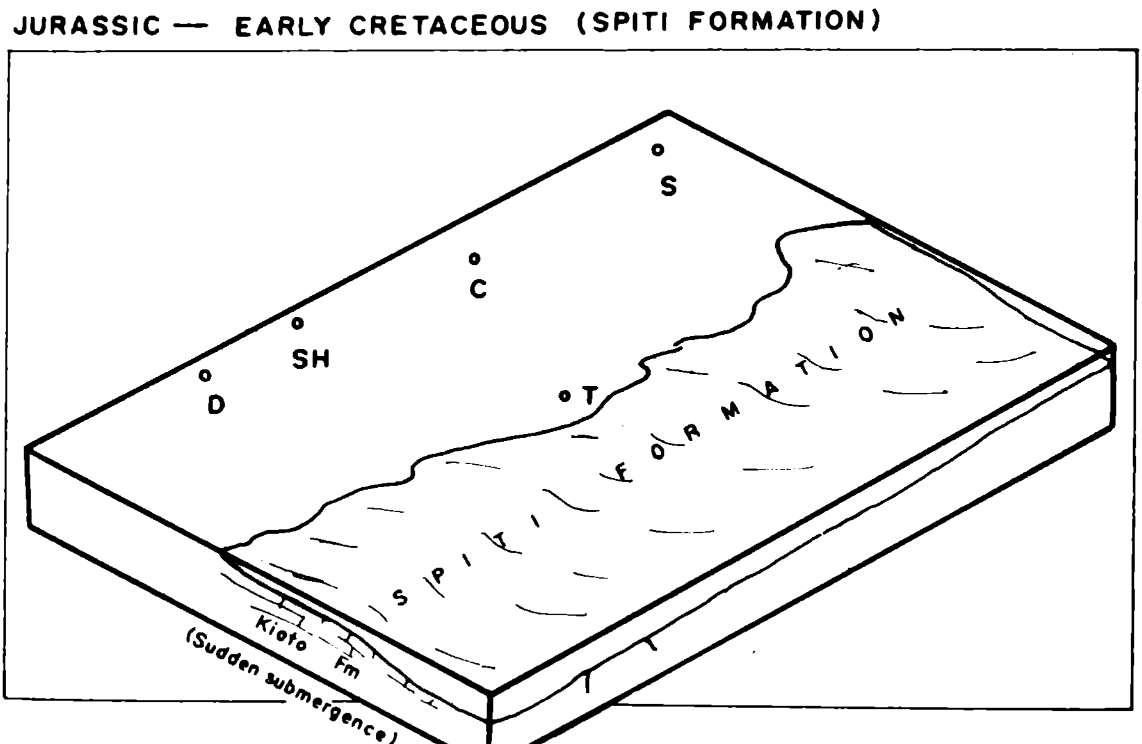


Fig. 7.12. Late Jurassic basin was mainly in shelf mud regime in Zanskar, Lahaul - Spiti, Kinnaur - Kumaon. It totally withdrew from Kashmir,Chamba and Tandi. In the Kumaon, towards end, the basin became deeper.

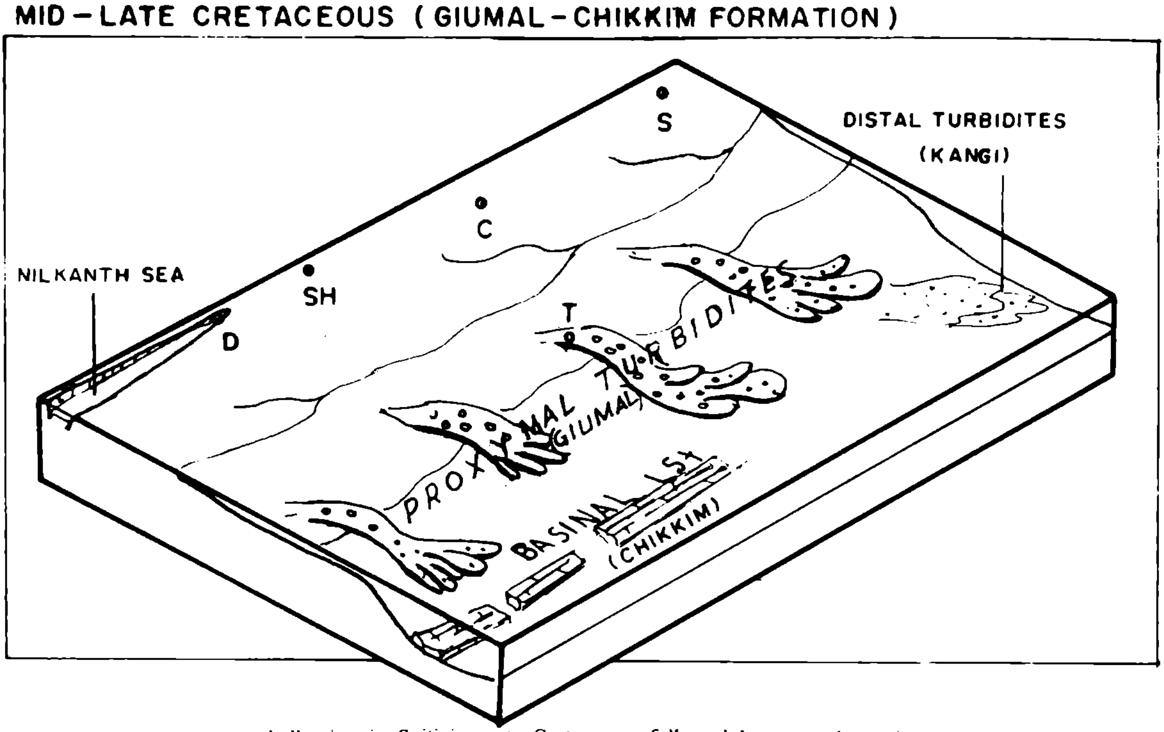


Fig. 7.13. There was a shallowing in Spiti in early Cretaceous, followed by some deepening, even then the basin in Spiti was shallower as compared to Kumaon and Zanskar. Proximal turbidites of variable depth were deposited. Late Cretaceous received sedimentation of basinal limestone and shale/distal flysch.

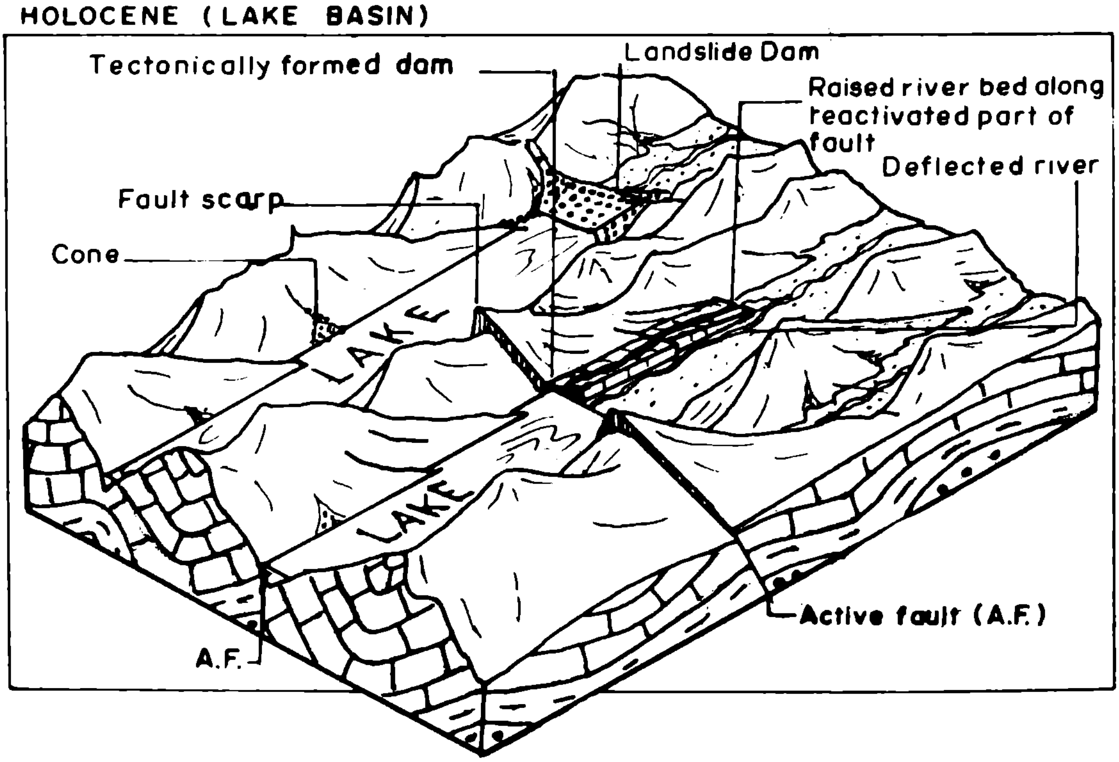


Fig. 7.14. During the Quaternary, in the post-glacial period, possibly as a response to (i) removal of glacial ice load, and (ii) indentation tectonics, several faults were reactivated. These deflected river courses, and generated landslides which dammed the rivers to form vast lakes

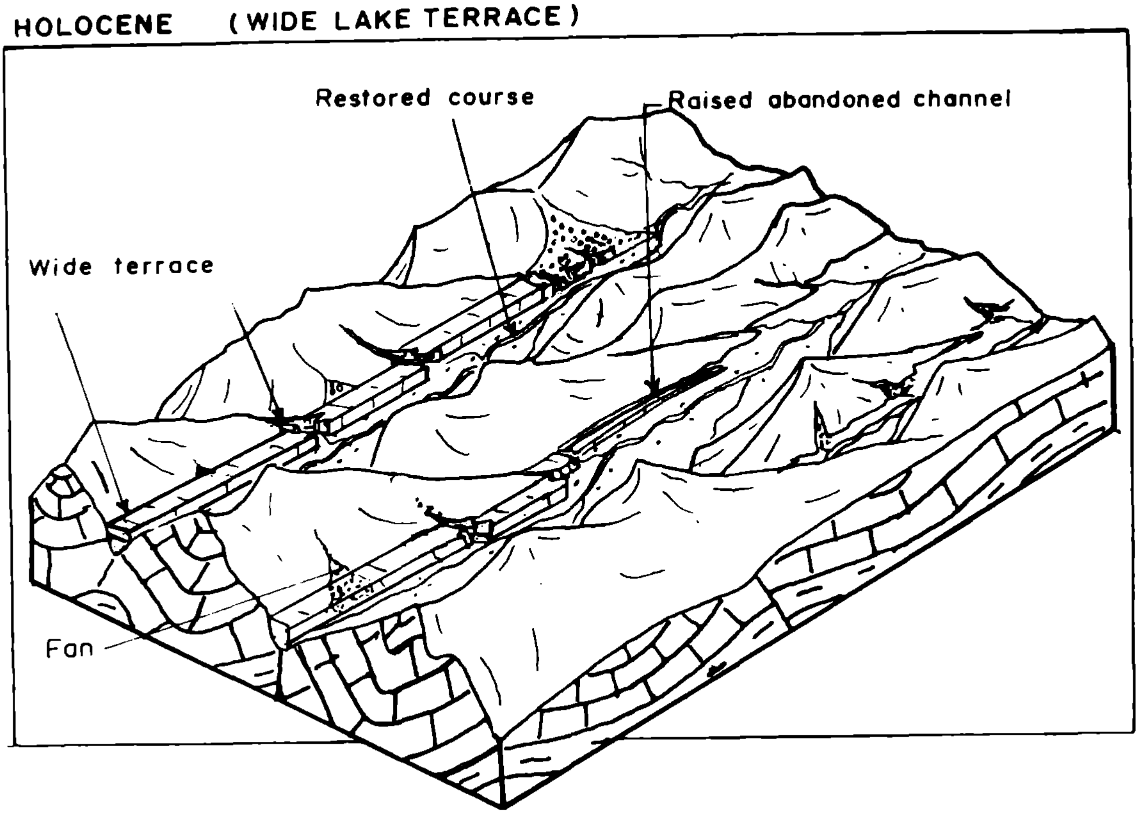


Fig. 7.15. The fault blockades and also landslide dams were eroded, restoring the river courses, some of which along new channels, leaving behind wide lacustrine terraces.

Probably at this time the folding ensued and the earliest recumbent MF_1 folds in the Palaeozoic-Mesozoic sequence (*e.g.* in Chikkim and Sakti Synclines), which are same as the F_3 folds encountered in the Precambrian Vaikrita Group, were formed. These movements also caused differential burial of sediments across the Kaurik, Syarma and More Plain Fault Complexes to impart local biotite grade metamorphism mainly to the Carboniferous rocks. While these movements were taking place, Palaeocene-Eocene rocks were deposited in the shallowed Zanskar part. Subduction of the Indian Plate, which had commenced, resulted in the emplacement of ophiolitic rocks (obducted masses) and rocks of northern facies as klippe over the *in situ* sequences of the Zanskar and Kumaon areas. As the subduction along the Indus Suture ceased due to buoyancy of the Indian Plate, the continued northward drift of the Indian Plate forced open the MCT to translate the Vaikrita Group along with the Tethyan rocks on its back onto their present position. The last two deformations, which involved even the thrust planes, obviously took place after the thrust sheets were emplaced in their present positions. These folds are reflected even in the Siwalik rocks, and thus, are of late Pleistocene age.

The morphogenic uplift was followed by the first major glaciation. The release of confined stress and opening of lineaments (Bhargava, 1990) developed new and reactivated old faults (Fig.7.14). These movements deflected and dammed several rivers which formed intra-mountain lake basins (Bhargava, 1990). Bursting of the dams restored the river flow and gradually the present topography was acquired (Fig.7.15).

Various events of the Western Himalayan Tethyan basin are depicted in Fig.7.16. A multicyclic history of north western Himalaya has also been synthesised by Gaetani and Garzanti (1991).

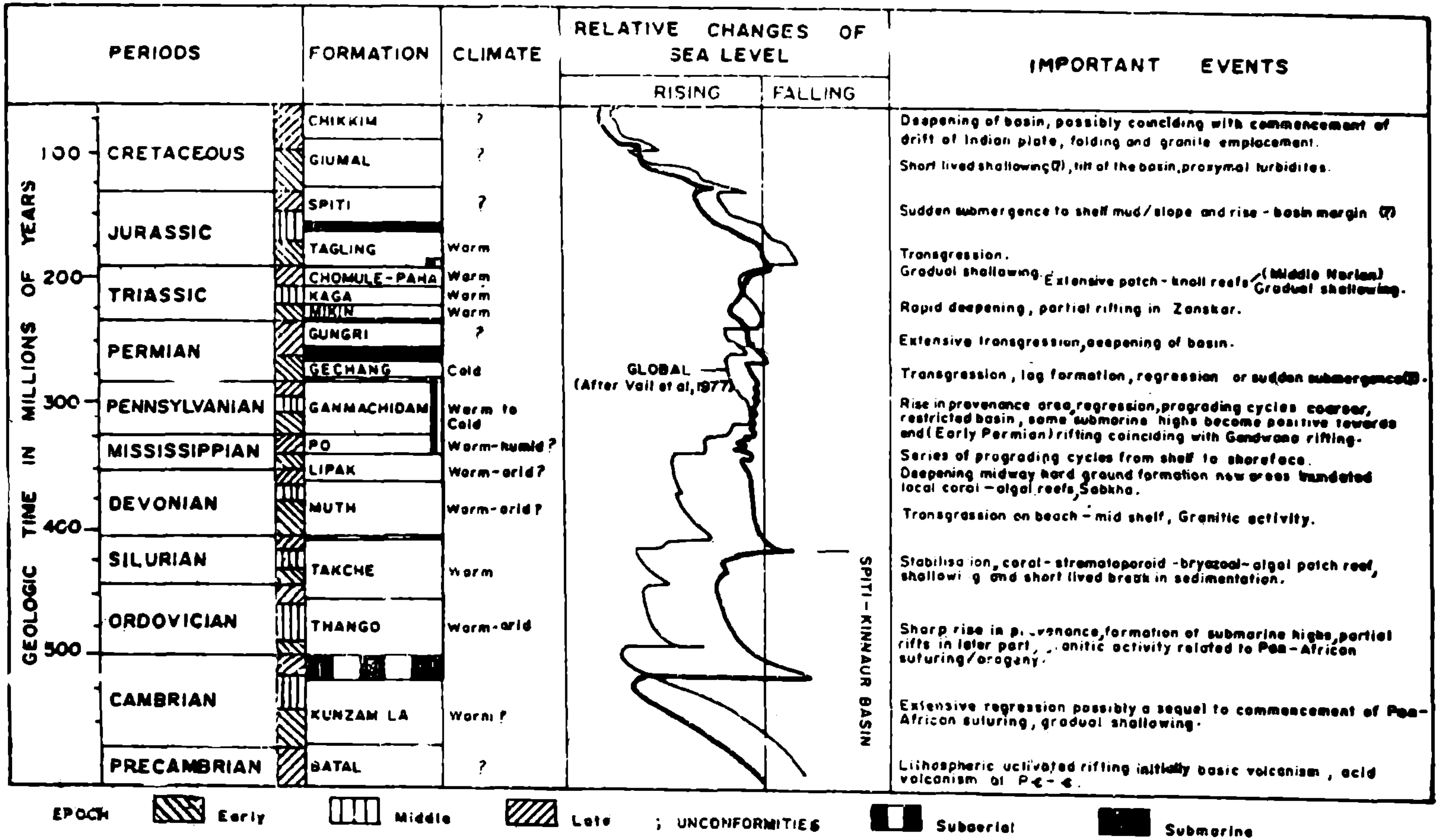


Fig. 7.16. Broad event stratigraphy, sea level fluctuations as related to global changes and palaeoclimatic variations during the Eocambrian, Palaeozoic and Mesozoic span.

8. ECONOMIC GEOLOGY

Study for economic minerals in Spiti-Kinnaur was first carried out by Mallet (1865) for the gypsum deposits of the lower Spiti Valley. Later, Iyengar (1949) examined several mineral occurrences of Kinnaur. Though a variety of minerals are known from Spiti-Kinnaur, but for barytes, gypsum and limestone, all others are merely of academic significance. About 2300 stream sediments were analysed for Sn, W, Cu, Pb, Zn, Ni, Co, Hg, Zr, Ti, Mn, Sb, V and Th. None, however, yielded encouraging results. A brief description of important mineral occurrences is given here.

8.1 Barytes

Snow white barytes occurs as epigenetic veins in the Thango quartzarenites in the Baspa, Tidong, and Tagla Valleys. About 5,000 tonnes of high grade barytes may be available from these occurrences (Bassi, 1988a).

In the Baspa Valley, massive and cryptocrystalline barytes occurs along east-west joints and as quartz-barytes lens along the crest of an anticline in the quartzarenite of the Thango Formation near Arsomang. Pinkish rosettes of barytes are observed along joints. In all, there are three veins. Chemical analysis shows 97.70% $BaSO_4$. The details of dimensions and the reserves of veins and lenses are furnished in Table 8.1. Barytes in small quantities also occurs at Tariya in the Pin Valley.

8.2 Beryl

Greenish and bluish beryl occurs in the pegmatite intrusive into the Proterozoic rocks, though no high concentration has been observed in any locality.

8.3 Building Stone

Gneisses and slates exposed around habitations in southern Kinnaur are extensively used as building stones. Small scale excavations are carried out near Kupa, Bhabe Dogri, Lipa, Labrang, Shiasu, Kanam etc. The dolomites of the Lilang Group find extensive use as building material in the Spiti Valley.

8.4 Clay

White to off-white lacustrine clay occurs near Atargoo, Hurling, Sumdo, Shalkar, Chango, Ganfa, Shiasu, Kanam and Ribba. The clay at Kanam is indigenously used for white washing. The clay at Shalkar is pale cream in colour with low hardness and high plasticity. Its shrinkage index is three, gets fused on firing and turns greenish at 1450°c.

8.5 Fluorite

Minor fluorite veins occur in the porphyroblastic gneiss of the Kilba Formation in the Wangtu area.

8.6 Glass Sand

Snow white quartzarenite of the Manikaran and

Table 8.1
Probable reserves of barytes in the Kinnaur district.

Sl. No.	Location	Nature	Length (m)	Width (m)	D/Depth Ext. (m)	Vol. (Cum)	Sp.Gr.	Reserves (Tonnes)
1.	Arsomang, Baspa Valley	Vein I	20	0.20	10	40	4.44	177.60
	do	Vein II	60	0.40	20	480	4.44	2131.20
	do	Vein III	15	0.15	10	11.25	4.44	99.90
	do	Lens	20	1.00	10	100.00*	4.44	222.00

*Only 50% is barytes while rest is quartz.

2.	Mangla Thach / Alingdar, Tidong Valley	Veins	30	0.20	10	60	4.40	264.00
3.	Gekod ,Tagla Valley	Vein	+20	1.20	20	4.80	4.40	2112.20

Net Probable Reserves = 5006.90 tonnes

Muth Formations may be a potential raw material for glass and ferrosilicon industries but the remoteness of the area and lack of local demand may pose serious constraints on any economic exploitation.

8.7 Gold

The sandbars along the Satluj River in the stretch between Morang and Karcham are seasonally panned for gold by the migrants from Bilaspur district. The extent of these sandbars is too small for any commercial interest.

8.8 Gypsum

Large deposits of gypsum occur at Chango, Shalkar, Hurling, Gyundi *Nala* and Duna Dangse and upper reaches of the Yulang *Gad* and small pockets in the Yangthang area. It occurs in the upper part of the early Carboniferous Lipak Formation. Some of these occurrences were studied by Mallet (1865). Kathiara and Raina (1965) assessed 1.25 million tonnes of gypsum down to a depth of 25m from Shalkar area alone. The occurrences at Yulang *Gad* and Shalkar-Sumra and Hurling sections are of much larger dimensions. Gypsum occurs as 30-35m thick beds extending upto two kilometres. These beds often contain limestone and sandstone lenses. The gypsum is generally granular and snow white in colour. The analysis of the alabaster variety shows 31.70% to 32.51% of Ca and 54.36% to 54.45% of SO_4. The other varieties associated with it are earthy, impure gypsite, transparent selenite and dense anhydrite. The anhydrite contains 40.13% of CaO and 67.53% of SO_4. A conservative estimate of the total *in situ* reserves of the gypsum in the Kinnaur-Spiti area may be over 10 million tonnes. Despite the huge reserves, the low market value of gypsum and the large transportation involved, render the deposit uneconomic.

8.9 Haematite

Ocurrence of haematite was first recorded in the rocks of the Thango Formation by Hayden (1904). The haematite band at Thango occurs in the basal part of the Thango Formation and is 120m long and 4.5m thick (Fig. 8.1). Similar but smaller lenses occur at Shitikar, Takche and Duna Dangse.

8.10 Hydrocarbons

Greasy black hydrocarbon encrustations in the form of '*Shilajeet*' are observed in the black slates near Kuno village in the Tidong Valley, Kinnaur.

8.11 Limestone

The Takche and Lipak Formations and Lilang Group contain enormous reserves of high grade limestone. The CaO contents of the metamorphosed Lipak limestone near Yangthang varies between 48.36% to 51.77%. This marble, though lacking good shades, can be used as chipstone for flooring purpose. Despite good quality and enormous reserves, remote terrain and huge cost of transportation make the limestone deposit uneconomic.

8.12 Lithium

A few samples of pegmatite from the Yangthang area gave upto 1000 ppm Li values but the follow-up studies were not encouraging.

8.13 Mica

Most of the pegmatite veins contain books of muscovite and biotite but these do not have any economic importance.

8.14 Molybdenite

A single speck of molybdenite was recorded in the schorl rock associated with the Rakcham Granite near the snout of the Jabtya Glacier in the Tidong Valley.

8.15 Phosphorite

Disseminated phosphatic nodules occur in the Gungri Formation. Nodules contain upto 25% P_2O_5, but constitute less than 5% of the whole rock. Similarly, some of the nodules found in the Spiti Formation are also phosphatic and these too constitute a small fraction of the total volume.

8.16 Potash

The quartzarenite of the Giumal Formation in thin sections have been found to contain as much as 50% glauconite by volume. The chemical analysis of these rocks, however, shows a maximum potash content of 5.64%.

8.17 Pyrite

Pyrite is profusely disseminated in the slate, phyllite and quartzite of the Batal Formation and shale of the Po Formation. Its concentration, however, is too insignificant. Pyrite's occurrence is known from the Purbani area where some old mining history also exists (Iyengar, 1949). Kathiara and Venugopal (1964) who re-examined it, however, found the occurrence of academic interest only.

8.18 Radioactive minerals

Geiger Muller counter survey carried out in the granitic terrains did not yield any significant

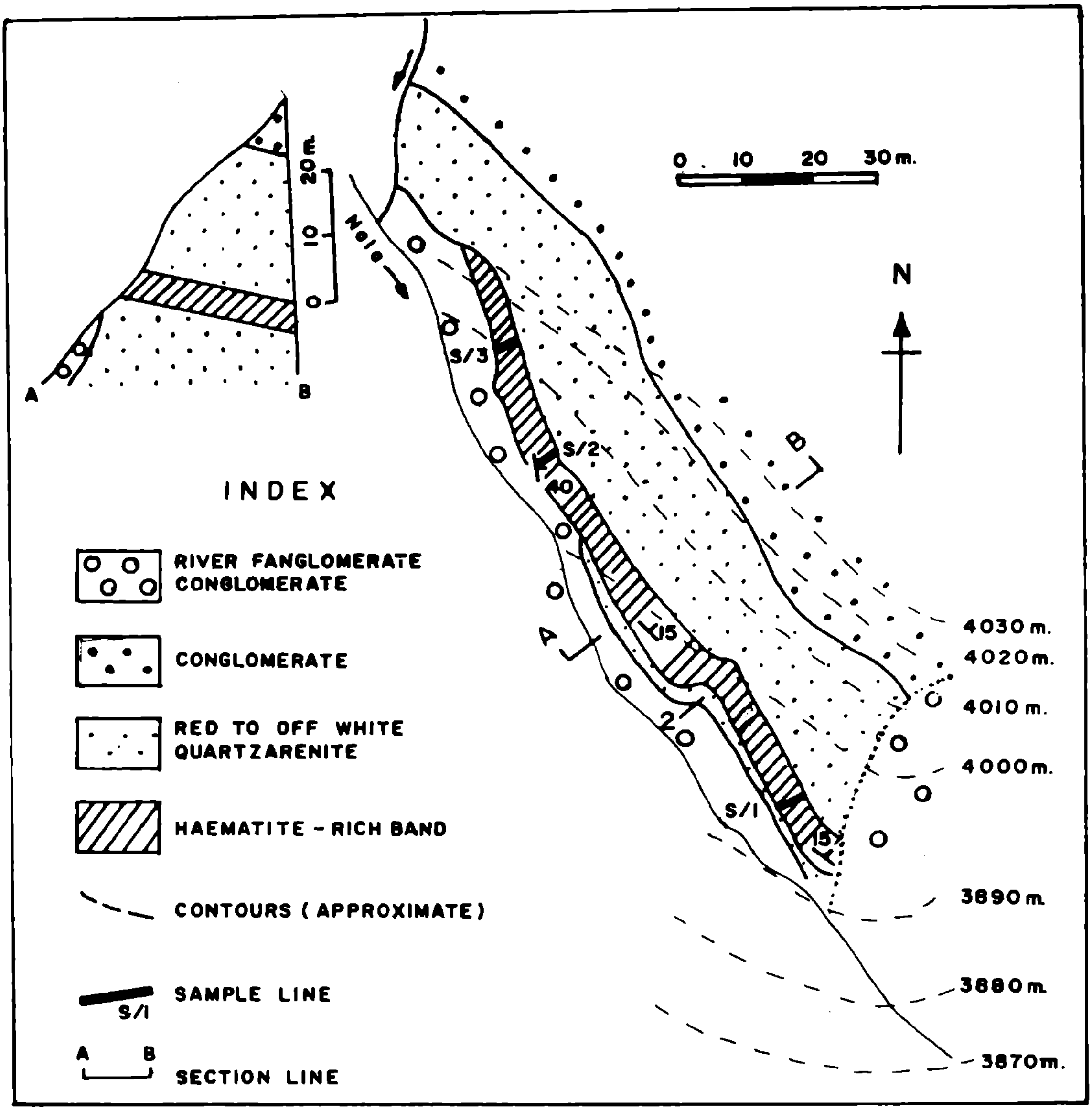


Fig. 8.1. Tape and compass map of the haematite rich band in the Thango Formation. Loc. Thango.

anomaly. However, the basal black slate horizon of the Batal Formation exposed near Ropa shows higher than background radiation counts but the anomaly is not high enough.

8.19 Silver

The quartz sulphide veins intrusive into the Wangtu rocks exposed 1.5 km east of Khetanang at Malti *Cho* are argentiferous. A sample analysed gave an Ag value of 10 ppm (Ameta and Swain, 1980).

8.20 Sulphide minerals (Base metals)

Malachite stained quartz veins are associated with the rocks of the Kunzam *La* Formation. Galena-sphalerite-quartz veins are observed close to the Rakcham Granite contact near Kombo. Many basic bodies, especially those in the Thango Formation, contain chalcopyrite specks. Rangbar (Ropa Valley) is probably the only place in Kinnaur where small scale excavation and smelting for copper has been carried out in the past. The Rangbar occurrence was examined by Gerard (1833), Hutton (1939), Iyengar (1949), Kathiara and Venugopal (1964), Sharma (1976) and Bassi and Chattopadhyaya (1984). Two small old workings are situated 7 km NW of Ropa; one at

Table 8.2

Results of Semi-Quantitative Spectrographic analysis of the Ferruginous Quartz-Arenite, Thango Formation

Samples collected by Bhargava *et al* (1984)

Sender's No.	Locality	Cr	Mo	V	Cd	Cu	Ag	Ni	Co	Sr	Ba	Sb	Ga	Ge	Bi	Y	Zr
Th/2	Thango	30	<10	<30	<300	<10	<10	50	<30	<100	200	<300	<10	<30	<100	<30	300
Th/2/1	Thango	50	<10	<30	<300	<10	<10	30	<30	<100	200	<300	20	<30	<100	<30	30
Th/7	Thango	30	<10	30	<300	10	<10	30	<30	<100	200	<300	<10	<30	<100	<30	100
LS/8	Takche	30	<10	<30	<300	<10	<10	50	<30	<100	20	<300	<10	<30	<100	<30	100
LS/9	Takche	30	<10	<30	<300	<10	<10	50	<30	<100	300	<300	<10	<30	<100	<30	100
LS/10	Shitikar	30	<10	<30	<300	<10	<10	100	<30	<100	200	<300	<10	<30	<100	<30	100
LS/11	Shitikar	50	<10	<30	<300	<10	<10	100	<30	<100	500	<300	<10	<30	<100	<30	30
LS/13	Shitikar	<30	<10	<30	<300	<10	<10	100	<30	<100	200	<300	<10	<30	<100	<30	30
SP/2/82	Dhuna Dangse	100	<10	<30	<300	<10	<10	200	<30	<100	300	<300	<10	<30	<100	<30	10
LS/68	-	30	<10	50	<300	<10	<10	50	<30	100	300	<300	<10	<30	<100	<30	30

Analysed at GSI, Faridabad by S/Shri J.K. Sachar, S.C. Gulati and R.K. Chopra

Samples collected by Bhandari & Sharma (1984)

Sender's No.	Locality	Cr	Mo	V	Cd	Cu	Ag	Ni	Co	Sr	Ba	Sb	Ga	Ge	Bi	Y	Zr
PK/21	Thango	200	<10	<30	<100	<50	<10	20	60	100	<10	<100	.10	<30	<100	50	300
PK/21A	Thango	200	<10	<30	<100	<50	<10	40	90	10	<10	<100	<10	<30	<100	30	300

Analysed at GSI, Faridabad by S/Shri V.S. Katiyar, S.N. Singh, V.K. Gupta, R.N. Aggarwal, B.K. Paul, R.K. Chopra and V.K. Kashyap

Samples collected by Bassi (1991)

Sender's	Locality	Cr	Mo	V	Cd	Cu	Ag	Ni	Co	Sr	Ba	Sb	Ga	Ge	Bi	Y	Zr	Mn	In	Zn	Fe	Au
1	Thango	200	50	50	10	12	5	<10	65	-	-	300	10	30	30	L	-	100	30	L	7.20%	0.04%
2	Thango	100	50	50	5	<10	5	<10	50	-	-	L	10	L	L	L	-	200	30	20	6.10%	0.60%
3	Thango	30	L	L	<5	10	<5	20	45	-	-	L	L	L	L	L	-	2000	10	L	1.40%	0.03%

Values for Pb, Sn, W, Nb, Mo, Be, Ta, Sc and La are below the normal detection limit.

Analysed at GSI, Chemical Laboratory, Faridabad, by S/Shri P.N. Razdan, K.S. Thakur, S. Bhan, Mrs. P. Tiwari , S/Shri R.K. Chopra, Moksha Ram, V. Srivastava and Dr. Renu Gupta.

3450 m and the other at 3750 m above m.s.l. Both the workings have followed a quartz-pyrite-chalcopyrite vein along a shear zone in the phyllite. These veins have a limited extent. The ore was smelted at Maneshar about a kilometre northwest of the old workings. Minor excavation here yielded the hearth earthen ware and matte. Detailed examination of the old workings rules out any commercial viability of the prospect.

Specks of arsenopyrite are observed in the carbonaceous shale of the Po Formation close to basic rocks in the Thibda *Nala*. The shale on analysis shows Cu-200 ppm, Pb-900 ppm, Ni-100 ppm, Co-50 ppm and As-500 ppm. Small lenticular pockets of galena occur in quartzarenite of the Po Formation about 1.5 km NW of Tabo along an escarpment.

8.21 Tin and Tungsten

In the Yangthang area, the limestone of the Lipak Formation has been extensively intruded by the tourmaline-bearing Nako Granite and associated/related pegmatite. It has thermally altered the limestone into calc-silicate rocks and marble. A grab sample from this rock yielded 3000 ppm of Sn. However, detailed investigation of pegmatite and marble, despite a favourable set-up, could not locate tin and tungsten mineralisation in the area (Bassi and Singh, 1987).

8.22 Wollastonite

Light greenish, bladed wollastonite is extensively developed in the metamorphosed limestone of the Lipak Formation near Yangthang on the NH-22. Its economic viability has yet to be assessed. Smaller occurrences of wollastonite exist in the Lingti Valley near Phiphuk.

9. GEOCHEMICAL EVENTS ACROSS THE PERMIAN-TRIASSIC BOUNDARY IN THE SPITI VALLEY

Extraordinary events of short duration and of global extent are often manifested in sediments in the form of rare earth/trace element anomalies, isotopic anomalies, shock minerals, microspherules, carbon soot, etc. Major stratigraphic boundaries across which mass mortality and mass extinction occurred are known to coincide with these geochemical events. This concept formed the basis of the I.G.C.P. Project-293 (Geochemical Events during Phanerozoic). As a follow-up in India, the Permo-Triassic sequence exposed in Lilang village was sampled to find if any geochemical anomaly existed at P/Tr boundary. A similar study was also carried out by Bhandari *et al*, (1992) in Spiti, who had collected samples at five centimetre interval across the P/Tr boundary. The P/Tr boundary traditionally is delineated along the Gungri-Mikin contact. However, Bhatt and Arora (1984) favour its delineation above the Otoceras bed, *i.e.* about 30cm above the base of the Mikin Formation.

In the Lalung section, a one centimetre thick ferruginous layer occurs above the Gungri Formation and below the Lilang Group (Fig.9.1). This ferruginous layer possibly marks a short hiatus during Dorashmian, the faunal elements of which are not known in Spiti.

In the present study samples, representing one centimetre stratigraphic width, were collected across the Gungri-Lilang succession with the help of a PVC chisel. These samples were powdered by agate ball mill for the analysis of the Rare Earth Elements at the Nuclear Activation Laboratory, Geological Survey of India, Pune.

9.1 Distribution pattern of Rare Earth Elements

32 samples were analysed for Ce, La, Sm, Eu, Yb, Tb and Lu (Table-9.1). All these REEs, particularly Eu, show a conspicuous positive anomaly confined to a one centimetre top black shale layer of the Gungri Formation, occurring immediately below the Fe-layer (Fig.9.1). The REE distribution pattern in the Gungri and Mikin Formations, *i.e.* across the P/Tr boundary, is summarised in Table-9.2.

From Table-9.2 and Fig. 9.1 it may be noticed that the REE in abundance pattern in the black shale of the Gungri Formation is abruptly disturbed by that of the top one centimetre layer. However, in one centimetre Fe-layer the REE re-acquire a trend similar to one found in the black shale occurring below the top one centimetre layer. The overall pattern of REE abundance in top one centimetre layer and that in the Mikin Formation are comparable (Fig.9.1). Similarly, overall pattern in the black shale below this and the Fe-layer are comparable. The changing patterns of REEs possibly suggest that event which occurred during the period represented by the sedimentation of top one centimetre black shale-layer caused an immediate but ephemeral impact on REE pattern. It, however, took quite some time to produce long lasting effect on normal sediments of the basin.

9.2 Implications of the REE anomalies

The positive anomaly of seven REEs in one centimetre zone represents a distinct geochemical event. The concentration of all the seven REEs in one centimetre layer points out to a single source.

Eu anomaly is known to be associated with volcanogenic sediments, sulphides and iron formations (for detailed references see Taylor and McLennan, 1985, Bhandari *et al*, 1992) and also in extra-terrestrial eucrites and lunar anorthosites (Consolomagno and Drake, 1977). No volcanogenic event of Permo-Triassic age is known in India. The Panjal Volcanics, being of early Permian age, are unlikely to have any influence on the constituents of this layer of late Permian age.

Is this concentration due to bolide impact or some indirect influence of extra-terrestrial phenomenon? If so, similar anomalies are likely to be of global extent. From only of one section of Spiti, it shall be premature to draw any definite conclusions regarding extra-terrestrial source as the cause of the REE anomalies.

The topmost one centimetre layer showing geochemical anomalies occurs just one centimetre below the traditional P/Tr boundary across which dramatic changes in faunal contents spread over 5 Ma (Teichert, 1990) are known not only in Spiti, but throughout the globe. The temptation is too high to conclude that whatever was the source of the REE anomalies, it was an important event and a causative factor to effect extinction of Palaeozoic faunal elements and cessation of

Table 9.1

REE distribution in sediments across Gungri Formation (Kuling Group) - Mikin Formation (Lilang Group) contact (P/Tr boundary), Lingti *nala*, Lalung Village. (Analysed at NAA Laboratory, GSI, Pune)

Sl. No.	Pune Lab. No.	Collector's Ref. No.	Description with locality	La	Ce	Sm	Eu	Tb	Yb	Lu	Th	Sc	Co	Cr	Hf	Ta
1.	322/92	L-1	Gungri (Kuling Gr.), Late Permian-Lingti *nala*, Lalung Village.	69.00	138.00	9.40	1.20	0.60	3.20	0.47	36.00	20.00	22.00	106.00	5.40	2.50
2.	323/92	L-2	–do–	47.00	104.00	6.40	0.90	0.20	2.20	0.35	18.00	13.00	13.00	83.00	4.00	1.40
3.	324/92	L-3	–do–	47.00	110.00	6.40	0.84	0.20	2.30	0.37	20.00	13.00	10.00	75.00	4.60	1.30
4.	325/92	L-4	–do–	49.00	113.00	7.50	0.82	0.36	2.70	0.47	24.00	16.00	18.00	117.00	5.40	1.60
5.	326/92	L-5	–do–	54.00	114.00	7.20	0.84	0.45	3.00	0.44	25.00	17.00	22.00	115.00	5.10	1.60
6.	327/92	L-6	–do–	55.00	123.00	7.80	0.90	0.30	1.60	0.57	29.00	19.00	20.00	126.00	5.80	0.58
7.	328/92	L-7	–do–	60.00	139.00	7.90	0.89	0.53	2.60	0.63	28.00	19.00	18.00	134.00	5.40	1.50
8.	329/92	L-8	–do–	45.00	83.00	5.20	0.77	0.20	3.00	0.48	26.00	20.00	27.00	136.00	5.70	1.80
9.	330/92	L-9	–do–	48.00	95.00	8.50	1.30	0.58	2.60	0.58	25.00	21.00	22.00	139.00	5.50	1.10
10.	331/92	L-10	–do–	120.0 0	328.00	54.5 0	16.0 0	8.80	9.90	1.50	13.00	16.00	69.00	63.00	3.00	0.72
11.	332/92	L-11	–do–	66.00	109.00	4.00	0.63	0.10	3.80	0.69	28.00	17.00	74.00	116.00	8.00	1.40
12.	333/92	L-12	Mikin (Lilang Gr.) Early Triassic-Lahaul & Spiti Dist.	24.00	67.00	9.60	2.30	0.77	2.00	0.39	3.77	6.20	1.90	16.00	0.91	0.25
13.	334/92	L-13	–do–	12.00	32.00	4.30	1.10	0.25	0.52	0.14	1.80	1.50	1.90	6.20	1.70	0.27
14.	335/92	L-14	–do–	6.40	18.00	2.20	0.60	0.18	0.45	0.10	1.50	1.00	1.10	6.00	0.25	0.50
15.	336/92	L-15	–do–	9.20	22.00	2.30	0.64	0.20	0.62	0.12	1.40	1.40	3.00	7.80	0.43	0.78
16.	337/92	L-16	–do–	6.90	13.00	1.50	0.36	0.18	0.60	0.15	1.30	1.20	1.00	9.00	0.36	0.54
17.	338/92	L-17	–do–	9.50	21.00	2.30	0.55	0.16	0.58	0.11	1.50	1.20	1.70	9.70	0.34	0.44
18	339/92	L-18	–do–	7.30	18.00	2.00	0.60	0.16	0.50	0.11	1.00	0.90	1.50	7.00	0.30	0.34
19.	340/92	L-19	–do–	8.60	14.00	2.40	0.55	0.16	0.60	0.15	1.00	0.60	0.55	5.40	0.33	0.24
20.	341/92	L-20	–do–	7.60	14.00	1.80	0.40	0.20	0.30	0.10	0.80	1.00	0.70	5.70	0.30	0.50
21.	342/92	L-21	–do–	8.70	12.00	2.00	0.37	0.16	0.43	0.12	1.00	1.00	1.10	8.30	0.35	0.15
22.	343/92	L-22	–do–	7.00	12.00	1.60	0.35	0.16	0.47	0.12	1.20	1.30	2.40	6.90	0.32	0.15
23.	344/92	L-23	–do–	7.00	13.00	1.80	0.30	0.16	0.47	0.10	1.40	1.30	1.00	3.60	0.30	0.24
24.	345/92	L-24	–do–	6.70	11.00	1.60	0.25	0.20	0.42	0.10	1.20	0.94	1.60	5.50	0.50	0.52
25.	346/92	L-25	–do–	4.40	12.00	1.00	0.20	0.32	0.55	0.06	1.00	0.90	0.91	7.40	0.40	0.55
26.	347/92	L-26	–do–	5.80	12.00	0.90	0.26	0.18	0.39	0.10	0.88	1.00	0.56	7.10	0.34	0.55
27.	348/92	L-27	–do–	13.00	26.00	3.00	0.53	0.28	0.73	0.10	2.00	1.80	1.50	12.00	0.50	0.88
28.	349/92	L-28	–do–	7.50	17.00	1.90	0.46	0.10	0.52	0.12	2.20	1.80	1.20	10.00	0.44	0.47
29.	350/92	L-29	–do–	8.40	21.00	2.10	0.36	0.27	1.10	0.17	2.30	2.60	1.90	9.00	0.45	0.97
30.	351/92	L-30	–do–	6.20	13.00	1.50	0.18	0.20	0.63	0.12	1.50	1.70	2.80	6.40	0.18	0.76
31.	352/92	L-31	–do–	5.00	10.00	0.92	0.22	[illegible]	0.35	0.10	1.40	2.00	0.52	5.00	0.33	0.72
32.	353/92	L-32	–do–	2.90	5.70	0.56	0.15	0.08	0.27	0.02	0.63	0.52	0.61	4.80	0.08	1.60

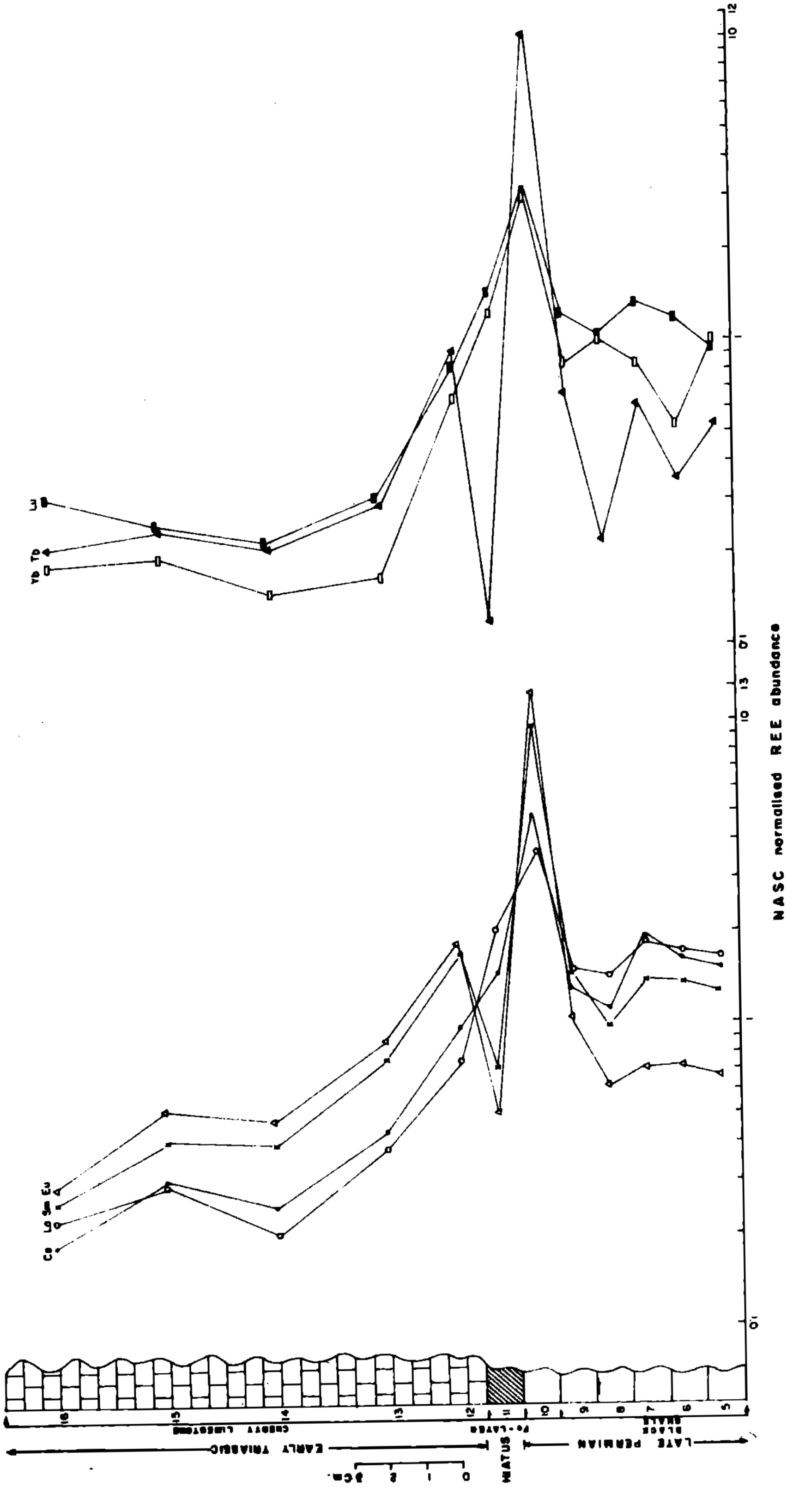

NASC normalised REE abundance
Ce La Sm Eu
Yb Tb Lu
EARLY TRIASSIC
LATE PERMIAN
HIATUS
CHERTY LIMESTONE
BLACK SHALE
Fe-LAYER
0 1 2 3cm.

Table 9.2
Summary of REE abundance across the P/Tr boundary

Attributes / Formation	Variation REE* (La+Ce+Sm+Eu+Tb+Yb+Cu) values	Variation of $(La/Lu)_n$ value	Overall pattern (Fig.9.1)
Mikin (bottom nine samples)	10 ppm-116 ppm (Average 19 ppm)	0.70-2 (Average 1.05)	Convex due to Eu anomaly. similar to Fe-layer
One centimetre Fe-layer above Gungri (One sample)	184 ppm	1.4	Concave due to -ive Tb anomaly
Topmost one centimetre black shale layer (One sample)	539 ppm	1.2	Convex -Eu anomaly +ive
Gungri (top nine samples)	137ppm-244ppm (Average 185ppm)	1.2-2 (Average 1.66)	Concave due to -ive Tb anomaly

* American shale composite is 116 ppm (Huskin *et al*, 1968)

sedimentation and to induce new Triassic elements. However, no model should be envisaged till the REE anomaly pattern is established over a wide region, at least of the Gondwanaland.

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Maneshar	31 49 30	78 24 00
Mangsu La	31 22 30	78 30 30
Manirang Pass	31 56 30	78 21 00
Mardang Nala	32 02 00	78 27 00
Mikin	32 02 30	78 03 30
Moppo Plain	32 02 30	78 56 00
Morang	31 35 45	78 26 30
Mud (Muth)	31 57 00	78 06 00
Na	31 57 00	78 37 00
Nako	31 52 30	78 38 00
Nakurche	31 14 15	78 54 15
Namgiya	31 48 15	78 39 30
Narkanda	31 15 00	77 28 00
Nessang	31 38 30	78 37 00
Nirth	31 22 12	77 34 00
Nulungpa	32 23 30	77 55 30
Nunuluka	32 06 30	78 08 00
Pamachen	31 55 00	78 23 00
Patseo	32 45 00	77 15 00
Phaldhar	32 26 00	77 55 00
Phiphuk	32 16 00	78 19 55
Pinglung	32 28 00	77 41 30
Poh	32 03 00	78 23 00
Pomarang	32 02 00	78 23 00
Pooh	31 46 00	78 35 00
Powari	31 33 00	78 17 00
Purbani	31 35 30	78 18 00
Rama	32 08 00	78 12 30

	o ' "	o ' "
Rampur	31 27 00	78 34 00
Rangbar	31 49 15	78 24 15
Rangchil	31 36 15	78 23 30
Rangrik (Rangring)	32 14 30	78 02 00
Rarang	31 36 00	78 21 15
Ratang	32 15 00	78 04 00
Raura Thach	31 36 15	78 09 30
Ribba	31 35 15	78 22 00
Rispa	31 34 45	78 26 15
Rohtang Pass	32 23 00	77 15 00
Ropa	31 48 00	78 26 00
Sachibang	32 18 30	78 11 50
Sakti	32 22 00	78 20 00
Salache	32 17 45	78 19 00
Sanglung	32 08 30	78 13 00
Sarchu	32 54 00	77 35 00
Schichling	32 03 30	78 13 00
Shalkar	32 00 00	78 37 00
Shiasu	31 43 00	78 30 30
Shipki	31 50 00	78 48 00
Shimla	31 07 00	77 11 00
Shitikhar	32 25 00	77 41 00
Shongtong	30 31 00	78 16 00
Skibba	31 35 30	78 22 15
Sonam (Soman)	32 01 30	78 17 30
Spilo	31 39 00	78 26 45
Sumdo	32 04 00	78 34 00
Sumna	31 53 00	78 13 45
Sumra	32 02 00	78 33 00
Sushin Thach	31 52 30	78 17 30
Syarma Nala	32 14 30	78 18 30
Tabo	32 05 00	78 27 00
Takal	31 01 00	78 36 30
Takche	32 27 00	77 41 30
Tanglangba	32 10 45	78 09 00
Tangmor	32 22 00	78 21 00
Tangpa Dok	31 36 00	78 48 00
Tapuk	31 37 30	78 48 00
Tariya	31 50 25	77 47 00
Tashigang	31 53 00	78 41 00
Telecon Pass	33 01 00	77 59 00
Telingkyu	31 40 00	78 28 00
Thangi	31 33 15	78 29 00
Thango	32 02 20	77 56 30
Thibda	32 03 45	78 27 00
Thopan	31 36 15	78 20 00
Tirung	31 34 30	78 27 00
Tso Morari	32 55 00	78 16 00

	° ' "	° ' "
Wangtu	31 32 40	78 00 00
Yangthang	31 51 00	78 37 00
Yangti	31 45 15	78 39 00
Yangtso	32 01 30	78 17 00
Yidsizi	32 03 45	78 32 00
Yulang Dogri	31 54 00	78 38 00

APPENDICES

DETAILS OF LITHOSTRATIGRAPHY AND SEDIMENTARY SEQUENCES

Details of stratigraphic section measurement are furnished in the Appendices I - XX. The top of each sedimentary cycle has been identified, e.g. cycle A. (IC) stands for incomplete cycle. These details have been some what generalised in the lithologs illustrated in the main text.

APPENDIX - I

REPRESENTATIVE LITHOLOG OF A PART OF THE BATAL FORMATION

e)	Fine sand, ripple bedding, low angled truncation.	3m
d)	Fine sand succeeded by shale at top.	5m
c)	Medium fine sand, fining-up cycle, ripple bedding.	6m
b)	Ripple bedded sand showing fining up.	6m
a)	Ripple bedded silty fine sand to fine sand, succeeded by finer silt and clay showing lenticular bedding and laminated clayey silt.	4m

APPENDIX - II

LITHOLOG OF THE KUNZAM *LA* FORMATION

Kunzam *La* Section

Thango Formation

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e)	Pinkish/maroonish silty shale, fine siltstone and fine grained sandstone. beds show cross-bedding and ripple lamination.	3m
d)	Dolomite bands silty at bottom and sandy towards top, showing algal column and mat and nodular bedding interbedded with shaly siltstone, fine sandstone and silty shale showing low angled cross-bedding in lenticular beds. These at point of pinching show thicker ripple unit less than one centimetre ripple layers mostly with mud drapes. Low angle cross-bedding, wavy bedding, festoon cross-bedding with local herringbone cross-bedding and mud cracks.	450m
c)	Matrix-poor sandy beds, showing large scale cross-bedding, ripple and lenticular bedding.	500m
b)	Graded rhythmites of limited lateral extent (50-100 cm), shaly sequences have thicker rhythms on dcm scale with lenticular and wavy bedding towards top. Sand packages with mud drapes show low angle truncation surfaces. Local flute and small scale ripple.	700m
a)	Siltstone, little shale and sporadic medium grained sandstone layers showing ripple bedding, lenticular bedding, low angled truncation, ripple marks, channel fills and sand over silty shale sequence. The channel sand and also underlying units show syn-depositional deformation and load casts. Rich in trilobite trace fossils.	1000m

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Batal Formation

Parahio Section

Thango Formation

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d)	Green-pink-white, cross-bedded quartzarenite-shale siltstone, mudcracks, ripple marks.	470m
c)	Siltstone-shale-dolomite sequence, local graded bedding between siltstone and shale of limited lateral extent, low angle truncation	

surfaces, local flute casts, high as well as low angle cross-bedding. The siltstone and shale show thin rhythmite, with sand lenses. Encloses *Ptychoparia spitiensis*, *Oryctocephalus* sp., *Opsidiscus* sp, *Lingulella* sp, *Argaulus* sp, below three metre thick dolomite bed occurring towards basal part. (Bhargava *et al*, 1982). *Hyolithes*, *Ptychoparia* sp, *Liostracina* sp, and *Emenerichelle* sp, in shale in between two dolomite beds developed in middle part and trilobite fragments in the two metre dolomite in upper part. 185m

b) Grey green micaceous siltstone-quartzwacke and claystone graded rhythmite of limited lateral extent ending in ripple bedding and low angle lamination. Sand packages, low angle truncation surfaces. Convolute bedding low angle ripple bedding, cone in cone structure. 60m

a) Siltstone, shale and fine grained sandstone, showing lenticular, ripple bedding, low angle truncation. Sand as channel fill showing syn-depositional deformation, load cast. Trace fossil ? *Astropolithon*, *Diplichnites*, *Planolites*, *Monomorphichnus*, *trilobite trackways*, *Dimorphichnus*, *Gyrochorte*, (Bhargava *et al*, 1982). 370m

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Batal Formation

APPENDIX - III

LITHOLOG OF THE THANGO FORMATION

Pin Section

Takche Formation

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g) Purple sandstone, cross-bedded, mudcracks, cuspate and oscillation ripple marks, often flat-topped. 43m

f) Cross-bedded sandstone with shale partings and trace fossils. 35m

e) Ferruginous sandstone, mudcracks and burrows in upper part, cross-bedding and ripple marks in basal part 145m

d). Fine to medium grained sandstone and interbedded shale with ripple cross-bedding in basal part and herringbone cross-bedding in upper 70m. 107m

c) Sandstone with mud cracks. 12m

b) Cross-bedded sandstone, herringbone cross-bedding and tidal bundle structures. Cross-bedded sandstone with shale (10-15%), local pebble beds, ripple marks, cross-bedding and local load cast. *Planolites* and *Rouaultia* in shale. Cross-bedded (30cm thick) sandstone local fine shale partings, low angle cross and planar beddings. 280m

a) Conglomerate with haematitic material, quartzarenite clasts are from Kunzam *La* as well red sandstone akin to that of Thango's. 50m

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Kunzam *La* Formation

Takche Section

Takche Formation

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j) Ferruginous fine grained medium bedded (20-40cm) sandstone. Ripple bedding, rare festoon bedding, bioturbation. 19.5m

i) Medium to thick bedded sandstone,thin bedded laminations, locally coarse. 180m

h) Mega cross-bedded, medium grained sandstone with cross laminations, mud

	cracks, rounded crest, bifurcating ripples.	12.5m
g)	Thick bedded fine to medium grained sandstone with shale beds (20%).	45m
f)	Massive thinly bedded, cross-bedded sandstone with shale partings.	12.5m
e)	Ferruginous medium to thick bedded sandstone. Planar and cross-bedding.	65m
d)	Thick cross-bedded sandstone.	66m
c)	Cross-bedded sandstone with shale pebbles.	17m
b)	Cross-bedded sandstone, siltstone-shale, low angle (10°-15°) cross-bedding, high angle, planar, rare cross-bedding, festoon bedding.	50m
a)	Cross-bedded medium to coarse sandstone with haematitic bands in basal part, trough cross-bedding, rare low angle cross-bedding, planar ripple layers with mud drapes and large cross-beds with tidal bundles.	170m

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Kunzam *La* Formation

APPENDIX - IV

LITHOLOG OF THE TAKCHE FORMATION

Takche Section

Muth Formation

		Cycle H
d')	Predominantly fine ripple bedded sandy dolomite to calcareous sandstone, a few centimetres thick bioturbated siltstone, wave ripples common.	2.5m
c')	Silty bioturbated siltstone with a few centimetres thick arenaceous dolomite.	2m
b')	Fine grained carbonate with thin bioturbated silty bands showing ripple bedding, parallel lamination with low angle discordance.	1.5m
		Cycle G
a')	Silty to fine grained bioturbated sandstone with 0.5 to 5 cm fine calcareous sandstone.	16m
z)	Bioturbated siltstone interlayered with centimetre thick rippled fine calcareous sand. The sand content increases towards top.	13.5m
y)	Shell rich coarse grained dolomitic limestone.	1.5m
x)	Calcareous, silty bioturbated siltstone with a few millimetre to eight centimetre thick calcareous sandstone. Sand content maximum in middle part.	14m
w)	Fossiliferous calcareous sandstone, interbedded with a few centimetre thick bioturbated siltstone.	9m
v)	Bioturbated siltstone, a few centimetre to four centimetre thick fossil-rich calcareous sandstone in basal one metre. ?*Psilophyton* and large crinoid ossicle.	7m
u)	Calcareous fossil rich sandstone showing low angle cross-bedding.	3m
t)	Decimetre-thick calcareous sandstone and bioturbated siltstone alternations with one centimetre thick sandstone intercalations.	9m
s)	Richly fossiliferous calcareous sandstone showing low angle cross-bedding. One metre above base large scale syn-depositional deformation structures.	4m
r)	Bioturbated siltstone with decimetre to centimetre thick calcareous horizon rich in fossils. Between three to four metres from top, horizon rich in corals; between six to seven metres from bottom, hummocky cross-bedding.	7m
		Cycle F
q)	Predominantly low-angled, cross-bedded, fossiliferous, calcareous sandstone showing ripple bedding and hummocky cross-stratification.	7m
p)	Bioturbated silty sandstone with several centimetre thick fine sandstone.	5m
o)	Bioturbated siltstone with millimetre thick fine silty sand.	9m

n)	Hummocky, cross-bedded, fine sandstone with thin bioturbated siltstone.	2m
		Cycle E
m)	Bioturbated silty sandstone with centimetre thick rippled sandy layers.	2m
l)	Bioturbated siltstone and a few centimetre thick parallel laminated, rippled sandy layers; top 1.5m shows several decimetre thick fine sandstone with hummocky cross-stratification and low angle discordance.	10m
		Cycle D
k)	Fossiliferous calcareous sandstone with millimetre to one centimetre thick silty intercalations increasing towards top.	10m
j)	Interlayered 30cm-1m thick fossiliferous calcareous sandstone and bioturbated silty clay.	11m
		Cycle C
i)	Fine grained sandstone showing hummocky cross-stratification and low angle discordance.	5.5m
h)	Bioturbated silty fine sand alternating with centimetre to 10 cm thick calcareous sandstone showing parallel lamination with low angle discordance.	22m
		Cycle B
g)	Fossiliferous calcareous sandstone.	2.2m
f)	Fine grained sandstone with bioturbated silty sandstone. Thicker units show hummocky cross-stratification.	12.8m
		Cycle A
e)	Brachiopod rich rippled, bedded and low angle cross-bedded sandstone containing fossil debris.	1.2m
d)	Fine grained sandstone showing low angle cross-bedding and hummocky cross-stratification.	1.8m
c)	Bioturbated fine grained sandy siltstone.	1m
b)	Alternation of medium to fine grained sandstone and calcareous medium grained sandstone, having individual unit of one to three metres. Non-calcareous sandstone show low angle cross-bedding, hummocky cross-stratification in calcareous variety, trough cross-bedding, ripple bed and thin silty clay intercalations common. Fossil debris at 5.30m above base.	15m
a)	Calcareous, medium grained sandstone showing festoon type cross-bedding. Bioturbated clayey siltstone with a few cm to 10cm thick fine sand horizon.	5m

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Thango Formation

Parahio River Section (Gechang)

Muth Formation

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o)	Thinly bedded dolomitic limestone with corals and stromatoporoids at 20m and 25m above base.	49.5m
		Cycle G
n)	Nodular dolomitic limestone	2.8m
m)	Ripple marked fossiliferous dolomitic limestone with wavy and ripple beddings.	1 0.6m
		Cycle F
l)	Shale with limestone.	9.6m

k)	Medium to thick bedded earthy, nodular dolomitic limestone with current and wavy bedding and shale partings in the basal part.	13.2m
		Cycle E (IC)
j)	Shale with limestone, occasional cross and wavy beddings.	24.7m
		Cycle D
i)	Shale with ripple marks and cuspate current bedding.	1.6m
h)	Thin to medium bedded marl.	14.2m
		Cycle C
g)	Interbedded shale and dolomitic limestone (fossiliferous).	27.5m
f)	Cross-bedded marly limestone with shale partings, trace fossils at eight metres from base.	18.4m
		Cycle B
e)	Cross-bedded sandstone with interference ripples and load cast; shale, siltstone.	3.8m
d)	Shale with marl.	0.8m
		Cycle A
c)	Thinly bedded calcareous sandstone; burrowed in upper part.	1.35m
b)	Greenish sandstone.	1.1m
a)	Crinoidal bioturbated mudstone.	3.2m

Thango Formation

Pin Valley Section (between Mud and Shian)

Muth Formation

		Cycle B
k)	Cross-bedded sandstone.	2.8m
j)	Calcareous sandstone with shale, bioturbated.	14.8m
i)	Dolomitic limestone.	10m
h)	Thin bedded limestone with syn-depositional slumps.	15.3m
g)	Nodular limestone (stromatoporoid) with shale partings.	46.9m
		Cycle A
f)	Cross-bedded calcarenite with shell fragments, syn-depositional slumps.	6.8m
e)	Coquina limestone.	0.2m
d)	Nodular (stromatoporoid, corals) limestone.	14.3m
c)	Bedded limestone.	6.3m
b)	Limestone, marl, calcareous shale with burrows.	32.6m
a)	Limestone (70%) with brown shale alternations.	16.5m

Thango Formation

Chuktyanjan Thach Section

Gechang Formation

		Cycle C
e)	Grey Sandstone.	4m
d)	Arenaceous limestone.	0.5m

		Cycle B
c)	Fossiliferous herringbone cross-bedded sandstone with lensoidal limestone.	16m
b)	Coquina limestone.	15m
		Cycle A
a)	Calcareous sandstone with shale band.	5m

Thango Formation

Ghunsa Larsa *Thach* Section (220m N of Chuktyanjan-Larsa Section)

Gechang Formation

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a)	Fossiliferous sandstone.	5m

Thango Formation

Gurgur Sumdo Section

Gechang Formation

		Cycle C
e)	Calcareous sandstone.	13m
d)	Limestone.	1.5m
		Cycle B
c)	Calcareous sandstone.	20.5m
b)	Fossiliferous limestone.	17.5m
		Cycle A
a)	Grey calcareous sandstone	2.5m

Thango Formation

Lankapanug Section

Muth Formation

		Cycle C
e)	Grey calcareous sandstone.	25m
d)	Earthy brown limestone with calcareous shale, rich in coral.	40m
		Cycle B
c)	Brown argillaceous sandstone.	5m
b)	Nodular limestone with coral.	10m
		Cycle A
a)	Brown sandstone with brachiopods.	60m

Thango Formation

Leo Section

Muth Formation

		Cycle B
e)	Cross-bedded grey to brownish weathered calcareous sandstone,	

occasional brachiopods. 50m

d) Brownish, calcareous sandstone, rich in corals and brachiopods. 20m

c) Thick-bedded to massive dolomitic limestone with *Halysites, Favosites*, other corals, sponge, stromatoporoids, rare brachiopods. 50m

b) Argillaceous limestone to marl, with nodular coral colonies. 30m

a) Cross-bedded calcareous sandstone with fossils. 50m

Thango Formation

Manchap Section (Tidong Valley)

Muth Formation

Cycle C

d) Brownish calcareous sandstone, arenaceous limestone with *Halysites*, brachiopod shells and ? *Psilophyton*. 40m

c) Bluish grey to grey dolomite, dolomitic limestone with large number of tabulate and rugose corals. 40m

Cycle B

b) Grey argillaceous marly limestone, minor interbedded shale. It encloses inverted basket-shaped *Favosites* colonies and crinoid remains. 70m

Cycle A

a) Brownish calcareous to ferruginous cross-bedded sandstone enclosing casts of orthids and pentamerids. 100m

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Thango Formation

APPENDIX - V

LITHOLOG OF THE MUTH FORMATION

Takche Section

Lipak Formation

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p^2) Calcareous ferruginous sandstone, interlayered with parallel laminated sandstone. 3m

o^2) Sub-parallel laminated sandstone with low angle cross laminations, calcareous, ferruginous, 10-30cm thick sandstone with low angle cross-laminations. 7m

n^2) Sub-parallel laminated 5-10cm thick low angle cross-bedded unit. 3.1,

m^2) Low angle cross-bedded units. 1.1m

l^2) Sub-parallel laminated sandstone with low angle truncation surfaces. 2m

k^2) 0.3 to 1.5m thick low angled cross-bedded sandstone interlayered with sub-parallel laminated (20-50cm) unit with truncation surfaces. 10m

j^2) Sub-parallel laminated (5-10cm) sandstone interlayered with a few low angled cross-beds. 7m

i^2) 0.3 to 1 metre thick low angled cross-beds with 5-10cm thick sub-parallel laminated beds; 1.5m towards top, the cross-bed units are 5-15cm thick and occur sub-horizontally over discordant surfaces representing channel fills. 8.5m

h^2) 10-20cm thick sub-parallel laminated layer with equally thick and in equal proportion of low angle, cross-bedded sandstone with prominent truncation surfaces. 9m

g^2)	Sub-horizontal, laminated sandstone with a few 10-15 cm thick low angled cross-beds and truncation surfaces (5°-7°).	5m
f^2)	0.5-1.5m thick sub-parallel, laminated sandstone alternating with thin low angled cross-beds with prominent discordant surfaces (10°-15°).	13.5m
e^2)	10-30 cm thick sub-parallel laminated sandstone, alternating with 10-20 cm thick low angle cross-beds.	13m
d^2)	0.3 to one metre thick irregular cross-bedded sandstone with an erosional base.	7m
c^2)	Sub-parallel laminated sandstone.	5m
b^2)	0.5 to 1.5m thick low angled cross-bedded sandstone, interlayered with equally thick units of sub-parallel, laminated sandstone. Discordant layers very prominent (maximum angle 20°).	8m
a^2)	Sub-parallel laminated sandstone with low angle discordance surfaces.	5m
z)	20-50 cm thick low angle cross-beds (low trough) interlayered with 0.3 to one metre thick low angle sub-parallel laminated units.	4.5m
y)	10-20 cm thick sub-parallel, laminated unit, interlayered with low angle cross-beds of equal tl ickness.	5m
x)	Low angle cross-beds with sub-parallel laminated units.	2m
w)	10-20 cm thick sub-parallel laminated beds, interlayered with low angle cross-beds of equal thickness.	5m
v)	20-30 cm thick low angled cross-bed with 5-10 cm sub-parallel laminations.	3.3m
u)	Sub-parallel lamination with low angle cross-bedding.	1.7m
t)	Low angle cross-bedded unit.	0.03m
s)	Sub-parallel laminated unit with a few 10-20 cm thick cross-beds.	2.4m
r)	Low angle cross-bedded unit.	0.7m
q)	Sub-parallel laminated unit.	2.7m
p)	Low angle cross-bedded unit.	0.7m
o)	Sub-parallel laminated unit.	0.8m
n)	Cross-bedded unit with moderate dip of the foreset.	0.6m
m)	Sub-parallel laminated unit.	0.7m
l)	Low angle cross-bedded unit with erosional base.	0.5m
k)	5-10 cm thick sub-parallel laminated unit with a few low angle cross-beds and discordances (3°-7°).	2m
j)	Low trough cross-beds.	1m
i)	10-40 cm low angle cross-beds (low trough), interlayered with 5-30 cm thick sub-parallel laminated unit with 10°-15° dip of discordant surfaces.	5m
h)	Predominantly 5-15 cm thick, sub-parallel laminations with a few 5-10 cm thick low angle cross-beds. Discordance surfaces mostly dip at 5° to 10°	4m
g)	10-30 cm thick low angle cross-beds, interbedded with 5-10 cm thick sub-parallel laminations. Discordance surfaces dip at 15°-20°	4m
f)	5-10 cm thick sub-parallel lamination with irregular erosional base.	2m
e)	5-10 cm thick units of sub-parallel lamination showing discordance surfaces upto 10° and low trough cross-beds with 10°-15° dip of the foreset in upper three metres and feeble discordance and rippled surface in lower four metres. Irregular erosional surface at base.	7m
d)	10-20 cm thick low angle cross-beds, interbedded with a few centimetre thick units of sub-parallel lamination, with low amplitude ripples. Rare low amplitude trough cross-beds and low angle discordance surfaces.	5.5m
c)	10-30 cm thick cross-beds alternating with 5-10 cm thick predominantly sub-parallel laminated unit with low angle truncation. Local low amplitude ripple laminations.	12m
b)	10-30 cm thick, low festoon cross-beds with bi- to polymodal palaeocurrent directions.	13m

a)	Trough cross-bedding and low angle cross-beds with discordance surface.	3m

———————— Contact erosional ? ————————

Takche Formation

Mud (Muth) Section
Lipak Formation

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g)	Ripple-marked (a few round crested) quartzarenite.	14.7m
f)	White, thin to medium bedded sandstone, oscillatory, wave and current ripples; mud cracks with ferruginous filling.	14.3m
e)	Thick and cross-bedded medium grained sandstone with burrows (cross-bed 30 cm thick).	21m
d)	Brownish, fine grained, thick bedded sandstone with green sandstone pebbles and thin dolomitic sandstone beds.	2.4m
c)	Cross-bedded sandstone with thin to medium horizontal lamination/bedding. At places friable and leached.	61m
b)	Cross-bedded (cross-bed 25 cm thick) fine to medium grained sandstone.	26m
a)	Medium grained ripple marked sandstone enclosing torrential cross-bedding in the middle part.	107m

———————— Contact erosional ? ————————

Takche Formation

Hango-Tumtum Thanga Section

Lipak Formation

---

e)	Snow-white sandstone.	8m
d)	Dirty brown, calcareous sandstone with bands of white sandstone.	6m
c)	Snow-white sandstone.	8m
b)	Haematite-rich zone with burrows.	2m
a)	White quartzarenite with trace fossils	60m

———————— Contact erosional ? ————————

Takche Formation

Khimokul *La* Section (Tidong Valley)

Gechang Formation

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e)	Snow-white sandstone.	15m
d)	Brownish, ferruginous sandstone.	15m
c)	Snow-white sandstone with brachiopods.	40m
b)	Grey, micaceous sandstone.	5m
a)	Snow-white sandstone.	45m

———————— Contact erosional ? ————————

Takche Formation

APPENDIX - VI

LITHOLOG OF THE LIPAK FORMATION

Takche Section

Top not exposed

Cycle G

p^3)	Quartzose sandstone.	1.5m
o^3)	Siltstone with fine grained sandstone interbeds.	0.3m
n^3)	Fine grained, partly silty limestone with sporadic algal mat. Top part has recrystallised fossils.	5.5m
m^3)	Micrite with clay interbeds.	1.5m
l^3)	Sparitic limestone (Oolitic).	2m
k^3)	Massive limestone.	2m
j^3)	Alternation of 70 cm-2.5 m thick micrite with fine algal laminations with fine silt and clay (1.5 m thick) bands.	7.7m
i^3)	Poorly laminated grey limestone.	2m
f^3)	Silty carbonate.	lm
e^3)	Partly silty, finely laminated with discordant surfaces, micrite with small channels.	3.8m
d3)	30-50 cm thick carbonate alternating with bioturbated silty and fine sandy beds showing poorly developed, low angle cross-bedding and rippled horizons.	12.5m
		Cycle F
c^3)	Alternating sequence finely laminated calcareous siltstone (low angle cross-bedded and bioturbated) clay and silty carbonate.	6.2m
b^3)	N.X.	13.5m
a^3)	Silty carbonate, calcareous siltstone and a few fossiliferous carbonate bands.	1.5m
z^2)	Alternation of silty micrite and calcareous siltstone.	4.5m
y^2)	Limestone with hard ground.	1.4m
x^2)	Calcareous shale.	1.7m
w^2)	Crinoidal limestone with hard ground.	0.4m
v^2)	Crinoid, coral and gastropod bearing limestone with hard ground, density increasing towards top.	1.4m
u^2)	Vuggy micrite.	0.35m
t^2)	Silty carbonate.	1.6m
s^2)	Carbonate with hard ground and bird's eye structures.	0.1m
r^2)	Silty carbonate.	1.4m
q^2)	Coral-brachiopod limestone with hard ground in upper part.	0.3m
p^2)	Calcareous shale and limestone.	2m
o^2)	Limestone with coral and fossil debris and intense hard ground at top.	0.3m
n^2)	Calcareous shale, silty carbonate and rippled and bioturbated calcarenite.	0.4m
m^2)	Calcareous shale.	0.3m
l^2)	Limestone rich in coral and brachiopods with incipient hard ground.	0.15m
k^2)	Calcareous shale.	0.2m
j^2)	Well laminated limestone with low angle truncations.	0.1m
i^2)	Calcareous shale.	0.75m
h^2)	Well laminated carbonate with low angle discordance 7 cm wide burrows at base.	0.1m
g^2)	Coral-rich shelly limestone with prominent hard ground.	0.6m
f^2)	Argillaceous limestone and calcareous shale.	1.5m
e^2)	Coral (not in-growth position) limestone with 25 cm top rich in fossils.	1.15m
d^2)	Well laminated, low angle cross-laminated, graded bioclastic limestone.	0.6m
c^2)	Argillaceous limestone, top 15 cm shell hash.	0.5m
b^2)	Argillaceous limestone with several levels of hard ground, top 30 cm very rich in large shells.	0.9m
a^2)	Shelly limestone, top 20 cm full of fossils.	1.5m
z)	Laminated shell hash and whole fossils clayey carbonate.	1.65m

y)	Micrite with silty clay intercalation in basal part.	5m
		Cycle E
x)	Bioturbated siltstone with fine sand intercalations.	8m
w)	Quartz sandstone with low angle cross-bedding.	0.5m
v)	Bioturbated siltstone.	0.04m
u)	Cross-bedded fine to medium grained sandstone.	1.5m
t)	Matrix-rich sandstone, calcareous sandstone with thin interbeds of bioturbated siltstone.	9m
		Cycle D
s)	Silty sandstone with intercalations of quartzarenite.	3m
r)	Cross-bedded quartzarenite.	3m
q)	Bioturbated siltstone with sandstone intercalations.	3m
p)	Mainly siltstone and micrite with cross-bedded sandstone in basal and upper part.	6m
o)	Clean fine grained sandstone with low angle cross-bedding in lower part and 0.5-1m thick rippled layer in upper part.	3m
n)	Fine grained sandstone intercalated with bioturbated siltstone/and micrite.	11m
		Cycle C
m)	Bioturbated siltstone with 5-15 cm thick fine sandstone with shell impression; sandstone shows parallel lamination with low angle discordance and ripple layers.	8.3m
l)	Fine grained sandstone with poorly preserved low angle cross-bedding.	3m
k)	Ripple bedded sandstone, a few silty clay and micrite interbeds.	3.2m
j)	Bioturbated siltstone.	2.5m
i)	Micrite	5m
		Cycle B
h)	Bioturbated siltstone.	3m
g)	Poorly cross-bedded sandstone.	2m
f)	Bioturbated siltstone (Poor exposure)	13m
		Cycle A
e)	Cross-bedded sandstone.	2m
d)	Sandy micrite, calcareous sandstone with centimetre thick ripple bedding.	2m
c)	Calcareous, fine sandstone with a few millimetre thick rippled layers and low angle discordances.	16m
b)	Calcareous, fine grained sandstone with low angled discordances, ripple bedding and rare scouring surfaces.	19m
a)	Micrite	0.2m

Muth Formation

Pinglung Section

Top not exposed

		Cycle H
f²)	Ferruginous dolomite.	10m
e²)	Thick bedded, bluish grey limestone with lenses of pink limestone.	22m
d²)	Thinly bedded, fossiliferous, bluish grey limestone.	15m
c²)	Arenaceous limestone.	7m
b²)	Massive pink dolomite.	5m
		Cycle G

a^2)	Fossiliferous grey, limestone with cross-bedded sandstone alternations.	12m
z)	Pink to bluish grey, platy limestone.	6m
		Cycle F
y)	Thinly bedded calcareous sandstone.	12m
x)	Fossiliferous limestone.	50m
		Cycle E
w)	Cross-bedded sandstone.	5m
v)	Light grey to bluish grey limestone.	38m
u)	Fossiliferous crinoidal limestone.	10.5m
t)	Pinkish limestone with one metre micrite band at 14m above base.	23.5m
s)	Bluish grey limestone.	13m
		Cycle D
r)	White, locally calcareous, limonitised sandstone.	24m
q)	Limestone, dolomite with shale partings.	44m
		Cycle C
p)	Sandstone-siltstone.	91m
o)	Massive pink limestone.	11m
n)	Bluish dolomite-limestone, calcareous sandstone.	24m
m)	Massive pink limestone.	17m
l)	Limestone dolomite.	29m
		Cycle B
k)	Limonite-coated, ripple marked sandstone and limestone.	11m
j)	Bluish grey dolomite, calc-shale.	37m
i)	Alternating pink and grey dolomite, arenaceous in basal 12m.	30m
h)	N.X.	22m
g)	Thinly bedded limestone with brachiopods.	8m
f)	Pink massive limestone.	4m
e)	Buff grey dolomite.	10m
		Cycle A
d)	Purple sandstone with trace fossils.	4m
c)	Sandstone, shale.	20m
b)	Grey dolomite.	19m
a)	Thinly bedded pink limestone.	30m

Muth Formation

Mud Section

Gungri Formation

		Cycle D (IC)
i)	Grey medium to fine grained, thinly bedded to cross-laminated limestone.	59m
		Cycle C
h)	Argillaceous, medium grained, grey limestone, locally cherty.	47.5m
g)	Coquina limestone, cross-bedded in basal part.	36m
f)	Limestone with syn-depositional deformational structures, fine to thin bedded marl, sharpstone conglomerate as channel-fill. Sandy bioclastic limestone with shell hash.	23m
		Cycle B

e)	N.X. (in Lateral extension limestone, shale, sandstone)	23m
d)	Brownish, fossiliferous limestone.	2.3m
		Cycle A (IC)
c)	Medium bedded sandstone and limestone with herringbone cross-bedding.	0.6m
b)	Sandstone.	3.2m
a)	Calcarenite with bird's eye structure.	1.2m

Muth Formation

Lipak *Gad* Section

Po Formation

		Cycle C (IC)
g)	Yellow and buff dark, flaggy hard and splintery limestone.	164m
f)	Grey shale and limestone alternations.	122m
		Cycle B
e)	White quartzarenite.	8m
d)	Compact, dark crinoidal limestone.	61m
		Cycle A
c)	White and grey sandstone, purple slate, minor flaggy limestone.	73m
b)	Limestone, weathering to yellowish and reddish brown colour.	43m
a)	Hard, dark grey and splintery coralline limestone.	118m

Muth Formation

APPENDIX - VII

LITHOLOG OF THE PO FORMATION

Pinglung Section

Ganmachidam Formation

		Cycle C
c)	Sandstone, local shale, pebbly in upper part.	80m
		Cycle B
b)	Shale, local sandstone, siltstone beds.	50m
		Cycle A
a)	Sandstone, shale, siltstone.	350m

Base not seen

Ganmachidam Hill Section (in part)

Ganmachidam Formation

		Cycle B
c)	Sandstone, local shale pebble in upper part.	50m
b)	Shale, siltstone, sandstone.	100m
		Cycle A
a)	Sandstone, shale	250m

——————— Base not seen ———————

Poh Section (in part)

Ganmachidam Formation

		Cycle H
q)	Medium-bedded, ferruginous sandstone with rare pebbles.	60m
p)	Shale with fine siltstone beds.	4m
		Cycle G
o)	Ferruginous sandstone.	24m n)
	Shale with fine siltstone beds.	5m
		Cycle F
m)	Sandstone.	19m
l)	Shale with fine siltstone beds.	22m
		Cycle E
k)	Medium-bedded sandstone.	23m
j)	Shale with fine siltstone beds.	30m
		Cycle D
i)	Medium-bedded ripple marked sandstone, bioturbated at base and top.	28m
h)	Carbonaceous shale.	1m
		Cycle C
g)	Sandstone.	8m
f)	Dolerite sill.	3m
e)	Bioturbated sandstone.	7m
d)	Thinly laminated shale, sporadic nodules.	110m
		Cycle B (IC)
c)	Ferruginous, medium-bedded sandstone.	11m
b)	Thinly laminated shale.	53m
		Cycle A
a)	Medium-bedded ferruginous sandstone.	16m

——————— Basal part not exposed ———————

Mardang *Nala* Section

Ganmachidam Formation

		Cycle B
e)	Light grey sandstone, minor shale (carbonaceous towards top); arenites are sporadically gritty.	160m
d)	Black shale with nodules commonly enclosing fossils, grey sandstone interbeds (upto two metres thick).	50m
		Cycle A
c)	Grey sandstone, minor shale.	20m
b)	Black shale, *Fenestella* bearing 20m below the sandstone; thin siltstone/sandstone bands.	50m
a)	Splintery shale; basal part contain plant remains including *Parasaggilaria* sp.	300m

——————— Base not seen ———————

APPENDIX - VIII

LITHOLOG OF THE GANMACHIDAM FORMATION

Ganmachidam Section

Gechang Formation

		Cycle H
p)	White to off white, fine grained cross-bedded sandstone, with granule, small pebble. Graded bedding along the cross-beds.	7.7m
		Cycle G
o)	Grey, earthy, brownish, gritty, sandstone, sporadic pebble.	12m
n)	Gritty sandstone.	3m
		Cycle F
m)	Conglomerate.	0.2m
l)	Siliceous, thick bedded, off-white sandstone.	4.7m
		Cycle E
k)	Gritty, earthy, grey coarse sandstone with granules.	12m
j)	Fine grained, off-white, siliceous sandstone with torrential, herringbone, parallel and ripple bedding.	9.5m
		Cycle D
i)	Grey, earthy brown, gritty sandstone with granules and small pebbles.	18m
h)	Dark brown, cherty sandstone.	6.8m
		Cycle C (IC)
g)	Light grey, thinly bedded grit, commonly conglomeratic.	10.2m
		Cycle B
f)	Coarse grained, grey grit with pebbles and granules along the bedding.	13m
e)	Siliceous, off-white, gritty sandstone, locally conglomeratic.	23m
d)	Dark grey, gritty sandstone, commonly conglomeratic.	5.2m
		Cycle A
c)	Gritty conglomerate.	2.5m
b)	Gritty sandstone, local conglomerate lenses.	25.5m
a)	Gritty, highly siliceous, thickly bedded sandstone and siltstone.	8m

Po Formation

Lingti-Schichling Section

Gechang Formation

		Cycle D
i)	Medium bedded, gritty conglomerate.	15m
h)	Shale.	6m
		Cycle C
g)	Conglomerate.	6m
f)	Shale with local pebble.	6m
		Cycle B
e)	Thickly bedded conglomerate.	22m
d)	Gritty shale.	10m

		Cycle A
c)	Gritty sandstone with conglomerate.	154m
b)	Shale.	5m
a)	Finely laminated gritty shale.	30m

Po Formation

APPENDIX - IX

LITHOLOG OF THE GECHANG FORMATION

Poh Section

Gungri Formation

		Cycle B
d)	Sandy, ferruginous sandstone with brachiopods.	11.2m
c)	Calcareous, medium-bedded, fine to gritty sandstone with shells, granules and pebbles.	25.1m
		Cycle A
b)	Grey, medium grained to gritty sandstone with mud cracks.	0.8m
a)	Off-white, fine grained, cross-bedded sandstone with small pebbles.	7.7m

Ganmachidam Formation

Guling Section

Gungri Formation

		Cycle A
c)	Compact, cross-bedded sandstone with spiriferids; lamellibranchs. Upper surface highly bioturbated.	5m
b)	Off-white, felspathic, ferruginous, medium to coarse grained, thin to medium bedded sandstone with a 20cm thick pebble bed one metre above base.	4.6m
a)	Ferruginous gritty to pebbly cross-bedded conglomerate.	0.3m

Lipak Formation

Ghunsa Larsa (Ghunsarang *Nala*) Section

Gungri Formation

		Cycle A
b)	Brownish coarse grained, bioturbated sandstone, calcareous at base, contains brachiopods.	1.5m
a)	Highly micaceous sandstone with *Skolithos*.	1.4m

Takche Formation

Ghunsarang Pass Section

Gungri Formation

		Cycle E (IC)
j)	Purplish, micaceous sandstone with brachiopods.	0.85m
		Cycle D
i)	Brownish, calcareous, medium grained sandstone.	0.95m
h)	Grey, micaceous sandstone.	1.15m
		Cycle C
g)	Medium grained sandstone with burrows.	1.2m
f)	Grey sandstone.	2m
e)	Micaceous grey sandstone with sandstone balls, brachiopods and *Chondrites*.	1.2m
d)	Brown micaceous sandstone with *Laevicyclus*.	0.75m
		Cycle B
c)	Medium grained sandstone with brachiopods.	0.45m
b)	Brown splintery shale.	0.2m
		Cycle A (IC)
a)	Grey sandstone.	1.15m

Takche Formation

Chuktyanjan *Thach* Section

Gungri Formation

		Cycle B (IC)
c)	Brownish, leached micaceous sandstone with *Skolithos* and brachiopods. Plant remains at base.	9.3m
		Cycle A
b)	Brown, coarse gritty sandstone with shell fragments.	2.8m
a)	Light green, micaceous sandstone.	3.2m

Takche Formation

Sumna Section (Ropa Valley)

Gungri Formation

		Cycle B
c)	Grey, micaceous sandstone with brachiopod and plant remains.	2.2m
		Cycle A
b)	Grey sandstone, rare shells and *Zoophycos*.	8.2m
a)	Brown calcareous sandstone.	0.8m

Takche Formation

Sirbo-*Chu* (Kidul) Section

Gungri Formation

		Cycle B
c)	Medium bedded, bioturbated cross-bedded sandstone.	13m
b)	Bioturbated shale.	10m

		Cycle A (IC)
a)	Medium bedded, bioturbated sandstone.	18m

Ganmachidam Formation

Khar Section (Pin-Parahio confluence)

Gungri Formation

		Cycle C
f)	Bioturbated, medium bedded sandstone.	5m
e)	Bioturbated, medium grained cross-bedded sandstone.	10m
		Cycle B
d)	Medium bedded sandstone.	5m
c)	Thick bedded, bioturbated, trace fossil enclosing cross-bedded sandstone.	9m
		Cycle A
b)	Cross-bedded sandstone.	2m
a)	Conglomerate.	50cm

Lipak Formation

Poh Section (Hill behind P.W.D. R.H.)

Gungri Formation

		Cycle C
h)	Gritty sandstone.	3m
g)	Cross-bedded sandstone with *Zoophycos.*	19m
f)	Shale.	8m
		Cycle B
e)	Coarse to medium grained, cross-bedded sandstone.	6m
d)	Grey shale.	8m
		Cycle A
c)	Cross-bedded, calcareous sandstone with *Eurydesma.*	8m
b)	Cross-bedded, calcareous sandstone.	1.5m
a)	Cross-bedded sandstone.	26m

Ganmachidam Formation

APPENDIX - X

LITHOLOG OF THE GUNGRI FORMATION

Poh Section

Mikin Formation

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c)	Black/dark grey shale with trace fossil in siltstone bed. *Zoophycos* between 22m and 28m from base.	50m
b)	Dark grey shale with pebbles.	2m
a)	Dark grey shale.	3m

Gechang Formation

Lalung Section

Mikin Formation

		Cycle B
e)	Thinly bedded to splintery dark grey shale with thin siltstone beds.	6m
d)	Medium to thinly bedded shale with millimetre fine silty layers.	16m
c)	Shale with nodules and burrows.	4.5m
		Cycle A
b)	Thinly to finely bedded shale with *Zoophycos*, rare fine siltstone bed.	5m
a)	Finely laminated shale.	5.5m

Gechang Formation

Sumna (Ropa Valley) Section

Mikin Formation

		Cycle C
h)	Grey, clayey splintery shale with rare fossils.	11.5m
		Cycle B
g)	Siltstone with fine sandstone lens.	0.3m
f)	Grey shale with nodule.	0.2m
		Cycle A
e)	Lenticular (5m x 0.3m) leached siltstone, profusely burrowed.	0.3m
d)	Grey micaceous shale with spiriferids.	5.5m
c)	Brownish calcareous shale with nodule and shell fragments.	1m
b)	Brownish shale with *Lamnimargus himalayensis*.	0.5m
a)	Black pyritous, calcareous shale with nodules, spiriferids and productids.	6m

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Gechang Formation

Chuktyanjan *Thach* Section (Left bank of Ropa Nala)

Mikin Formation

		Cycle C (IC)
g)	Black shale with nodules and brachiopods.	23m
f)	Shale rich in fossils.	0.4m
e)	Shale with nodules.	0.15m
		Cycle B
d)	Brownish leached sandstone and siltstone.	0.3m
c)	Black shale with brachiopods and nodules.	16.2m
b)	Micaceous shale full of *Lamnimargus himalayensis*.	0.4m
		Cycle A
a)	Grey shale with spiriferids.	8m

Gechang Formation

Ghunsarang *Nala* Section

Mikin Formation

		Cycle E
m)	Black pyritous shale.	12.6m
		Cycle D
l)	Brownish, weathered, hard sandstone with brachiopods shell hash.	0.3m
k)	Black shale with *Lamnimargus himalayensis*.	4.25m
		Cycle C
j)	Brownish, weathered hard sandstone with brachiopod shell hash.	0.5m
i)	Black shale with nodules.	7m
h)	Black shale with cephalopod (pyrite replaced *Cyclolobus*), bryozoa in nodules.	1m
g)	Black shale with nodules (5%) thin lenses of siltstone with brachiopods at two levels, profusely crinoidal.	14m
		Cycle B
f)	Brownish, argillaceous sandstone with calcitised brachiopod.	2.8m
e)	Shale rich in *Lamnimargus himalayensis*.	0.4m
d)	Pyritous, black micaceous shale with nodules.	3.2m
c)	Micaceous shale.	0.9m
		Cycle A
b)	Medium grained, micaceous sandstone.	0.4m
a)	Highly micaceous shale with brachiopod.	1.3m

Gechang Formation

Ghunsarang Pass Section

Mikin Formation

		Cycle B (IC)
f)	Black, splintery shale with nodules.	1.8m
		Cycle A
e)	Brownish micaceous sandstone, dark brown shale with spiriferids.	0.95m
d)	Chocolate coloured shale.	0.24m
c)	Shale with *Lamnimargus himalayensis*.	0.1m
b)	Black shale with nodules and brachiopods	0.3m
a)	Grey-black shale with nodules and rare fossils.	1.2m

Gechang Formation

Jongchen Section

Mikin Formation

Dark grey shale with *Cyclolobus* sp. 1.5m below the top.	5m

Erosional surface

Muth Formation

APPENDIX - XI

LITHOLOG OF THE MIKIN FORMATION

Lalung Section

Kaga Formation

		Cycle C (IC)
h)	Concretionery limestone with minor shale partings, especially in upper part.	6.1m
		Cycle B
g)	Dark grey shale and limestone.	1.8m
f)	Nodular dolomitic limestone.	18.2m
e)	Argillaceous limestone.	0.9m
		Cycle A
d)	Dolomitic limestone with minor shale partings.	3m
c)	Thinly bedded limestone with shale partings.	3m
b)	Grey limestone	0.3m
a)	Brownish dolomitic limestone.	0.6m

Gungri Formation

APPENDIX - XII

LITHOLOG OF THE KAGA FORMATION

Lalung Section

Chomule Formation

		Cycle F (IC)
k)	Calcareous grey-green shale.	5m
		Cycle E
j)	Limestone.	3m
i)	Shale.	25m
		Cycle D
h)	Argillaceous, fine grained limestone.	12m
g)	Shale.	25m
		Cycle C
f)	Argillaceous, fine grained limestone.	3m
e)	Shale.	2.5m
		Cycle B
d)	Argillaceous, fine grained limestone.	2m
c)	Shale.	2m
		Cycle A
b)	Limestone.	0.5m
a)	Shale.	2m

Mikin Formation

APPENDIX - XIII

LITHOLOG OF THE CHOMULE FORMATION

Lalung Section

Sanglung Formation

		Cycle E
i)	Fine grained limestone, locally argillaceous.	2.5m
h)	Cherty limestone/dolomite.	15m
		Cycle D
g)	Argillaceous limestone/dolomite.	28m
f)	Cherty, fine grained dolomite.	22m
		Cycle C (IC)
e)	Argillaceous limestone.	9.5m
		Cycle B
d)	Shale.	2.5m
c)	Fine grained dolomitic limestone.	20m
		Cycle A
b)	Argillaceous fine grained dolomitic limestone.	17.5m
a)	Fine grained dolomitic limestone.	6m

Kaga Formation

APPENDIX -XIV

LITHOLOG OF THE SANGLUNG FORMATION

Lalung Section

Member A

Member B

		Cycle L (IC)
b^2)	Grey shale.	9m
a^2)	Limestone.	2.5m
		Cycle K
z)	Shale.	7m
y)	Cherty limestone.	1m
		Cycle J
x)	Shale with silty shale and siltstone in upper part.	16m
		Cycle I
w)	Siltstone.	4m
v)	Argillaceous, fine grained limestone.	2m
u)	Cherty shale.	1m
		Cycle H
t)	Shale with thin siltstone beds	6m
s)	Cherty shale with siltstone interbeds.	21m
r)	Shale.	5m

		Cycle G
q)	Siltstone.	2m
p)	Shale.	20m
o)	Cherty shale.	0.5m
n)	Shale.	2.5m
m)	Argillaceous limestone.	3m
		Cycle F
l)	Shale.	3m
k)	Argillaceous, fine grained dolomite/limestone.	12m
		Cycle E
j)	Shale.	10m
i)	Argillaceous fine grained limestone.	5.5m
h)	Fine grained limestone/dolomite.	12.5m
		Cycle D
g)	Argillaceous dolomite.	8m
f)	Dolomitic limestone.	6m
e)	Argillaceous fine grained dolomite.	5m
		Cycle C
d)	Shale with silty shale and siltstone in upper part.	19m
		Cycle B
c)	Siltstone.	5m
b)	Dolomite.	2.5m
		Cycle A (IC)
a)	Siltstone with shale partings in basal part.	7m

Chomule Formation

Member B

Member C

		Cycle G (IC)
n)	Limestone/dolomite.	22.5m
		Cycle F
m)	Sandstone.	2m
l)	Limestone.	1.5m
		Cycle E
k)	Sandstone with herringbone cross-bedding.	9m
j)	Argillaceous dolomite.	5.5m
		Cycle D
i)	Shale.	9m
h)	Argillaceous limestone/dolomite.	10m
g)	Dolomitic limestone.	16m
		Cycle C
f)	Shale, siltstone.	13m
e)	Argillaceous dolomite/limestone.	19m
		Cycle B
d)	Shale, siltstone.	12.50m

c)	Argillaceous limestone.	40m
		Cycle A
b)	Shale.	13m
a)	Cherty dolomitic limestone.	73m

Member A

Atargoo-Guling and Lalung Sections (pieced together)

Member C

Hangrang Formation

		Cycle Q
o^2)	Thinly bedded siltstone with *Rhizocorallium*.	10m
n^2)	Limestone.	1.5m
		Cycle P
m^2)	Rippled and low angle cross-bedded sandstone.	10m
l^2)	Shale.	9m
		Cycle O
k^2)	Shale, siltstone.	7m
j^2)	Argillaceous dolomite.	4m
i^2)	Limestone/dolomite.	3.5m
		Cycle N
h^2)	Sandstone.	3.5m
g^2)	Shale.	1.5m
f^2)	Thinly bedded limestone.	8m
		Cycle M
^{2})	Shale.	3m
d^2)	Argillaceous limestone/dolomite.	30m
c^2)	Limestone.	3m
		Cycle L
b^2)	Shale.	4m
a^2)	Argillaceous limestone.	1m
		Cycle K
z)	Shale.	11m
y)	Siltstone.	3m
x)	Cherty limestone.	6m
		Cycle J
w)	Shale.	30m
v)	Limestone.	1m
		Cycle I
u)	Shale.	2m
t)	Limestone.	1.5m
		Cycle H
s)	Shale.	7m
r)	Cherty limestone.	2m
		Cycle G
q)	Shale.	2m

p)	Dolomitic limestone.	6m
o)	Cherty limestone.	7.5m
n)	Dolomitic limestone.	9m
m)	Cherty limestone.	6.5m
		Cycle F
l)	Shale and siltstone.	13m
k)	Limestone.	1m
		Cycle E
j)	Shale.	3.5m
i)	Limestone.	1m
		Cycle D
h)	Shale.	3m
g)	Limestone with pebbles.	2m
		Cycle C
f)	Shale, limestone intercalations.	7m
e)	Limestone/dolomite.	17m
		Cycle B
d)	Siltstone.	7.5m
c)	Shale.	35m
b)	Limestone	0.5m
		Cycle A (IC)
a)	Shale, thin siltstone beds.	30m

Member B

APPENDIX - XV

LITHOLOG OF THE HANGRANG FORMATION

Hangrang Section A

Alaror Formation

		Cycle C
j)	Solitary corals, crinoid stem, rhynochonellids, fossil debris zone, fenestral fabric (10% organism).	2m
i)	Oncolites, solitary corals, algal bedding, bioclastic debris in upper part, fenestral part filled with ferruginous matter (10% organisms).	8m
		Cycle B
h)	Stromatoporoid, tabulozoan, solitary corals (15% organisms).	0.75m
g)	Solitary corals, *Thecosmilia* colonies mud-filled corals, oolites (15% organism).	2m
f)	Oncolites, oolites, solitary corals *Rhynchonella*, bioturbation, bird's eye/fenestral structures filled with ferruginous matter, two sets of calcite veins (10-15% organism).	2.5m
		Cycle A
e)	Solitary corals with *Thecosmilia* colonies, crinoid stems (30% organisms).	0.5m
d)	*Thecosmilia* (5cm tall, 1cm diameter) colonies (*in situ* position). Stromatoporoid, giant thecosmilid (3.5cm diameter), *Colospongia*,	

	tabulozoa, open spaces, filled by oolites, gastropods, oysters (80% organism).	0.5m
c)	Oolites, stromatoporoid, solitary corals *in situ*, also broken, rare branching corals and algal bedding, massive to crudely bedded, bedding defined by algae or brown shell fragments (10% organism)	1.25m
b)	Cortoidal, ooidal, crinoidal bioturbated dolomite. Burrows filled with ferruginous matter.	0.1m
a)	Dark grey oolitic dolomite.	3m

Sanglung Formation

Hangrang Section B (29m south of A)

Alaror Formation

		Cycle B
f)	*Thecosmilia, Thamnaestrea,* giant solitary corals, grainstone in open space.	1m
e)	Small nodular colonies (3cm x 1cm), lenticular zone with *Thecosmilia* (2m x 0.4m).	1m
d)	Solitary corals zone.	4m
		Cycle A
c)	Exclusively bushy *Thecosmilia* colonies (*Thecosmilia* 1cm wide, 9cm high).	2.5m
b)	Crinoidal, oolitic grey limestone.	2m
a)	Cross-bedded (defined by shell layers) shell hash. A few shells show geopetal fabric.	8m

---

Sanglung Formation

Hangrang Section C (25m south of B)

Alaror Formation

——— Fault ———

		Cycle B
f)	Upper most layer shows fragmented *Thecosmilia* colonies in near prostrate position. *Thecosmilia* in in-growth position, coarse to medium grained cross-bedded dolostone.	2m
e)	Dark grey mudstone with 10-15cm layering, shells aligned parallel to the bedding, reworked solitary corals.	2m
		Cycle A
d)	*Thecosmilia*, broken shells, fenestral cavities.	3.5m
c)	Rare corals, fine to medium grained rock, shells, crinoids.	2.5m
b)	Arenaceous greyish to brownish limestone.	4m
a)	Zones of cavities filled with ferruginous limesand.	15m

Sanglung Formation

Hangrang Section D (400m west of the Hangrang Pass)

Alaror Formation

		Cycle B (IC)
d)	Bioclastic recrystallised grainstone/packstone. Solution cavities filled mostly by argillaceous material; solitary corals.	6m
c)	Light pink-grey wackestone/mudstone, rare organic debris.	3m

		Cycle A
b)	*Thecosmilia* colonies, *Rhynchonella*, micrite in open space.	2.5m
a)	Sponge parallel to the bedding large size solitary corals, *Colospongia* and bryozoa	4m

Sanglung Formation

APPENDIX - XVI

LITHOLOG OF THE ALAROR FORMATION

Attargoo-Guling road Section

Nunuluka Formation

		Cycle E
j)	Cross-bedded limestone, shale, sporadic nodules.	12m
		Cycle D
i)	Sandstone.	1m
h)	Argillaceous limestone/dolomite.	26m
		Cycle C
g)	Shale with nodules.	17m
f)	Thick bedded argillaceous dolomite/limestone.	20m
		Cycle B
e)	Shale, medium bedded argillaceous limestone.	32m
d)	Thinly bedded limestone with shale.	77m
		Cycle A (IC)
c)	Shale with nodules.	33m
b)	Cherty shale.	30m
a)	Shale.	30m

Hangrang Formation

APPENDIX - XVII

LITHOLOG OF THE NUNULUKA FORMATION

Attargoo-Guling road Section

Kioto Formation

		Cycle C
i)	Limestone and shale.	26m
h)	Argillaceous limestone showing wavy bedding.	15m
		Cycle B
g)	Shale.	5m
f)	Dolomitic limestone.	2m
e)	Argillaceous limestone.	40m
d)	Limestone with wavy ripple marks.	2m
c)	Argillaceous limestone.	23m
		Cycle A
b)	Sandstone with herringbone cross-bedding.	7m

a)	Sandstone, large scale cross-bedding in basal five metres.	35m

Alaror Formation

APPENDIX - XVIII

LITHOLOG OF A PART OF THE KIOTO FORMATION

Ullah Section

		Cycle D (IC)
h)	Ooidal, pelletoidal, bioclastic cross-bedded dolomite.	1m
		Cycle C
g)	Massive limestone.	2.5m
f)	Cross-bedded dolomitic limestone with wavy ripple bedding.	2m
		Cycle B
e)	Massive dolomitic limestone.	1.5m
d)	Cross-bedded dolomite with uneven lower contact (Channel fill).	0.6m
		Cycle A
c)	Grey limestone.	1.5m
b)	Pelletal limestone.	0.1m
a)	Argillaceous ooidal bioclastic limestone.	1.5m

Nunuluka Formation

Rangring Section

Top not exposed

		Cycle C
i)	Well bedded dolomite.	0.05m
h)	Dolomite showing imbricated sand oolite grains.	0.04m
g)	Dolomite with sub-parallel bedding and low-truncation surfaces.	0.02m
		Cycle B
f)	Ooidal grainstone/packstone.	1.5m
e)	Sharpstone conglomerate.	0.01m
d)	Ooidal gritty dolomite.	0.25m
c)	Ooidal dolomitic limestone.	0.1m
		Cycle A
b)	Dolomitic limestone (2cm as Channel fill).	0.04m
a)	Cross-bedded dolomite with brecciated base.	0.04m

Bottom not exposed.

APPENDIX - XIX

LITHOLOG OF THE GIUMAL FORMATION

Chichim Peak, Section

Chikkim Formation

		Cycle D
m)	Limonitic, glauconitic, fine to medium grey sandstone with gritty bands.	14m

l)	Limonitic brownish medium grained sandstone.	23.8m
k)	Limonitised glauconitic sandstone.	11.9m
j)	Gritty sandstone with a few pebbles.	1m
		Cycle C
i)	Laminated ash grey silty shale.	53m
h)	Glauconitic sandstone.	29m
g)	Non-glauconitic sandstone.	53.5m
		Cycle B
f)	Laminated silty shale/siltstone.	12m
e)	Carbonaceous leached silty shale interbedded with calcareous shale.	12.9m
d)	Silty sandstone with about 20% calcareous shale.	12.1m
c)	Fine grained sandstone.	14.5m
b)	Sandstone interbedded with fossiliferous calcareous silty shale and glauconitic sandstone.	7.6m
		Cycle A (IC)
a)	Fine grained calcareous sandstone.	2.5m

Spiti Formation

APPENDIX - XX

LITHOLOG OF THE LIMESTONE MEMBER (CHIKKIM FORMATION)

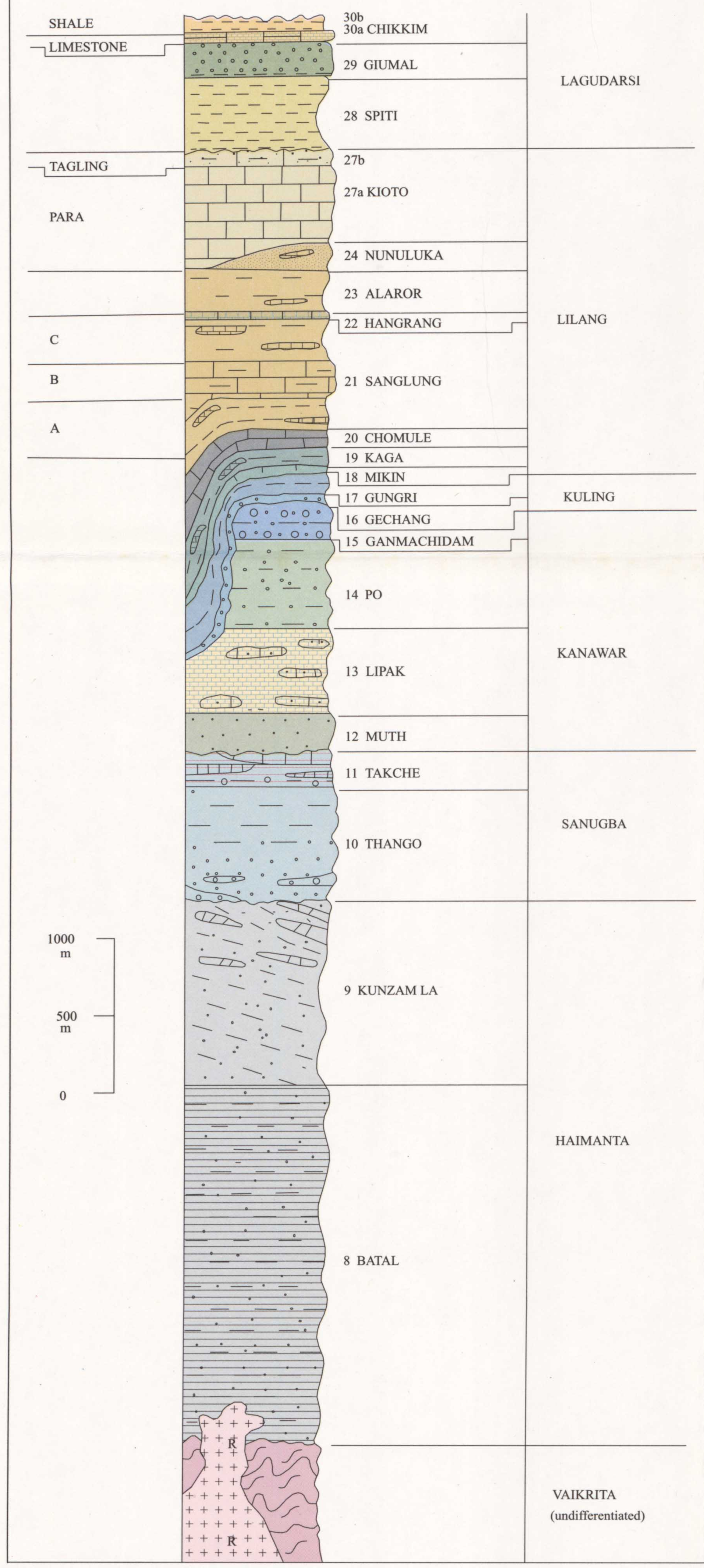
Chichim Peak Section

Shale Member

		Cycle C
i)	Limestone, marly limestone.	4.8m
		Cycle B
h)	Shale.	0.25m
g)	Limestone, marly limestone.	0.75m
		Cycle A
f)	Shale.	12.2m
e)	Argillaceous limestone with shale bands.	3.55m
d)	Off-white dolomite.	4.5m
c)	Thickly bedded, bluish grey dolomite.	10.2m
b)	Light pink dolomitic limestone.	14.25m
a)	Sandy fossiliferous limestone.	3m

Giumal Formation

LITHOLOG OF THE TETHYAN SEQUENCE, SPITI-KINNAUR



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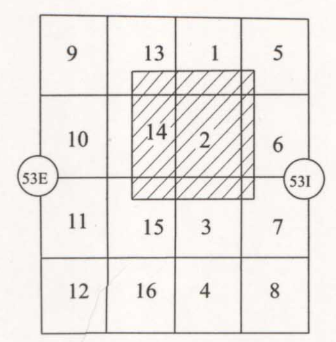
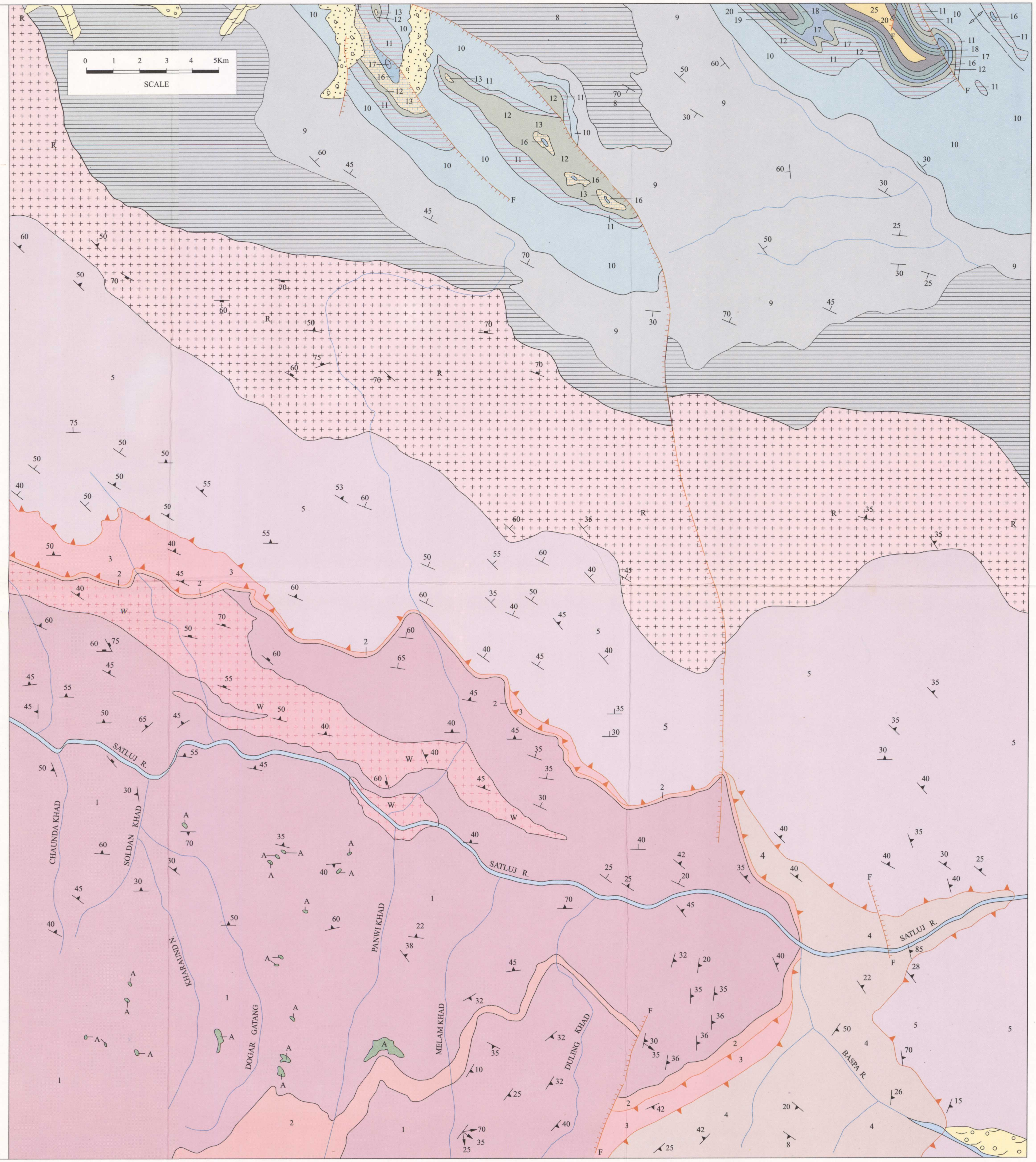
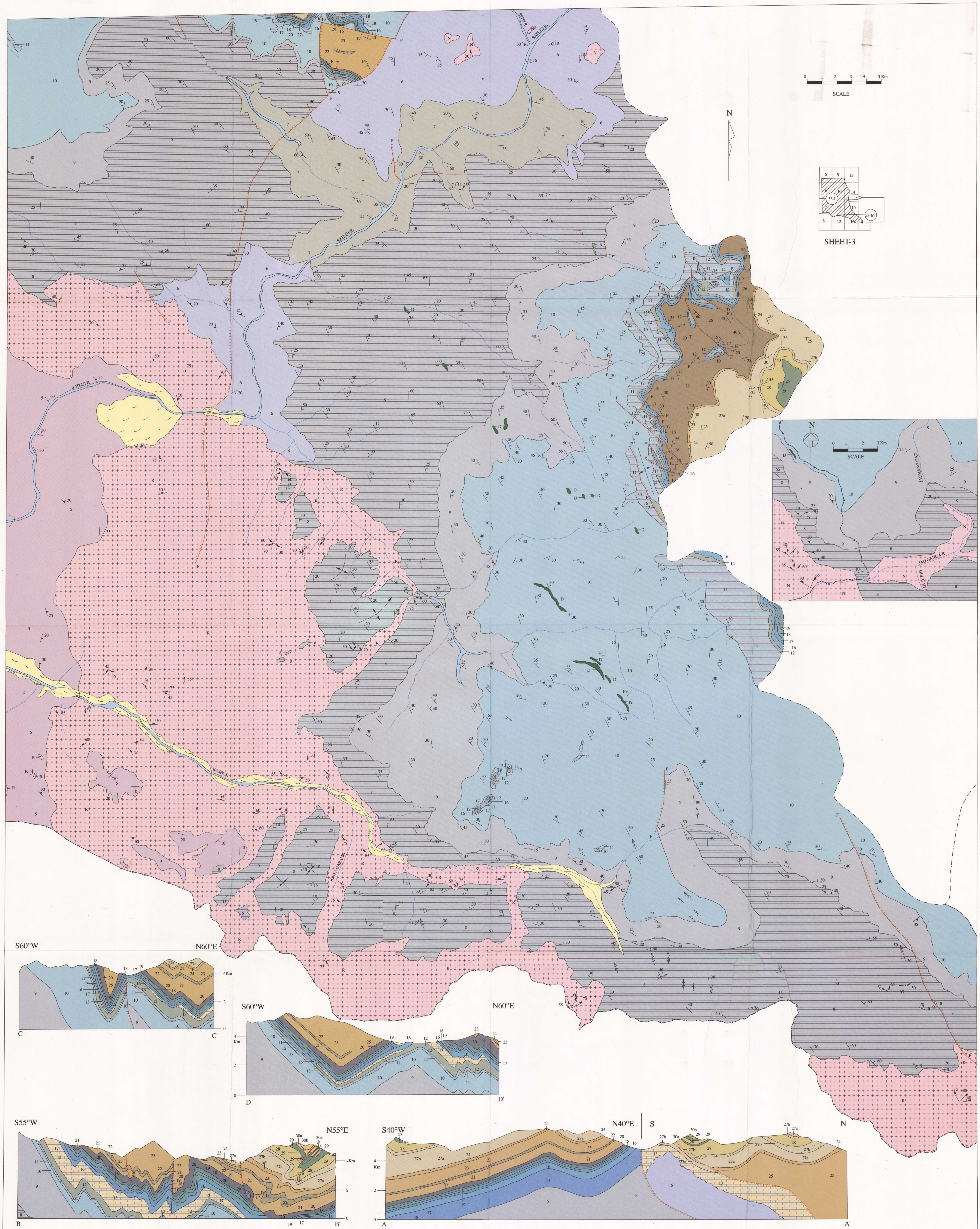


SHEET-4

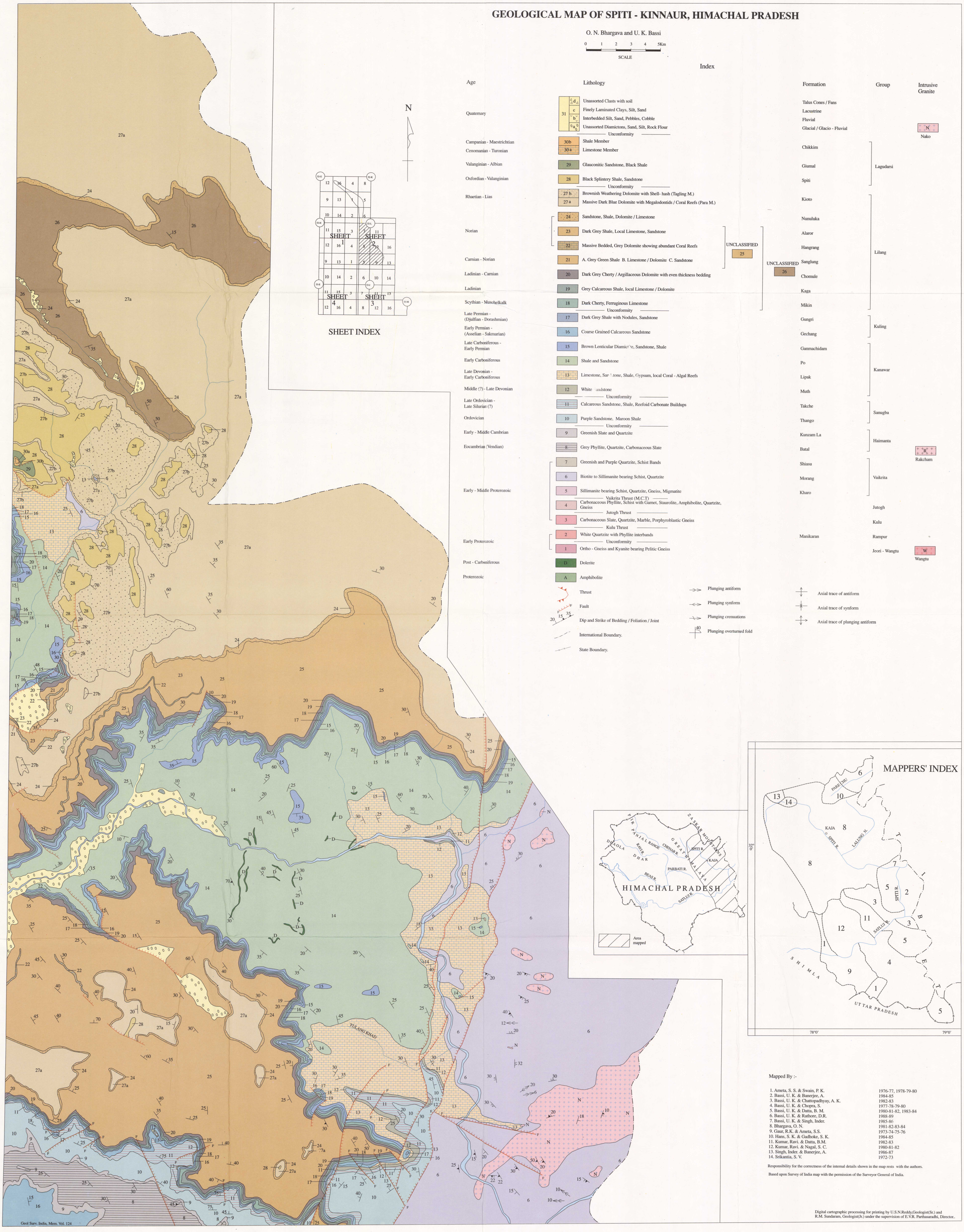
LEGEND

- CARBONATE
- DIAMICTITE
- SANDSTONE,SILTSTONE
- SHALE
- CRYSTALLINES
- GRANITE





SCHEMATIC SECTIONS ALONG A-A', B-B', C-C', D-D' LINES (SHEET 1)



GEOLOGICAL MAP OF SPITI - KINNAUR, HIMACHAL PRADESH
O. N. Bhargava and U. K. Bassi
0 1 2 3 4 5Km
SCALE
Index
Age
Lithology
Formation
Group
Intrusive Granite
Quaternary
31
Unassorted Clasts with soil
Finely Laminated Clays, Silt, Sand
Interbedded Silt, Sand, Pebbles, Cobble
Unassorted Diamictons, Sand, Silt, Rock Flour
Talus Cones / Fans
Lacustrine
Fluvial
Glacial / Glacio - Fluvial
Unconformity
Campanian - Maestrichtian
Cenomanian - Turonian
30b Shale Member
30a Limestone Member
Chikkim
Valanginian - Albian
29 Glauconitic Sandstone, Black Shale
Giumal
Oxfordian - Valanginian
28 Black Splintery Shale, Sandstone
Spiti
Lagudarsi
Unconformity
Rhaetian - Lias
27b Brownish Weathering Dolomite with Shell- hash (Tagling M.)
27a Massive Dark Blue Dolomite with Megalodontids / Coral Reefs (Para M.)
Kioto
Norian
24 Sandstone, Shale, Dolomite / Limestone
Nunuluka
23 Dark Grey Shale, Local Limestone, Sandstone
Alaror
22 Massive Bedded, Grey Dolomite showing abundant Coral Reefs
Hangrang
UNCLASSIFIED 25
Carnian - Norian
21 A. Grey Green Shale B. Limestone / Dolomite C. Sandstone
Sanglung
UNCLASSIFIED 26
Ladinian - Carnian
20 Dark Grey Cherty / Argillaceous Dolomite with even thickness bedding
Chomule
Ladinian
19 Grey Calcareous Shale, local Limestone / Dolomite
Kaga
Lilang
Scythian - Muschelkalk
18 Dark Cherty, Ferruginous Limestone
Mikin
Unconformity
Late Permian - (Djulfian - Dorashmian)
17 Dark Grey Shale with Nodules, Sandstone
Gungri
Early Permian - (Asselian - Sakmarian)
16 Coarse Grained Calcareous Sandstone
Gechang
Kuling
Late Carboniferous - Early Permian
15 Brown Lenticular Diamictite, Sandstone, Shale
Ganmachidam
Early Carboniferous
14 Shale and Sandstone
Po
Late Devonian - Early Carboniferous
13 Limestone, Sandstone, Shale, Gypsum, local Coral - Algal Reefs
Lipak
Kanawar
Middle (?) - Late Devonian
12 White Sandstone
Muth
Unconformity
Late Ordovician - Late Silurian (?)
11 Calcareous Sandstone, Shale, Reefoid Carbonate Buildups
Takche
Ordovician
10 Purple Sandstone, Maroon Shale
Thango
Sanugba
Unconformity
Early - Middle Cambrian
9 Greenish Slate and Quartzite
Kunzam La
Eocambrian (Vendian)
8 Grey Phyllite, Quartzite, Carbonaceous Slate
Batal
Haimanta
Early - Middle Proterozoic
7 Greenish and Purple Quartzite, Schist Bands
Shiasu
6 Biotite to Sillimanite bearing Schist, Quartzite
Morang
Vaikrita
5 Sillimanite bearing Schist, Quartzite, Gneiss, Migmatite
Kharo
Vaikrita Thrust (M.C.T)
4 Carbonaceous Phyllite, Schist with Garnet, Staurolite, Amphibolite, Quartzite, Gneiss
Jutogh
Jutogh Thrust
3 Carbonaceous Slate, Quartzite, Marble, Porphyroblastic Gneiss
Kulu
Kulu Thrust
Early Proterozoic
2 White Quartzite with Phyllite interbands
Manikaran
Rampur
Unconformity
1 Ortho - Gneiss and Kyanite bearing Pelitic Gneiss
Jeori - Wangtu
N Nako
R Rakcham
W Wangtu
Post - Carboniferous
D Dolerite
Proterozoic
A Amphibolite
Thrust
Fault
Dip and Strike of Bedding / Foliation / Joint
International Boundary.
State Boundary.
Plunging antiform
Plunging synform
Plunging crenulations
Plunging overturned fold
Axial trace of antiform
Axial trace of synform
Axial trace of plunging antiform
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SATLUJ R.
SHIMLA
UTTAR PRADESH
TIBET
YULANG KHAD
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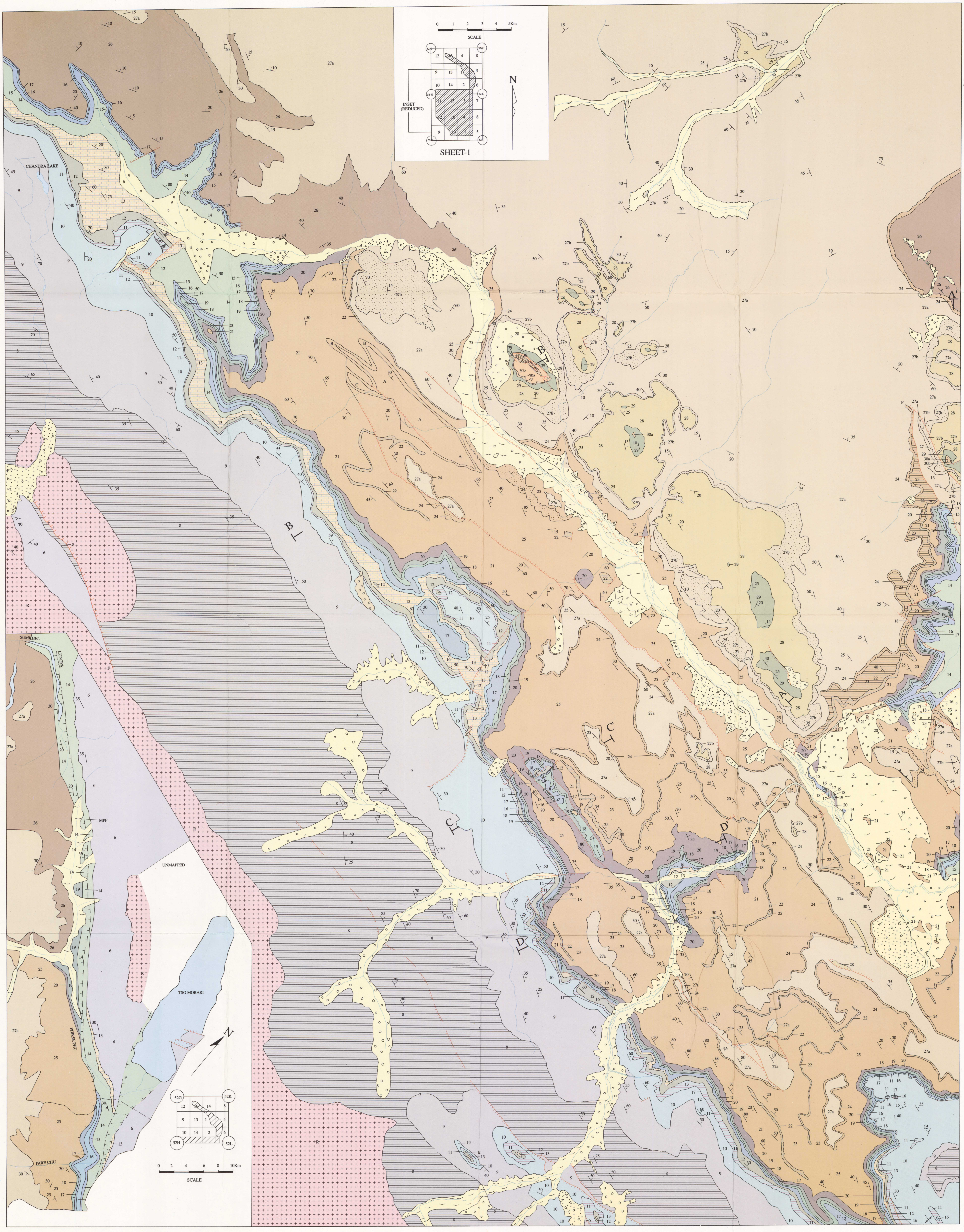
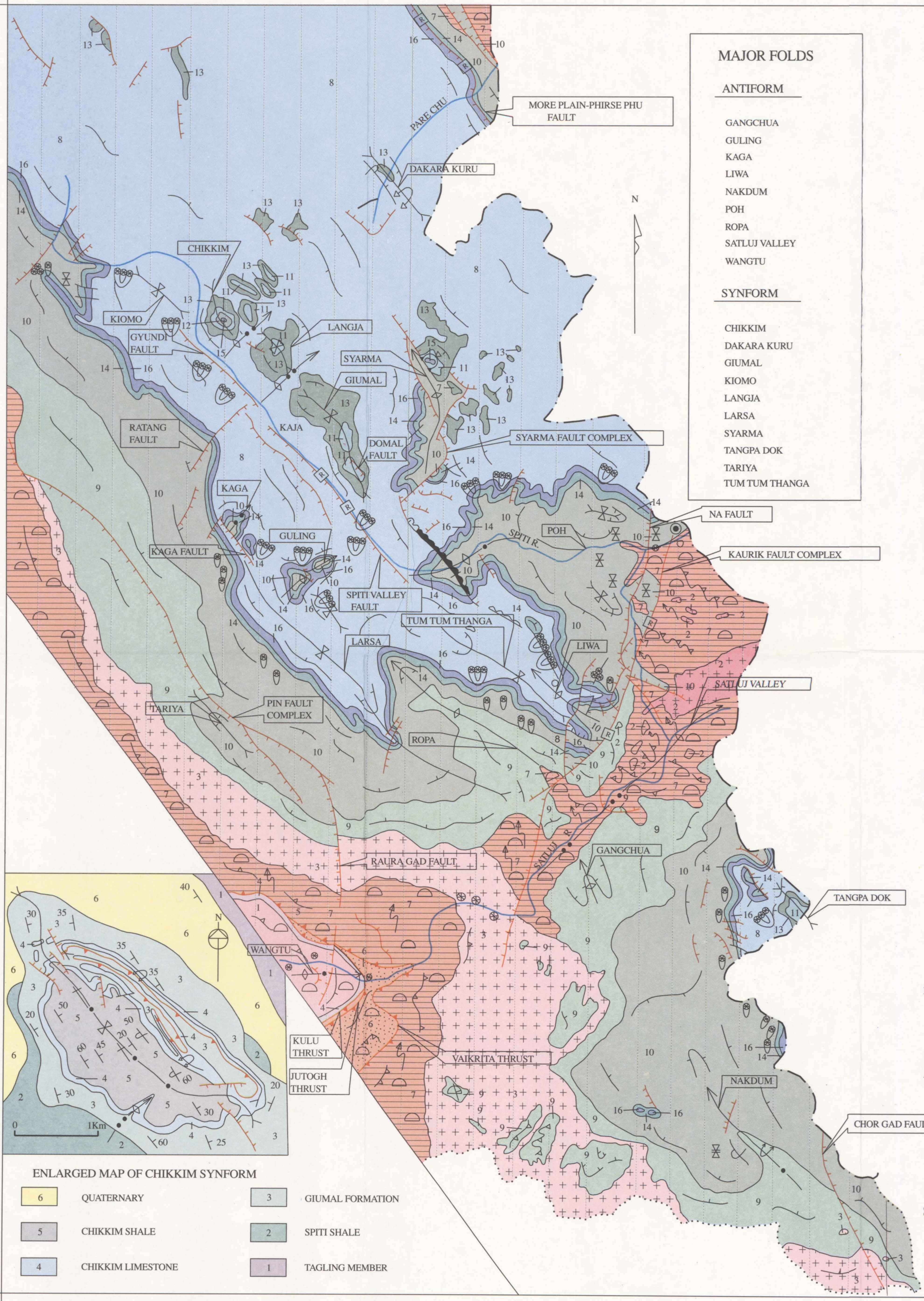

SHEET-1
SCALE
0 1 2 3 4 5Km
N
INSET (REDUCED)
CHANDRA LAKE
SUMKHEL
LUNGPA
MPF
PHIRSE PHU
PARE CHU
UNMAPPED
TSO MORARI
SCALE
0 2 4 6 8 10Km
52G
52K
52H
52L



Geol Surv. India, Mem. Vol. 124, Fig. 4.27

TECTONIC MAP OF SPITI-KINNAUR, HIMACHAL PRADESH

O. N. Bhargava and U. K. Bassi

0 50 100 150 200 250 300 Km
SCALE

1. TECTONIC UNITS OF CONTINENT-FRAGMENTS WITHIN PHANEROZOIC MOBILE BELT

1 ARCHAEAN-EARLY PROTEROZOIC BASEMENT COMPLEX SUBJECTED TO REPEATED TECTONO-THERMAL REACTIVATION; FINAL CONSOLIDATION AT 1240 Ma

2. MAGMATISM

GRANITE-GRANODIORITE ASSOCIATION (S-TYPE GRANITES)

2 OROGENIC (LATE CRETACEOUS)

3 ANOROGENIC (MAINLY EARLY PALAEOZOIC)

3. RIFT RELATED VOLCANIC-VOLCANOSEDIMENTARY ROCKS

4 EARLY PROTEROZOIC

4. THRUST SHEETS INVOLVED IN MULTIPLE DEFORMATIONS AND POLYPHASE TECTONOTHERMAL REACTIVATIONS

ORIGINAL STRUCTURE MORE OR LESS OBLITERATED

5 KULU — 6 JUTOGH — 7 VAIKRITA

5. FOLD COMPLEXES

END OF CRETACEOUS TO END OF MIO-PLIOCENE

PROTEROZOIC

6. SEDIMENTARY SEQUENCES

6.A. MAINLY SHALLOW WATER (TERRIGENOUS AND CARBONATE)

8 MESOZOIC

9 10 EOCAMBRIAN-PALAEOZOIC

6.B. DEEPER WATER

i. TERRIGENOUS

PROXIMAL TURBIDITE

11 VALANGINIAN-ALBIAN (GIUMAL)

SHELF MUD-SLOPE AND RISE

12 CAMPANIAN (CHIKKIM)

13 OXFORDIAN-VALANGINIAN (SPITI)

14 DJULFIAN-DORASHMIAN (GUNGRI)

ii. CARBONATE

15 CENOMANIAN-TURONIAN (CHIKKIM)

16 SCYTHIAN-EARLY CARNIAN (MIKIN-KAGA-CHOMULE)

7. PATCH/KNOLL REEFS ON PLATFORM

NORIAN (HANGRANG)

TOURNAISIAN (LIPAK)

SILURIAN (TAKCHE)

8. EVAPORITE SEQUENCE (GYPSUM)

TOURNAISIAN (LIPAK)

ORDOVICIAN (THANGO)

9. STRUCTURAL TRENDS

SEDIMENTARY SEQUENCES

POLYMETAMORPHIC COMPLEXES

10. FAULTS

NORMAL, HACHURED TOWARDS DOWN THROW SIDE

LISTRIC, EXPOSED, BLIND

STRIKE SLIP

ACTIVE DURING HOLOCENE

11. THRUST PLANE MAINLY INVOLVING COVER ROCKS

KULU, JUTOGH, VAIKRITA

12. FOLD AXES

TF2 ANTIFORM/SYNFORM

TF1 ANTIFORM/SYNFORM

MF1 ANTIFORM/SYNFORM

PrF2

13. THERMAL SPRINGS

14. EPICENTRE 1975 EARTHQUAKE

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16. INTERSTATE BOUNDARY

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