GEOLOGY AND TECTONICS OF THE HIMALAYA

SPECIAL PUBLICATION 26

GEOLOGICAL SURVEY OF INDIA
Cover

Mirror image of Landsat imagery (FCC) of the Himalaya covering parts of Ganga and Jamuna Valleys. Original Slide by courtesy D.R. Nandy.
In response to a multi-institutional call for evaluating the constraints for tectonic modelling in Himalaya, GSI has been carrying out various exercises within a very short time frame. The aim of such endeavour is to formulate futuristic detailed specialised programmes to validate ideas and to commence work on new concepts, and possibly to find the best locales for deep parametric drilling in Himalaya. The impact of such intellectual application to voluminous data to produce generalised updated synthesis and overviews is bound to be felt on the theories related to evolutionary aspects of Himalaya as also on the understanding of possibilities of resource potentiality of diverse kinds in various temporal/spatial geological cum tectonic environments encompassed in the complex Himalayan belt.

I had the privilege of organising a number of meetings in this respect and discuss details with the scientists of the survey on various aspects of Geology and Tectonics of the Himalaya. Most of these experts also figure as authors of the papers presented in the volume.

I am happy to see that the efforts of these experts having long association with the Himalaya, are being published in the form of this write up at a short notice. More detailed papers by various workers on different topics of Himalayan geology are being processed to be published in due course.

I am confident that this volume will be able to serve significant objectives of the conference slated towards the end of September, 1989 at the Wadia Institute of Himalayan Geology. Hopefully the proceedings of the Conference will enable organisers and participating Organisations to produce another useful volume on Himalayan Geology.

Dated, the 25th August'1989
Calcutta

(D. P. Dhoundial)
Director General
Geological Survey of India
"When I see the map of India and I look at the Himalayan range, I like the Himalayas myself. I like mountains and all that. I think of the vast power concentrated there which is not being used, and which could be used, and which really could transform the whole of India with exceeding rapidity if it were properly utilized. It is an amazing source of power, probably the biggest source anywhere in the world this Himalayan range, with its rivers, minerals and other resources".

Jawaharlal Nehru
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</tr>
</thead>
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</tr>
</tbody>
</table>
Abstract

On critical review, reassessment and evaluation of the available data base on lithography, fauna and flora, metamorphism and magmatism, and the limited geochronological data, the exposed sequences in the Himalaya, ranging in age from Proterozoic to Recent, have been regrouped into eleven different stacks, Sedimentary Cycle I to XI, each corresponding to different phases in the history of its evaluation and possibly reflecting global and regional tectonic events. Each of these stacks has distinct tectono-sedimentary, magmatic, metamorphic and structural characteristics.

A generalised geological map with eleven stacks is presented in three parts (Plate I-1, I-2, I-3) with common legend. Tables 1 (a) and 1 (b) give broad and composite lithological assemblage characterising these Sedimentary Cycles (stacks) along with the listing of the important Groups/Formations included in each of these in different sectors of the Himalaya.

1 Introduction

The status of knowledge on various aspects of the geology of Himalaya was reviewed, evaluated and very well documented in the proceedings of Himalayan Geology Seminar held at New Delhi during September, 1976 (GSI Misc. Pub. No. 41, Pts. I to V). Since then considerable amount of geoscientific data has been collected as new areas are mapped, systematic stratigraphic measurements are done, fresh fossil collections are made and studied, and more radiometric data are generated.

Consequently many new facts have come to light, the most significant amongst them are palaeontological discoveries in the supposedly unfossiliferous sequence of Krol Belt in the Lesser Himalaya and fossiliferous Eocene sequence in the Siang valley of Arunachal Pradesh, which give additional inputs in understanding the complex problems of geological evolution of this fascinating mountain range. It becomes imperative, therefore, to have another look at the available data base and identify constraints, and/or gaps in our contemporary knowledge to be filled in by suitably designed programmes of data acquisition and re-interpretation with a view to proposing model/models for geological and tectonic evolution of Himalaya for eventual testing as an ultimate goal. With this primary objective, various aspects of the geology of Himalaya viz., stratigraphy and sedimentation, structure and tec-
tonics, magmatism and metamorphism, metallogenesis, geomorphology and neotectonism, seismology and seismotectonics, gravity and magnetics, and geodesy need to be re-examined.

This chapter deals with the reappraisal of the data base concerning stratigraphy and sedimentation in the Himalaya. For the sake of convenience the Himalayan orographic belt (including Ladakh-Karakoram ranges) has been broadly divided into two segments along the southern margin of Indus Suture Zone (ISZ). While the segment to its south has been further subdivided into two viz., Lesser Himalaya (including Sub Himalaya) and Higher Himalaya; the northern segment has been divided in three parts viz., Indus Valley, Shyok Valley and Karakoram.

2 STRATIGRAPHY AND SEDIMENTARY CYCLES (STACKS)

Himalaya contains within its confines sequences with long history of sedimentation, magmatism and tectonism which got involved in the Himalayan orogeny. Sizeable portion of the geological sequences exposed in the Himalaya is Proterozoic in age with Phanerozoic cover of varying thickness in different parts. The possibility that these Proterozoic sequences could be the northern extension of the sequences exposed to the south and west of Indo-Gangetic alluvium in the northern part of Indian Shield has been kept in view while evaluating relative stratigraphic positions of various sequences.

Attempt has been made to identify and segregate these sequences on gross lithological assemblages, grade of metamorphism, limited radiometric data on synsedimentary metavolcanic beds and/or identifiable events of migmatisation and emplacement of granites, presence of diagnostic bedded sedimentary deposits (like iron ores, manganese, stromatolitic limestone, phosphorites, evaporites) characterising specific mineralogenic global events, presence of unconformities represented by boulder beds/diamictite and/or recognisable faunal breaks.

Based on the above considerations, eleven different stacks of sedimentary sequences, possibly representing distinct sedimentation cycles, have been identified (Tables 1a & 1b). Each one of them is broadly separated from the other by a hiatus of varying magnitude and exhibits distinct tectono-sedimentary, magmatic, metamorphic and structural characteristics. Many of the stack boundaries correspond to major regional and global events, the evidences of which are reported from several parts of Gondwana-land/Pangea. Even while making these stacks, some generalisations have been made to obviate the difficulties arising out of multitude of local formational names, which overburden the literature on one hand and hamper the proper understanding of the stratigraphy on the other. This happens because physical extensions of
### Stratigraphy & Sedimentation

#### Table 1a: Generalised Stratigraphy of Himalaya, South of Indus Suture Zone

<table>
<thead>
<tr>
<th>Geological Time Scale</th>
<th>General Lithology</th>
<th>Lesser Himalaya</th>
<th>Higher Himalaya</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quaternary</strong></td>
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<td></td>
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<tr>
<td>Pleistocene</td>
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<tr>
<td>Holocene</td>
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<tr>
<td><strong>Neogene</strong></td>
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<tr>
<td>Oligocene</td>
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<td>Paleocene</td>
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<td>Eocene</td>
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<td>Cretaceous</td>
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<td>Jurassic</td>
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<td>Triassic</td>
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<td>Permian</td>
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<tr>
<td>Carboniferous</td>
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<td>Devonian</td>
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<tr>
<td>Silurian</td>
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<td></td>
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<tr>
<td>Ordovician</td>
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</tr>
<tr>
<td><strong>Cambrian</strong></td>
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</tr>
<tr>
<td><strong>Proterozoic</strong></td>
<td></td>
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<tr>
<td><strong>Archaean</strong></td>
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</tr>
</tbody>
</table>

**Sedimentary Cycle**

- **XI**: Holocene
- **X**: Pleistocene
- **IX**: Oligocene
- **VIII**: Paleocene
- **VII**: Eocene
- **VI**: Cretaceous
- **V**: Jurassic
- **IV**: Triassic
- **III**: Permian
- **II**: Carboniferous
- **I**: Devonian
- **H**: Silurian
- **G**: Ordovician
- **F**: Cambrian
- **E**: Proterozoic
- **D**: Archaean

---

**Generalised Stratigraphy of Himalaya, South of Indus Suture Zone**

- ** Lesser Himalaya**: Generalised Stratigraphy of Himalaya, South of Indus Suture Zone
- **Higher Himalaya**: Generalised Stratigraphy of Himalaya, South of Indus Suture Zone

**Geological Time Scale**

- **Holocene**: Recent
- **Pleistocene**: Quaternary
- **Neogene**: Tertiary
- **Oligocene**: Paleogene
- **Paleocene**: Mesozoic
- **Eocene**: Mesozoic
- **Cretaceous**: Mesozoic
- **Jurassic**: Mesozoic
- **Triassic**: Mesozoic
- **Permian**: Paleozoic
- **Carboniferous**: Paleozoic
- **Devonian**: Paleozoic
- **Silurian**: Paleozoic
- **Ordovician**: Paleozoic
- **Cambrian**: Paleozoic
- **Proterozoic**: Proterozoic
- **Archaean**: Archaean

**Sedimentary Cycle**

- **XI**: Holocene
- **X**: Pleistocene
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- **VIII**: Paleocene
- **VII**: Eocene
- **VI**: Cretaceous
- **V**: Jurassic
- **IV**: Triassic
- **III**: Permian
- **II**: Carboniferous
- **I**: Devonian
- **H**: Silurian
- **G**: Ordovician
- **F**: Cambrian
- **E**: Proterozoic
- **D**: Archaean

---

**Stratigraphy & Sedimentation**

- **Table 1a**: Generalised Stratigraphy of Himalaya, South of Indus Suture Zone

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**Generalised Stratigraphy of Himalaya, South of Indus Suture Zone**

- **Lesser Himalaya**: Generalised Stratigraphy of Himalaya, South of Indus Suture Zone
- **Higher Himalaya**: Generalised Stratigraphy of Himalaya, South of Indus Suture Zone

**Geological Time Scale**

- **Holocene**: Recent
- **Pleistocene**: Quaternary
- **Neogene**: Tertiary
- **Oligocene**: Paleogene
- **Paleocene**: Mesozoic
- **Eocene**: Mesozoic
- **Cretaceous**: Mesozoic
- **Jurassic**: Mesozoic
- **Triassic**: Mesozoic
- **Permian**: Paleozoic
- **Carboniferous**: Paleozoic
- **Devonian**: Paleozoic
- **Silurian**: Paleozoic
- **Ordovician**: Paleozoic
- **Cambrian**: Paleozoic
- **Proterozoic**: Proterozoic
- **Archaean**: Archaean

**Sedimentary Cycle**

- **XI**: Holocene
- **X**: Pleistocene
- **IX**: Oligocene
- **VIII**: Paleocene
- **VII**: Eocene
- **VI**: Cretaceous
- **V**: Jurassic
- **IV**: Triassic
- **III**: Permian
- **II**: Carboniferous
- **I**: Devonian
- **H**: Silurian
- **G**: Ordovician
- **F**: Cambrian
- **E**: Proterozoic
- **D**: Archaean
TABLE 1b
GENERALISED STRATIGRAPHY OF HIMALAYA, NORTH OF INDUS SUTURE ZONE

<table>
<thead>
<tr>
<th>GEOLOGICAL TIME SCALE</th>
<th>GENERAL LITHOLOGY</th>
<th>INDUS VALLEY</th>
<th>SHYOK VALLEY &amp; KARAKORUM</th>
<th>ARUNACHAL PRADESH</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOLOCENE</td>
<td>Unconsolidated pebble, sand, clay</td>
<td></td>
<td>River terraces</td>
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<tr>
<td>QUATERNARY PLEISTOCENE</td>
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<tr>
<td>PIocene</td>
<td>Conglomerate, coarse sand, grit, shale with palm, leaf impressions &amp; vertebrate fossils</td>
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<tr>
<td>Neogene</td>
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<td>23 my</td>
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<tr>
<td>Oligocene</td>
<td></td>
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<tr>
<td>Palaeogene Eocene</td>
<td>Shale, sandstone, siltstone, carbonaceous shale, diamicrite</td>
<td>INDUS GP.</td>
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</tr>
<tr>
<td>65 my</td>
<td>Sandstone, conglomerate &amp; Orbolithina limestone, chart with basic and ultrabasic rocks (ophiolite)</td>
<td>SANGELLIAN Co.</td>
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<tr>
<td>Palaeocene</td>
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<td>Cretaceous</td>
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<td>Palaeozoic Silurian</td>
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<td>Proterozoic</td>
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<td>2900 my</td>
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<tr>
<td>Archaean</td>
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NOT YET RECOGNISED

Geol. Surv. Ind., Spl. Pub. No. 26
some formations have often been designated differently in different parts or at times the same name was given to different sequences in widely separated areas. Even with liberal generalisation many problems remained unresolved at the boundaries of some of the stacks/cycles. Many factors such as undoubted evidences of unconformity either in the form of basal conglomerates or diagnostic fossils or details of lithology are lacking, and the discontinuous nature of various stacks either due to tectonic elimination or erosion are the chief constraints in establishing unequivocally their inter-relationship. Insufficient data base or large quantitative and qualitative contrast in the geological information in different parts of the Himalaya is another major constraint in identifying sequences of various stacks (sedimentary cycles).

Generalised geological map with eleven stacks of sedimentary cycle (I to XI) is presented in three parts (Plate I-1, I-2, I-3) with common legend. Tables-1a & 1b give broad and composite lithological assemblage in each of these sedimentary cycles along with the listing of the important Groups/Formations included in each of these stacks in different sectors of the Himalaya.

3 CHARACTERISTICS OF DIFFERENT CYCLES

Each of these eleven sedimentary cycles is briefly described in this section.

3.1 Sedimentary Cycle-I (Early Proterozoic)

The oldest stack consists of thick pile (12000-15000m) of metamorphic sequence characterised by polyphased regional metamorphism varying from green schist facies to amphibolite facies. The sequence of this cycle is essentially exposed in the core of the Himalaya and has been designated by various names in different sectors. Moving from NW to SE it includes undifferentiated Crystallines of Nanga Parbat and Suru Crystallines (in J&K), Vaikrita Group, Rohtang Gneissic Complex, Tso Morari Gneissic Complex (in H.P.), Central Crystallines (in U.P.), Himal Group (in Nepal), Kanchanjunga Gneiss (in Sikkim), Thimpu Group (in Bhutan) and Sela Group (in Arunachal Pradesh). Certain rock formations/groups, like the Salkhala, Jutogh and Paro, which were considered equivalent or part of the Central Crystallines and other similar regionally metamorphosed sequences in the earlier compilations are being excluded from this cycle and placed under later cycles for the reasons duly explained at appropriate places under respective cycles.
The best studied and measured sections of this cycle are in Kumaon Himalaya along Kali and Gori Valleys (Table-2). A very thick quartzite sequence is exposed in the Alaknanda Valley (Pandukeshwar quartzite) which is not so well developed elsewhere. Intense migmatisation and granitic intrusions are common. The radiometric data, though scanty, indicate at least three phases of Proterozoic granite intrusion and associated migmatisation averaging around 2200 ± 125 Ma, 1800 ± 200 Ma and 1130 - 1318 Ma. In addition, granite intrusions dating 725 Ma and 581 ± 9 Ma have also been recorded besides Tertiary granites, aplites and pegmatites. Keeping the oldest dates in view this metasedimentary pile has been assigned Early Proterozoic (Proterozoic-I, Plumb and James, 1986). The Archaean basement is nowhere found so far in this belt.

---

TABLE - 2

GENERALISED LITHOSTRATIGRAPHY OF CENTRAL CRYS TALLINE (KUMAON HIMALAYA, U.P. (SEDIMENTARY CYCLE I)*

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martoli Formation</td>
<td>1300-1500+</td>
</tr>
<tr>
<td>(v) Intercalated sequence of quartzite, mica schist, marble, minor calc-silicate bands and metabasics, biotite gneiss, and intrusive granite. Chlorite and biotite.**</td>
<td></td>
</tr>
<tr>
<td>(iv) Mica schist, greenish grey quartzite migmatized biotite gneiss, streaky gneiss, porphyroblastic granite gneiss, basic sills. Chlorite and biotite.**</td>
<td>3500-4000</td>
</tr>
<tr>
<td>(iii) Grey and dark grey mica schist, garnetiferous mica schist, quartzite, calc-silicate bands, biotite gneiss, streaky gneiss, augen gneiss. Biotite and garnet.**</td>
<td>2000-2500</td>
</tr>
<tr>
<td>(ii) Dark grey to grey garnetiferous mica schist with quartzite bands, rare calc-silicate</td>
<td>1800-2200</td>
</tr>
</tbody>
</table>

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Geol. Surv. Ind., Spl. Pub. No. 26
bands, porphyroblastic gneiss, biotite gneiss.
Biotite and garnet, staurolite (?).**

(i) Grey, bluish grey, white and buff kyanite-bearing schist, garnetiferous mica schist, quartzite, and bands of psammitic gneiss.
** Garnet, kyanite and sillimanite.**

-------- Base not exposed--------


** Characteristic metamorphic minerals

Physically the southern contact of the rocks of this cycle is invariably sheared/ faulted. Consequently these rocks are found to abut against rocks of different younger cycles (II & III). In U.P. part, these rocks (Central Crystallines) abut against the rocks of the Cycle II (Garhwal Group) to its south with a thrust contact which was first described by Heim and Gansser (1939) and designated as Main Central Thrust (MCT)—a term now well entrenched in the literature. The proper understanding of this thrust plane probably holds the key to many existing problems of stratigraphy and structure in the Himalaya. For this reason repeated reference to this feature becomes unavoidable even though stratigraphy is being discussed. Moving northwards from the MCT in Kumaon-Garhwal Himalaya initially the sequence with inverted metamorphism (increase in grade from chlorite through biotite-garnet-kyanite to sillimanite zone) is observed by many as major tectonic plane designated as Vaikrita Thrust. In some sectors (like in H.P.) the zone of inverted metamorphism is not exposed (possibly due to tectonic reasons) and only normal order of metamorphic sequence from sillimanite facies to chlorite facies is developed. Consequently MCT is placed at the junction from where high grade metamorphic rocks come to rest over rocks of younger cycles. At such places this contact has also been called Vaikrita Thrust by some (Bassi, 1989). Inverted metamorphism in Kali valley has been ascribed to folding by Chittora and Srivastava (1989) and also demonstrated in the thermal model from Geol. Surv. Ind., Spl. Pub. No. 26
Zanskar Himalaya (Searle and Rex, 1989, p. 127-134). They have shown that high grade metamorphites occur in the cores of anticlines. In such a situation Vaikrita Thrust seems to be a second order structural feature within the sequence of Cycle-I and may represent the overstretched limb of anticlinal folds in certain sections, whereas MCT is important 1st order tectonic feature bringing the Crystalline rocks to rest and/or abut against other rocks. For this reason only "MCT" is demarcated in the accompanying maps (Plate I - 1,2,3).

The rocks of this Cycle (Central Crystallines/Vaikrita Group) extend roughly with NW-SE trend from Kumaon through Garhwal upto east of Kulu in Himachal Pradesh delimited to the south by the Main Central Thrust, the latter also roughly following the same trend. Further to the northwest the Main Central Thrust is not clearly discernible, hence the problems in demarcating the southern limit of the rocks of this cycle. It is generally considered that the MCT swerves southwards and taking a sinuous outcrop pattern forms the sole of Jutogh nappe and Kulu Crystallines and ultimately joins with the Panjal Thrust of Jammu Himalaya, where the rocks above the thrust are grouped under the Salkhala Formation. However, the present paper deviates from this so far followed view for following reasons:

(i) The sequence above the so conceived MCT does not show the lithostratigraphic association, assemblages, and metamorphism of Central Crystallines.

(ii) Due to characteristic association of sedimentary gypsum bed, the Salkhala Formation appears to belong to a later cycle,

(iii) Though scanty, the ages reported from Kulu Crystallines, Jutogh and Salkhala are much younger than the magmatic/metamorphic events (1600 - 2300 Ma) reported from Central Crystallines.

Accordingly, the present map shows sequence of Cycle-I along with MCT to continue north-westwards (without swerving round Kulu) upto east of Zojila, where it is truncated against a N-S trending fault. Further westwards these rocks are probably overlapped, by the rocks of Indus Ophiolite Belt, till near Nanga Parbat where from regionally metamorphosed high grade schists and migmatites are reported. Though for a short stretch west of Rohtang Pass (in Spiti-Zanskar area) the MCT has not been clearly deciphered possibly due to an overlap of younger cycle (Cycle-III) and due to insufficient structural details but in the Kilar area of Chamba district and near Atholi in Rishtwar area thrusts have been noticed at the southern and
Southwestern limit of the Crystallines. These are probably the traces of continuation of the MCT and have been shown accordingly in the accompanying map.

East of U.P. in Nepal, Sikkim, Bhutan and Arunachal Pradesh the position of the rocks of Cycle-I is slightly different. Various maps available, show the southern limit of the Crystalline rocks to be very sinuous and this limit has generally been shown as the MCT. Critical review and re-evaluation of the data base available for Nepal and Sikkim suggests that some of the sequences included in the Crystallines could be regrouped with later cycles (Cycle-II) of the present scheme and some of these might be representing transitional rocks. Accordingly, the present map digresses from the pre-existing maps in this respect.

Towards north, the rocks of Cycle-I are generally overlain with an unconformity by the rocks of Late Proterozoic and Phanerozoic Tethyan sediments classified with Cycle III and younger cycles. In U.P. Himalaya, the northern contact of the Central Crystalline is also a tectonic plane designated as Dar-Martoli Fault.

In addition to the main belt of the Cycle-I, there are outliers of the metamorphic rocks, viz. the Askot, Dharamgarh, Baijnath, Dudatoli-Almora Crystallines in U.P. and Dailekh/Jaljala in Nepal, overlaying the sequences of Cycle-II and III to its south. They, in general, exhibit inverse order of metamorphism and are believed to be representing the overthrust transitional outliers of the Central Crystallines. The view gets additional support of Rb-Sr whole rocks isochron radiometric dates of the granitic gneisses varying between 1620 ± 90 Ma (Bhanot et al., 1981; Trivedi et al., 1984; Powell, 1979) and 1960 ± 100 Ma. The sequence also contains elements of 1307 ± 79 Ma (Bhanot et al., 1980) and 560 ± 20 Ma (Trivedi et al., 1984) phases of granite and granitic gneisses. However, the mineral ages in many of the metamorphic rocks indicate imprints of Tertiary thermal events. These outliers had been considered (by some workers) to be autochthonous to para-autochthonous in nature (Kumar et al., 1974; Misra and Sharma, 1972; Saxena, 1974; Saxena and Rao, 1975) and assigned to younger cycles. Inversion in metamorphism had been attributed by these workers to the presence of thermal domes, recumbent folding and subnappe structure, and interplay of overturned folds and reverse faults, respectively.

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In Sikkim the Lingtse Gneiss appears to represent the basement for the Daling Group and is emplaced as tectonic wedges (Sinha Roy, 1980a,b). The Lingtse Gneiss which is an important lithotectonic unit in the Sikkim-Darjeeling Himalaya may belong to Cycle-I. Similar gneissic bodies having tectonic emplacement characteristics within the Proterozoic cover sequence of other parts of the Himalaya would represent the basement rocks in the Himalaya (Sinha Roy and Sengupta, 1986).

3.2 Sedimentary Cycle-II (Middle Proterozoic)

The second cycle comprises a thick sequence of quartzite + metavolcanic association which passes upwards into a carbonate-orthoquartzite facies overlain by a sequence of quartzite and associated metavolcanics. Penecontemporaneous lava flows are characteristic feature of this cycle. Laterally and vertically all these three sequences interfinger and at times, the carbonate facies is either absent or developed on a very reduced scale. The rocks of this cycle are generally unmetamorphosed or metamorphosed up to green schist facies. However, in some areas, relatively higher grade of metamorphism (amphibolite facies) is also seen and ascribed to periodic post-depositional granitic activity. The sequence is extensively developed from Kashmir to Arunachal Pradesh. The presence of Lower and Middle Riphean stromatolites in the carbonate facies are sometimes associated with phosphorite beds. The evidences of this event of phosphate genesis are also available in parts of Rajasthan and Madhya Pradesh, and may correspond to global event of Middle Proterozoic times. In addition, many metalliferous occurrences are located within this cycle.

The generalised lithostratigraphy of this cycle is given below:

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Group/Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominantly quartzite with penecontemporaneous basic metavolcanics, phyllite.</td>
<td>Kalamund Quartzite, Rampur (Manikaran)-Berinag, Dirang.</td>
</tr>
</tbody>
</table>

Geol. Surv. Ind., Spl. Pub. No. 26
<table>
<thead>
<tr>
<th>Stratigraphy &amp; Sedimentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominantly carbonate sequence made up of dolomite, phyllite, limestone with stromatolites and occasional phosphorite and magnesite and quartzite.</td>
</tr>
<tr>
<td>Dominantly quartzite with penecontemporaneous flows of spilite-keratophyre, purple phyllite</td>
</tr>
<tr>
<td>Carbonaceous phyllite, quartzite, metavolcanics, marble</td>
</tr>
</tbody>
</table>

The Paro Formation of Sikkim and Bhutan is now regrouped with the sequence of this cycle, though its precise stratigraphic designation may have to await more systematic work. Lithologically, it is made up of flaggy quartzite, bedded clac-silicate and marble, graphitic schist and gneiss, garnet-mica schist, with reddish-bronze coloured biotite, porphyroblastic biotite schist, migmatite gneiss with kyanite and sillimanite and granitic gneiss. It also contains amphibolites which are occasionally amygdaloidal (Acharyya, 1975; Acharyya and Sastry, 1979). But for higher grade of metamorphism, the general lithological associations and the presence of basic metavolcanics in the Paro suggest its gross characteristics to be similar to that of Cycle-II. Acharyya (1975) considers them to be more metamorphosed Buxa. Sinha Roy (1972) considered the Buxa Formation of the Sikkim to be Cambro-Silurian in age from stromatolite evidence, and he correlated the Buxas with Chunthangs (Paro) of North Sikkim which on tectonic considerations was suggested to represent metamorphosed correlative of the Buxas.

On similar considerations the metamorphic rocks referable to Bhimpedi and Kathmandu Groups in Nepal and part of Thimpu Group in adjoining western Bhutan, which appear to be in physical continuity of the Paro Formation of Sikkim, have also been tentatively grouped in this Cycle. Similarly Khetabari Formation in Arunachal Pradesh has been grouped in this cycle.

The sequence originally designated as the Dogra Slate by Wadia (1928) in the Pir Panjal Range, Poonch district, J&K, which contains penecontemporaneous lava flows has been placed under this cycle. The complete succession in the area comprises three lithostratigraphic units - viz. lower quartzite/slate with Volcanics (Bafliaz Fm.), middle slate/limestone with volcanics.
(Chandimar Formation) and upper quartzite with volcanics (Kalawat Quartzite). Kalawat Quartzite earlier considered as Tanawal is placed in this cycle on the criteria of presence of syndepositional volcanism which is not present in the Tanawal of the type area.

The basement for the sequence in Cycle-II is generally not exposed, or is not clearly discernible primarily because of insufficient data base. However, a sequence of metasediments locally referred as Agastmuni and Bhilangana Formations in the Mandakini valley, tentatively included within the Central Crystallines (Cycle-I), could possibly be considered as most likely basement for the rocks of Cycle-II (Garhwal Group) in Garhwal and Kumaon Himalaya. Parts of metamorphic sequence (Bhimpedi and Kathmandu Group and Himal Group) enclosing sequence of this cycle (Cycle-II) in the core of synclines, exposed in Bhot Kosi and Okhaldunga (in Nepal), could be representing the original basement of Cycle-II (Plate I-2). Similarly, further east in Sikkim and Bhutan some of the sections may represent exposures of the Paro Formation along with the underlying Crystal-line basement and the two have not been differentiated. The possibility that sequence of the Paro and Khetbari Formations (now placed under Cycle-II) may be representing a transitional zone between Cycle-I and II can not be ruled out. Much more needs to be done to resolve these issues.

The metavolcanics in the sequence at Mandi (Darlaghat) have been radiometrically dated to be 1190±35 Ma (Sinha, 1977) whereas the uraninite disseminations in the Manikaran Quartzite (Rampur Formation) have been dated as 1232±120 Ma (Bhalla et al., 1979; Trivedi et al., 1984). The gneisses and granites associated with Bomdila Group have been dated as 1500-1650 Ma and 480–500 Ma in Arunachal Pradesh (Bhalla J.K. and Bishui, 1989), while in Ramgarh area radiometric dates range between 1170±20 to 1215±100 Ma (Bhanot et al., 1975).

From the assemblage of radiometric data and stromatolites, this stack of sequence is assigned Middle Proterozoic age (Proterozoic-II) (Plumb and James, 1986) ranging between 1600-1000 Ma. The sediments of this cycle were best studied with stratigraphic measurements carried out in parts of Kumaon and Garhwal. The generalised measures sections are given in Tables 4a and 4b.

**TABLE 4a**

**LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLE II GARHWAL/DEOBAN/LARJI/SHALI GROUPS**

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### Formations

<table>
<thead>
<tr>
<th>Cycle-III - Jaunsars</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Berinag Arenaceous facies</strong></td>
<td>White, grey and light green, fine to medium grained, sericitic arenite with penecontemporaneous volcanic flows</td>
</tr>
<tr>
<td><strong>Kanalichina transitional facies</strong></td>
<td>Interbedded sequence of slate/phylite quartzite, dolomite with basic flows</td>
</tr>
<tr>
<td><strong>Pithoragarh calcareous facies</strong></td>
<td>Medium to thinly bedded grey dolomite with minor bands/pockets of chert, siliceous dolomite, talcose phyllite, calc arenite</td>
</tr>
<tr>
<td><strong>Rautgara argillo-arenaceous facies</strong></td>
<td>Fine to medium grained, grey, greyish white arenite and purple and green slate with bands/lenses of limestone and volcanic flows and basic intrusives</td>
</tr>
<tr>
<td><strong>Dharagad/Sundernagar/Larji/Naraul</strong></td>
<td>Base not exposed Contact Faulted</td>
</tr>
</tbody>
</table>
TABLE 4b
LITHOSTRATIGRAPHY OF CYCLE II
JAMMU & KASHMIR **

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalamund</td>
<td>Grey rhythrite, massive to schistose quartzite, white, purple, greyish green siltstone</td>
<td>1150</td>
</tr>
<tr>
<td>Buniyar</td>
<td>Dark grey rhythrite, grey phyllite, conglomerate</td>
<td>600-800</td>
</tr>
<tr>
<td>Bafliiaz</td>
<td>Greyish white schistose to massive quartzite with metabasics, lenticular dolomitic limestone, phyllite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Base not exposed</td>
<td></td>
</tr>
</tbody>
</table>

** Modified after Kumar and Srivastava, 1986

This cycle represents deposition in unstable platform conditions with associated intracontinental rifting and associated volcanism. This may broadly be equivalent to the Jinningian Tectonic Stage of China and commences with the Zhongyuean orogenic movements (Kumar and Gopal Singh in press).

3.3 Sedimentary Cycle-III (pre-Vendian - Late Proterozoic)

The Cycle-II ended with a phase of granitic intrusions ranging in age around 1000 ± 100 Ma and the rocks of Cycle I and II were uplifted and became provenance for the deposition of next cycle of shallow marine sediments, commencing with the accumulation of conglomerate beds (e.g. Mandhali, Basantpur, Biyali etc.) in parts of HP and UP. The cycle includes the sediments of Simla and Jaunsar Groups, and Ramban Formation in Lesser Himalaya; and Salkhala-Tanawal Formations, Kulu and Chamba, Bhaderwah, part of Batal and Martoli Formations of Higher Himalaya (Plate I-1). Its equivalents are Lakharpata Subgroup and Lower Nawakot Group in Nepal (Plate I-2), the Shumar Formation in Bhutan, and Lumla Formation in Arunachal Pradesh (Plate I-3). The sequence is essentially of arenitic-argillaceous facies with minor bands of carbonates, typi-
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cal of stable platform deposits. The carbonates are occasionally stromatolitic with Upper Riphean affinity. Another characteristic association in this cycle is the presence of evaporitic facies in the form of gypsum accumulations in certain parts of J&K and Bhutan. The penecontemporaneous basic volcanism characteristically associated with the Cycle-II is absent in this cycle. The generalised lithostratigraphy of this cycle as established in NW Himalaya is given in Table-5.

TABLE -5
LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLE III NW HIMALAYA

HIMACHAL AND UTTAR PRADESH

<table>
<thead>
<tr>
<th>Group</th>
<th>Formation</th>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blaini-Tal Sequence (Cycle IV)</td>
<td>Unconformity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nagthat/</td>
<td>White, purplish and greenish</td>
<td>700-1600</td>
<td></td>
</tr>
<tr>
<td>Sanjauli</td>
<td>quartz arenite, quartz wackes interbedded with thin slates and conglomeratic bands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jaunsar/</td>
<td>Quartz arenite interbedded with greyish slates; with occasional metabasic rocks</td>
<td>1000-2800</td>
<td></td>
</tr>
<tr>
<td>Simla</td>
<td>Chhaosa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kunihar</td>
<td>Shale and siltstone alternation with algal limestone (earlier referred to as Kakarhatti Limestone)</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>locally</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>developed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mandhali/</td>
<td>Boulder bed, thinly bedded limestone, shale, quartzite and massive limestone</td>
<td>1000-1200</td>
<td></td>
</tr>
<tr>
<td>Basantpur</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Garhwal Group and Equivalents (Cycle II)

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Several phases of post depositional granitic activity in the age range of $950 \pm 100$ Ma, $550 \pm 100$ Ma, $300 \pm 50$ Ma have been recorded in parts of Himachal Pradesh and J&K, which have resulted in metamorphism of the sequences at times up to amphibolite facies in certain parts (e.g. Jutogh, Kulu and Salkhala Group). As bedded gypsum deposits, which are generally not reported in sequences older than the boundary of Middle/Late Proterozoic, Salkhala, Ramban and Shumar formations are considered as Late Proterozoic. Also the rocks around Nanga Parbat mapped by Wadia (1931) as "Salkhala" do not match lithologically with the Salkhala of the type locality in Kishanganga Valley hence they are excluded from this cycle in the present map. Regarding Jutogh and Kulu Formations, though a solitary $\text{Sr/Rb}$ isochron age of $1430 \pm 155$ Ma has been reported from the gneisses in the Baragaon area (Bhanot et al., 1978) in the Satluj Valley, the oldest mineral age (biotite) in Chor granite by K/Ar is 1000 Ma (Dixit, 1977). Besides, K/Ar whole rock ages reported for the Chor granite and gneisses range between $250 \pm 30$ Ma (Nagpaul and Nagpaul, 1974). In addition, the carbona-
ceous phyllite from the Jutogh Formation have yielded the microbiota of Late Proterozoic to Early Cambrian affinity (Maithy et al., 1981). The reappraisal of the same fossil record indicates that the age of this microbiota could be assigned to pre-Venedian part of Late Proterozoic (Maithy personal communication). Avasthy and Pande (Mss) has also recorded microbial elements which have Riphean affinity from the Kulu Group. The stromatolites in the carbonate facies in the Simla Group also indicate Late Riphean affinity (Tewari, 1984). Based on these evidences, the lower limit of this sedimentary cycle has been tentatively placed around 1000 ± 100 Ma and the upper limit as 670 Ma (base of Vendian). This can broadly be correlated to the Sibaoan orogenic movements of the Jinningian Tectonic Stage of China, Gothain and Grenvillin (?) orogenic movements in Europe and North America (Hongzhen et al., 1986).

The cycle ends essentially with a thick sequence of medium to coarse-grained quartzite, occasionally with quartz-pebble conglomerate indicating gradual regressive phase and uplift in provenance areas.

3.4 Sedimentary Cycle-IV
Late Proterozoic (Vendian) - Cambrian

The unconformity between Cycle III and IV is very widespread and is represented by a diamicritic sequence all through the Lesser Himalaya. This has been variously named as Blaini Formation in UP & HP, Manjir Formation in Chamba district, HP, basal part of the Bhimdasa Formation and Ramsu Formation in J&K. The angular unconformity between Upper and Lower Nawakot Formation represents this zone in Nepal. The Kabak and Niumi Formations in Arunachal Pradesh have also been tentatively grouped with this Cycle (Kumar, in press). However, in the Higher Himalaya of Spiti-Zanskar this horizon is not so far clearly identified within undifferentiated Batal Formation which includes elements of Cycle-III as well as Cycle-IV. Its equivalents in parts of Darjeeling and Sikkim are not known so far.

The Krol Belt in HP and UP exposes the best developed sequence of this cycle and includes rocks of Blaini, Infra-Krol, Krol and Tal Formations. The thickness of this sequence varies between 2000 m and 4500 m gradually increasing northwards (Shanker, 1975). The generalised composite stratigraphy of this cycle is given in Tables 6a and 6b.
The Krol Formation is essentially a carbonate facies with evaporite beds in the middle section, whereas the overlying Tal Formation is essentially an argillo-arenaceous facies with well developed phosphorite deposits at its base. This sequence had been a subject of keen interest to stratigraphers and palaeontologists in last decade and a half, as a result of which its litho- and biostratigraphy is much better known now. This cycle is equally well developed in parts of Kashmir and Spiti-Zanskar areas where it is the sequence dominantly silliciclastic (aren-o-argillaceous). It includes Ramsu, Machhal (Dogra Slate-Wadia, 1932); Lolab-Karihul Formations in Kashmir and Batal-Kunzam La Formations in Spiti-Zanskar (including the Parahio Series of Hayden, 1904). Recently the Cambrian elements have been found in the Martoli Formation in U.P. (Jamwal and Kacker, 1989).

TABLE 6A
LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLE IV
LESSER HIMALAYA*

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manikot</td>
<td>Shell</td>
<td>Sandy limestone with broken shells</td>
<td>15-30</td>
</tr>
<tr>
<td>Limestone/Nilkanth/Singtali</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phulchatti</td>
<td>Quartz arenite, greenish grey shale interbedded with thin quartz arenite, felspathic arenite, algal limestone interbedded with siltstone and quartz arenite and quartz arenite interbedded with minor shale and siltstone</td>
<td>145-1700</td>
<td></td>
</tr>
<tr>
<td>Tal</td>
<td>Calcareous Ferruginous and calcareous siltstone and siliceous limestone</td>
<td>15-45</td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arenaceous</td>
<td>Greyish, purplish siltstone, calcareous at places</td>
<td>90-496</td>
</tr>
<tr>
<td>Argilla-ceous</td>
<td>Black shale ± calcareous bands</td>
<td>25-330</td>
</tr>
<tr>
<td>Chert-Phosphate</td>
<td>Black chert interbedded with black shale and phosphate rock dominating at top</td>
<td>10-70</td>
</tr>
<tr>
<td>Upper Krol</td>
<td>Calcareous shale, limestone interbedded with siltstone, limestone and dolomite</td>
<td>600-1230</td>
</tr>
<tr>
<td></td>
<td>Dolomite limestone interlayered with shale ± quartzitic bands ± gypsum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dolomitic limestone/ limestone</td>
<td></td>
</tr>
<tr>
<td>Krol</td>
<td>Purplish and greenish shale with thin limestone lenses ± gypsum</td>
<td>20-125</td>
</tr>
<tr>
<td>Middle Krol</td>
<td>Purplish and greenish shale with thin limestone lenses ± gypsum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Argillaceous limestone interbedded with calcareous shale</td>
<td>80-470</td>
</tr>
<tr>
<td>Lower Krol</td>
<td>Well bedded quartz arenite with phosphate rock streaks (developed only in NW part of basin)</td>
<td>25-100</td>
</tr>
<tr>
<td>Krol Sandstone</td>
<td>Blackish shale/slate with thin siltstone; Pinkish limestone diamictite horizons interbedded with arenite, shale ± thin limestone bands</td>
<td>180-2135</td>
</tr>
</tbody>
</table>

*Pre-Blaini sequence belonging to Simla/Jaunmar Group of Sedimentary Cycle-III*

*Modified after Shanker et al., 1975; Kumar et al., 1989*
### TABLE 6b
#### LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLE IV

KASHMIR*

<table>
<thead>
<tr>
<th>Formation Member</th>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sediments of Cycle V</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Unconformity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>Shales, greenish grey, laminated, subordinate micaceous sandstone and lenticular limestone bands. Trilobites.</td>
<td>350</td>
</tr>
<tr>
<td>Karihul</td>
<td>Sandstone, micaceous, greyish green in colour and laminated shales with lenticular limestone. Trilobites</td>
<td>350</td>
</tr>
<tr>
<td><strong>A</strong></td>
<td>Sandstone micaceous, greenish grey with shaly interbeds. Trilobites</td>
<td>495</td>
</tr>
<tr>
<td><strong>Vel.</strong></td>
<td>Grey to dark grey and greenish grey shales with interbands of micaceous sandstone. Trilobites, Hyoliths</td>
<td>832</td>
</tr>
<tr>
<td><strong>Lolab</strong></td>
<td>Räzdain Rhythmic alternation of grey argillite and grey quartzite with interference ripple marks. Abundant trace fossil.</td>
<td>650</td>
</tr>
<tr>
<td><strong>Machhal</strong></td>
<td>Slates, grey to dark grey, slaty phyllite, carbonaceous phyllite, locally limestone</td>
<td>+725</td>
</tr>
</tbody>
</table>

*Geol. Surv. Ind., Spl. Pub. No. 26*
Stratigraphy & Sedimentation

Ramsu Quartzite, grey to greenish, slates, grey to dark grey; diamicrite

-------------------Unconformity-------------------

Sediments of Cycle-III

* Modified after Kumar et al., 1982-83; Raina and Sehgal, 1983-84

The Precambrian-Cambrian boundary may lie within these sequences in the basal part of Tal, Lolab and Kunzam La Formations and somewhere in the upper part (?) of Martoli Formation.

Major biological changes have occurred during this cycle leading to the rapid evolution in life. This led to the appearance of calcareous algae and acritarchs (Joshi et al., 1988 and Maithy et al., 1988); soft bodied animals Ediacaran fauna (Mathur, 1989; Mathur and Shanker (in press) and Mathur and Kumar (MSS)) and animals with hard parts—the small shelly fossils towards the end of Proterozoic Era and advent of Cambrian around 570 Ma. The Cambrian period witnessed much greater diversification with the appearance of trilobites, brachiopods, gastropods, poriferids etc. and their remains are found in this cycle [Singh, 1976; Singh et al., 1983; Azmi et al., 1981; Azmi, 1983; Bhatt et al., 1983, 1985; Kumar et al., 1983, 1987(a), (b); Rai and Singh, 1983; Shah et al., 1980; Tewari, 1984; Tripathi et al., 1984 and 1986; Joshi et al., 1989; Mathur et al., 1987; Mathur and Shanker (in press)].

The cycle is terminated by a large scale regression of the sea from this part of the Himalaya towards upper part of the Cambrian. The uplift may be connected with the orogenic movement equivalent to Xingkaian and Salarian phases of crustal movements during Caledonian orogeny of China and Europe, respectively. The plutonic activity dating 525 ± 50Ma has been recorded in many parts of Himalaya which may be associated with this phase of crustal movements.

3.5 Sedimentary Cycle-V (Ordovician to Early Carboniferous)

This cycle represents predominantly the marine sedimentary pile deposited with an angular unconformity over the sequence of Cycle-IV in parts of Kashmir, Spiti-Zanskar, Kumaon-Garhwal, Nepal and Bhutan in the Higher Himalayan Tethyan basin and ranges in age from Ordovician to Early Carboniferous. The se-
quences grouped within this stack of sedimentary cycle-V includes Margan Formation to Fenestella Shale in Kashmir, Thango to Po Formations in Spiti-Zanskar, Ralam Formations to Kali Formation in Kumaon, Everest Limestone and upper part of Phulchauki Group in Nepal and Black Mountain Group in Bhutan.

The entire stretch of Lesser Himalaya possibly remained a positive area, except in Kathmandu valley in Nepal, where the upper part of the Phulchauki Group may belong to this cycle, consequently no trace of sediments of Cycle-V are found.

The generalised litho-stratigraphy of this cycle is given in Tables 7a and 7b.

**TABLE 7a**

**LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLE VI**

**KOAMON-GARHWAL**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuling Shale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kali/</td>
<td>Sandy dolomite, micaceous shale and bluish grey limestone</td>
<td>30-300</td>
</tr>
<tr>
<td>Girthigal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muth</td>
<td>White, massive, mature quartzite</td>
<td>100-175</td>
</tr>
<tr>
<td>Variegated</td>
<td>Brown, calcareous quartzite with red crinoidal shale</td>
<td>200-750</td>
</tr>
<tr>
<td>Shiala</td>
<td>Green, sandy calcareous shale with limestone intercalations</td>
<td>675-1050</td>
</tr>
<tr>
<td>Garbyang</td>
<td>Pink, calcareous quartzite/shale with pink/blue micritic limestone with quartzite. Calc phyllite with ferruginous dolomite</td>
<td>1100-4300</td>
</tr>
<tr>
<td>Ralam</td>
<td>Brown/pink pebbly quartzite with conglomerate at the base</td>
<td>0-370</td>
</tr>
</tbody>
</table>

Geol. Surv. Ind., Spl. Pub. No. 26
Martoli

Darji grey slate, brown slate/phylite, quartzite spotted schist, thin marble bands, mica schist and intrusive granite, pegmatite and vein quartz

-------Base not exposed Tectonic contact-------

Central Crystalline Group

* Modified after Jamwal & Kacker, 1989; Malaviya and Pande, 1989

**TABLE 7b**

**LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLE V KASHMIR**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fenestella Shale</td>
<td></td>
<td>E Quartz arenite with lenticular conglomerate, shales with marine fossils</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D Shale-siltstone with bands of quartz arenite-marine fossils</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C Quartz arenite with shale-siltstone inter beds. Plant fossils.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B Dominantly shale-siltstone with interbeds of sandstone. Marine fossils</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A Quartz arenite with shale-siltstone intercalations. Plant fossils</td>
</tr>
<tr>
<td>Syringothyris Limestone</td>
<td>C</td>
<td>Alternations of limestone, sandstone and shale. Fossiliferous (Flora &amp; Fauna)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Limestone, massive with shaly intercalations. Fossiliferous</td>
</tr>
</tbody>
</table>

Measured Thickness (metres)

| Fenestella Shale | 210-690 |
| Syringothyris Limestone | C +125 |
| Syringothyris Limestone | B 235 |

Geol. Surv. Ind., Spl. Pub. No. 26
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Limestone, siliceous and sandstone fossiliferous</td>
<td>110</td>
</tr>
<tr>
<td>B</td>
<td>Siltstone, yellowish green with bands of shale. Plant fossils</td>
<td>75</td>
</tr>
<tr>
<td>A</td>
<td>Quartz arenite, variegated purple, green white with intercalations of siltstone</td>
<td>180</td>
</tr>
<tr>
<td>Muth</td>
<td>Milky white, thick to thin bedded orthoquartzite with occasional calcareous lenticular bands</td>
<td>690</td>
</tr>
<tr>
<td>Margan</td>
<td>E Arenite, calcareous with limonitic patches and grey shale partings. Fossiliferous corals</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>D Sandstone, purplish to grey and shale sandstone intercalations. Fossiliferous Brachiopods, crinoids, trilobites</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>C Quartz arenite, white to greyish white thick-bedded. Trace fossil Planolites</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>B Sandstone, grey to buff, calcereous at places with limonitic patches, Fossiliferous. Brachiopods, crinoids, corals.</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>A Quartz arenite, grey to greyish white purplish arenite, silty shale with calcareous lenses. In some sections conglomerate with clasts mainly of quartzite. Brachiopods</td>
<td>215</td>
</tr>
</tbody>
</table>

*Modified after Kumar et al., 1982-83*
During the deposition of the sediments of this cycle, fluctuations in the sea level had occurred periodically as reflected in the intertonguing of marine and continental facies and finally in the total regression of the sea towards the end of Early Carboniferous. Evolutionary changes, especially in plant life are noticed in the form of first appearance of vascular plants in the Late Devonian and pre-Gondwana *Rhaetopteris* flora in Early Carboniferous (Singh et al., 1982).

The regression may be temporarily related to Tianshanian orogenic movements of China and Suditian of Europe during the Hercynian (Variscan) tectonic stage. The leucogranites and pegmatites represented in some parts of Himalaya and dating around $300 \pm 50$ Ma may be related to these movements.

3.6 Sedimentary Cycle-VI (Late Palaeozoic to Middle Jurassic)

It includes a pile of sediments from Late Carboniferous (?) to Early Jurassic age in the parts of Kashmir and Higher Himalaya of Spiti-Zanskar and Garhwal-Kumaon. In Lesser Himalaya, however, the cycle is restricted only to Early Permian sedimentation in parts of Garhwal and Kumaon and further eastwards.

The generalised composite lithostratigraphy of this cycle is given in Tables 8a and 8b.

**TABLE 8a**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spiti Shale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>--------Unconformity---------------------------</td>
<td></td>
</tr>
<tr>
<td>Laptal</td>
<td>Grey, shell limestone; thinly bedded grey limestone with shaly bands</td>
<td>50-60</td>
</tr>
<tr>
<td>Kioto Limestone</td>
<td>Dark grey, massive, thickly bedded limestone, grey oolitic limestone with white quartzite towards base</td>
<td>250-700</td>
</tr>
</tbody>
</table>

Geol. Surv. Ind., Spl. Pub. No. 26
Kuti Shale  Dark grey shale with limestone intercalations  300-900
Kalapani Limestone Grey, massive limestone, nodular limestone with shaly partings  12-50
Chocolate Grey shale, grey, hard, compact limestone  15-25
Kuling Shale Dark grey, thick splintery shale with calcareous bands  30-170

-------------------Unconformity-------------------
Kali Formation

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wuyum</td>
<td></td>
<td>Massive limestone, siliceous limestone</td>
<td>Not measured</td>
</tr>
<tr>
<td>Khrew</td>
<td></td>
<td>Thin bedded limestone and shales</td>
<td></td>
</tr>
<tr>
<td>Khunamuh</td>
<td></td>
<td>Dark grey shale with bands of limestone</td>
<td>80</td>
</tr>
<tr>
<td>Zewan</td>
<td></td>
<td>D Silty shale, dark grey to black with occasional nodules</td>
<td>200-410</td>
</tr>
</tbody>
</table>

TABLE 8b
LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLE VI KASHMIR **
Stratigraphy & Sedimentation

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Sandstone, calcareous with occasional bands of limestone. Fossiliferous</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Shale and siltstone alternations. Richly fossiliferous. Cephalopods, brachiopods, corals, crinoids, bryozoa</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Massive limestone with shale partings or black calcareous shale. Fossiliferous - Brachiopods, bryozoa, corals</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mamal</th>
<th>Description</th>
<th>50-300</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbonaceous shale, tuffaceous shale with plant fossils</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Purplish shale with sandstone, limestone, novaculite</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panjal Volcanics</th>
<th>Description</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Andesitic basalts</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nishatbagh</th>
<th>Description</th>
<th>340</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Black shale, siltstone with sandstone bands - Plant fossils</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Agglomeratic Virsar Slate</th>
<th>Description</th>
<th>330</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Siltstone, sandstone and tuffaceous shale. Marine fossils</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Owz</th>
<th>Description</th>
<th>880</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sandstone, grey to greyish white with lenticular conglomerate, diamicrite with argillo-arenaceous matrix. <em>Eurydesma-Deltopecten</em>, gastropods etc.</td>
<td></td>
</tr>
</tbody>
</table>

Geol. Surv. Ind., Spl. Pub. No. 26
The cycle commences with a sequence of conspicuously arenaceous rocks with diamictite enclosing marine fossils. It is overlain by a continental facies made up of felspathic sandstones and grits with carbonaceous shales containing Lower Gondwana Gangamopteris-Glossopoteris flora. The mixing of this Gondwanic flora with northern flora is recorded in parts of Kashmir (Singh et al., 1982), and also in Arunachal Pradesh (Sinha et al., 1986).

Widespread basic volcanism, represented by Panjal Volcanics in Kashmir and Spiti-Zanskar, diorite intrusives (228 ± 10 Ma) in Bhowali-Bhim Tal area and Lichi Volcanics in Arunachal Pradesh, is a characteristic feature of this cycle during Permian period. The phyllitic rocks associated with the Lower Bijni Formation in Mussoorie and Garhwal synclines could be metamorphosed tuffs and may be the manifestation of this volcanism. Isolated occurrences of reported orthoamphibolites in older formations, radiometrically dated as 277 ± 8 Ma, could also belong to this episode of volcanic activity. This volcanic episode may be related to the rifting associated with fragmentation of Gondwanaland.

Another significant litho-association of this cycle is the deposition of large thicknesses of carbonates in Triassic times under stable platform environment. The Permo-Triassic boundary lies within this cycle, which witnessed large scale extinction of Palaeozoic invertebrates. The epeirogenic movements in Early Jurassic culminated in temporary withdrawal of the sea. This marked the end of this cycle in the Callovian times.
3.7

Sedimentary Cycle-VII (Late Jurassic to Early Cretaceous)

This cycle commences with the marine transgression during Late Jurassic times in the Tethyan belt of the Higher Himalaya. The marine conditions persisted through Late Jurassic to Early Cretaceous resulting in the deposition of Spiti Shale-Giumal Sandstone sequence in parts of Himachal Pradesh and Uttar Pradesh, part of undifferentiated Tethyan pile in Nepal and Lingshi Group in Bhutan. In Kashmir only Jurassic part of this cycle is present (Wumuh Formation) and there is no record of any sedimentation for the rest of the Cycle-VII.

The composite stratigraphy of this cycle in Kumaon is given below:

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Measured thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malla Johar</td>
<td>White limestone, oolitic limestone</td>
<td></td>
</tr>
<tr>
<td>Balcha Dhura Volcanics</td>
<td>Greenish and reddish spilite, and associated serpentinites</td>
<td>150-225</td>
</tr>
<tr>
<td>Chikkim</td>
<td>Greyish, yellow-weathered, calcareous shales, thin bedded limestone</td>
<td>400-600</td>
</tr>
<tr>
<td></td>
<td>Greyish blue limestone with lenses of quartzite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-------------------------Unconformity-------------------------</td>
<td></td>
</tr>
<tr>
<td>Giumal Sandstone</td>
<td>Quartzite to sandstone with lenses of limestone; glauconitic, micaceous sandstone and green phyllite/shale</td>
<td>500-700</td>
</tr>
<tr>
<td></td>
<td>Grey sandy and marly limestone</td>
<td></td>
</tr>
</tbody>
</table>

Geol. Surv. Ind., Spl. Pub. No. 26
Spiti Shale  Dark grey shale with dirty brown sandstone and ferruginous oolite (1-3 m) band at the base

-------------Disconformity-------------
Laptal Formation

* Modified after Kumar et al., 1972

The entire Lesser Himalaya remained a positive area but for a part in Nepal where fresh water sediments (Taltung Formation) containing Rajmahal flora and basalt flows (Aulis Basalt) have been reported (Sakai, 1983)

Sea regressed from the Higher Himalaya also towards the end of Early Cretaceous possibly due to uplift/upwarping of the area. This movement could be the result of compressive forces accumulated just prior to the opening of the Indus Suture which was an area under extreme tensional stresses.

3.8 Sedimentary Cycle-VIII (Middle Cretaceous to Middle Eocene)

The sedimentary stack of the cycle contains the record of perhaps the most significant part of the history of Himalaya from Middle Cretaceous to Early Eocene (120-40 Ma).

The release of rapidly growing stresses as Indian Plate approached Asian (Tibetan) Plate was manifested in a complex manner either in the form of epeirogenic movements leading to differential vertical uplift or sagging of different segments of Himalaya, causing marine transgressions and regressions of variable temporal and aerial extent, or lateral movements with rupturing and/or suturing. Along these sutures and other weak planes at intersegmental boundaries extensive sub-aerial to submarine, basic to ultrabasic volcanism has taken place. This volcanism is, however, confined only in the Cretaceous times and so far has not been found to extend in Tertiary part of this cycle.

The sedimentary as well as magmato-tectonic history was different in three different segments of the Himalaya, viz., Indus Suture Zone and to its north, Higher Himalayan belt, and the outer and frontal folded belt.

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The initiation of this cycle saw the rupturing along the Indus-Tsangpo Suture Zone (ISZ) and deposition of Indus Ophiolites and associated melange (3000-4500 m) between Albian-Cenomanian and Maestrichtian (Shanker et al., 1976, 1982) as a consequence of the subduction of Indian Plate under the Asian Crustal Plate. Immediately to the north of ISZ thick pile (2000-3500 m) of marine sediments (Indus Formation) without any trace of synsedimentary volcanism, was deposited unconformably over the basement of emerging Ladakh range essentially made up of pre-existing granites/ granodiorites. This marine sedimentary sequence continued up to Early Eocene times. The suture seems to have closed by Maestrichtian time and two continents must have started colliding at upper crustal levels after Early Eocene (Ypresian - 52 Ma) causing sea to be completely regressed from this area.

The generalised stratigraphy of this cycle in Indus Suture Zone is given below:

| TABLE 10 |
| LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLES VIII & IX |
| INDUS BASIN* |
| INDUS SUTURE ZONE |

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liyan Mio-Pliocene</td>
<td>Conglomerate, gritty sandstone and shale bearing palm leaf and vertebrate fossils</td>
<td>250 to +875</td>
</tr>
<tr>
<td>SANGELUMA</td>
<td>(e) Calc shale-chert-jespar and grit alternations</td>
<td>3000-4500</td>
</tr>
<tr>
<td>GROUP/SAMDO</td>
<td>(d) Basalt (pillow lavas) with calc grit and bands of chert, limestone and shale</td>
<td></td>
</tr>
<tr>
<td>Maestrichtian</td>
<td>(c) Diorite and gabbro intruded by dolerite dykes and sills</td>
<td></td>
</tr>
<tr>
<td>to Cenomanian</td>
<td>(b) Serpentinite, peridotite pyroxenite and dunite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a) Phyllite with flows, tuffs and limestone</td>
<td></td>
</tr>
</tbody>
</table>

Geol. Surv. Ind., Spl. Pub. No. 26
NORTH OF INDUS SUTURE ZONE

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liyan Mio-Pliocene</td>
<td>Conglomerate, gritty sandstone and shale bearing palm leaf and vertebrate fossils</td>
<td>250 to +875</td>
</tr>
</tbody>
</table>

---Unconformity---

INDUS GROUP/

UPPER INDUS FORMATION

(i) Shale-sandstone- grit alternations with thin limestone lenses

Palaeocene

(h) Nummulitic limestone with green calc shale, calc grit, purple and green calc shale bearing gastropod and lamellibranch fossils

to Lower

Eocene

1500 to 3000

LOWER INDUS FORMATION

(g) Purple and green shale-sandstone and grit alternation, conglomerate pebble beds with thin bands/lenses of fossiliferous limestone and arkose

(f) Purple green shale with thin bands of pebbly limestone bearing fossils

(e) Green conglomerate containing boulders/pebbles of granite, quartzite, shale, sandstone and chert

(d) Purple conglomerate consisting clasts of sandstone, shale, granite, quartzite, chert and limestone in arenaceous matrix

(c) Sandstone grit with minor shale bearing gastropod and lamellibranch fossils, arkose and limestone lenses

(b) Grey green splintery shale-siltstone, sandstone, grit alternations

(a) Dull green conglomerate, grit containing clasts of granite, basic rock, sandstone, chert and limestone

* Modified after Shanker et al., 1976, 1982

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Further to the north, in the Shyok valley, the ophiolites and the associated sedimentaries of Shyok Group (Srimal 1982, 1986, 1987) represent the stack of Cycle VII. Though the remnants of an earlier suturing during Permian times are also recorded in the Shyok valley the data base is not sufficient to clearly demarcate these two phases. Thus in fact strictly speaking Shyok Group may be representing the composite undifferentiated sequence from Cycles V to VIII.

To the south of Indus Suture Zone after a brief period of regression the sea again returned to the Higher Himalaya in parts of Spiti-Zanskar, Garhwal, Kumaon resulting in the deposition of "Chikkim Formation" physically overlain by volcanics and associated sediments in Spiti-Zanskar known as Shilakong Ophiolites, and Balchadhura Volcanics (in Malla Johar) which has been radiometrically dated as 107.5 ± 5 Ma (Sinha and Bagdase, 1976). These volcanics have been generally regarded as southward thrusted blocks from the main ophiolite belt of Indus Suture Zone, possibly before the continent-continent collision commenced in Eocene times. No Palaeocene-Eocene sediments are found in Central Himalayas of Kumaon and Garhwal while only Early Eocene Nummulites are found in Spiti-Zanskar and adjoining Chamba-Kashmir areas.

The Abor Volcanics (94-96 Ma) and associated sediments constitute the Cretaceous component of this cycle in eastern Himalaya.

Further to the south a large part of the Lesser Himalaya in Himachal Pradesh, Uttar Pradesh and Nepal, which remained a positive area ever since Cambrian times but for a short marine interlude during Early Permian, was transgressed by a shallow sea at the initiation of this cycle in Late Cretaceous times resulting in the accumulation of Shell Limestone over the Tal Formation (Cycle-IV).

During the Palaeocene-Early Eocene part of this cycle thin cover of marine beds (Subathu Formation was formed over Tal Shell Limestone in H.P., U.P. and Nepal. During the same time continental facies developed in Jammu area, where the coal beds are found interlayered with marine Subathu. In Arunachal Pradesh also the continental facies is identified in the lower part (Geku member) of Yinkionog Formation (overlying the Abor Volcanics) which has yielded plant fossils (Tripathi et al., 1979), while its upper part (Dalbuing Member) have yielded Nummulites (Gaur and Singh, 1980; Tripathi, 1981).
Palaeocene-Eocene sea covered much wider areas in Lesser Himalaya as well as in the developing sag in the frontal zone to its south. Consequently Nummulitics/Subathu Formation is found unconformably overlying widely diverse sequences belonging to different sedimentary cycles like Shell Limestone (Cycle-VIII), Punch-Mandi Formation (Cycle-VI), Krol and Blaini Formations (both of cycle IV), Simla Slates (Cycle III), Riasi Limestone, Bilaspur Limestone, Sataun Limestone (all of Cycle-II).

Thickest accumulations of Subathu crop out along outer Himalayan belt between Satluj and Yamuna valleys. Limestones belonging to Cycle-II form the basement for the Subathu towards the southern edge of the outcrop area in this part of Himalaya. The subcrops of Subathu Formation have so far not been found in any of the deep wells drilled south of its present exposed limit in H.P. and U.P. The northern limit of the Subathu sea in the Lesser Himalaya was at the southern edge of main belt of Cycle-II. The Subathu sequence of this part is exposed as discontinuous patches over the older rocks and is generally unfolded with them and tectonised. This may imply that Subathu sea was confined within linear belts, of variable width, all along the Himalaya possibly controlled by pre-existing topographic and tectonic features.

Regression of sea took place from the entire Himalayan range but for the frontal zone during Late Eocene times, which marks the end of this sedimentary cycle (Cycle-VIII).

Various pulsations and sea level changes during cycles VII and VIII could be broadly synchronous to Yansahanian Tectonic Stage of China, Late Cimmerian and Pyrenean movements in Europe and Nevadian and Laramidian movements in North America.

Strong orogenic movements and uplift in the Himalayan region leading to large scale regression of sea in Late Eocene times and initiation of the development of foredeep in the south could be regarded as the beginning of Himalayan Orogeny (Himalayan Orogenic Movement-1 = HOM-1). Couple of Sr/Rb whole rock dates in granite and gneisses in the range of $50 \pm 7$ Ma, large number of mineral ages in the granites and metamorphic rocks, in dated events of volcanics and associated intrusives in the range of $42 \pm 8$ Ma indicate a phase of intense syntectonic magmatism and associated thermal event marking the Himalayan Orogenic Movement-1 and associated uplift on one hand and development of well defined fault bound fore deep to its south.
3.9 Sedimentary Cycle-IX (Oligocene to Early Pleistocene)

The Cycle VIII ends with the large scale regression of sea following the first major uplift of the Himalaya, a sequel to the commencement of continent-continent collision.

With a brief hiatus after cycle-VIII, the deposition of Cycle-IX commenced in the newly formed foredeep with the accumulation of thick pile of essentially brackish water sandstone-red shale alternations, variously designated as Murree-Dharamsala Group, Dagshai-Kasauli Formations in NW Himalaya. The main centre of deposition in early part of this cycle was confined to the south of a major tectonic line commonly referred as Main boundary Thrust (= Murree Thrust = Krol Thrust) in contemporary geological literature.

This fault, thus, becomes a boundary fault controlling the sediments of Cycle-IX towards north,. The southern limit of this basin during early part (Murree-Dharamsala sedimentation) must have been an incipient fault plane, whose present day trace could be the Foot Hill Fault marking the northern limit of Ganga Alluvium. The inference is drawn based on the observation that Murree-Dharamsala sediments were not encountered below the Siwaliks in any of deep structural wells drilled in Ganga Valley, and Siwaliks were found to rest directly over the basement of older cycles.

In the southern part of Arunachal Pradesh, the Barail, Tipam and Dihing Formations represent sediments deposited during the period of this cycle and the Disang Formation of earlier cycle (Cycle-VIII). These sediments are the extension of Assam Tertiary and thus belong to different regime than that of Himalayan Foothill belt. Even then, these have been shown in the Table 1-a, legend and map (Plate I-3) to suggest the possibility of interconnection of the Himalayan basin and the Assam-Bengal basins during upper part of this cycle in the eastern part of the Himalaya.

In Early Miocene times the next phase of major Himalayan uplift and folding took place. This is designated as Himalayan Orogenic Movement-2 (HOM-2). It coincides with series of granitic intrusions and re-setting of mineral ages in the metamorphic sequences of the older cycles in the age range of 20 + 5 Ma. As a result of this movement the foredeep to the south of rising Himalaya shifted further southwards during the later part of Cycle-IX. Now the fluvial conditions prevailed and the thick pile of Siwalik molasse was deposited. The main centre of deposition during later part of Cycle-IX (Siwalik time) was, in general, limited in the north by what is presently known as Main Boundary Fault (MBF) in the literature. The Siwalik foredeep
covered large part of alluvial plains of Punjab, U.P. and Bihar as those sediments were encountered resting over older basement rocks in number of drill holes.

Further to the north, in the Indus Suture Zone between rising Himalaya and Ladakh ranges, another basin developed where moderate thickness (250-800 m, Table-10) of fluvial deposits similar to those of Siwaliks were deposited. They are designated as the Kargil molasse, Liyan Formation in Indus valley, and Kailash conglomerates in Tibet/Nepal. The cycle continued until Early Pleistocene times.

The sediments of Cycles-VIII and IX in the Lesser Himalayan belt have been studied in great detail during the course of systematic hydrocarbon exploration. Very exhaustive details are available concerning stratigraphy, sedimentation, palaeontology and limited details on magneto-stratigraphy supported by subsurface information based on geophysics and structural drilling (Karunakaran and Ranga Rao, 1976; Many papers Proc. Himalayan Geology Seminar, 1976, Sec. III, GSI Misc. Pub. 41, Pt-V; Raiverman et al., 1983; Ranga Rao et al., 1988; Batra, 1989)

3.10 Sedimentary Cycle-X (Late Pliocene to Late Pleistocene)

Even before the sedimentation of the cycle IX was completed a major uplift in parts of Himalaya in the Pir Panjal Range (J&K) took place during the Early Pliocene times, which initiated the sedimentation of lacustrine deposits Karewa Formation of the Kashmir Valley, simultaneously with the Upper Siwalik in the frontal belt. Mineral ages of some granites, aplites, pegmatites in the range of 3.5 ± 1 Ma may be connected with plutonism during this phase of Himalayan Orogenic Movement (HOM-3). This period also witnessed the uplift of Central Himalayan Range and gradual exposure of the core portions containing higher grade metamorphic rocks to the erosional agencies. This gradual emergence of the Central Crystallines is evident in the progressive increase in the higher grade of metamorphic minerals as heavy mineral residue in the sediments from Lower Siwalik to Upper Siwalik.

The fourth uplift (HOM-4) took place after Early Pleistocene time which saw and end of the thick Siwalik sedimentation and also of the Cycle-IX in the frontal zone, and the development of an angular unconformity between Lower and Upper Karewa. The general lithostratigraphy of Karewa Group, which represents the Cycle-IX in Kashmir valley is given in Table-11.
### TABLE 11

**LITHOSTRATIGRAPHY OF SEDIMENTARY CYCLE - X**

**KAREWA GROUP**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Lithology</th>
<th>Measured Thickness (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>Holocene</td>
<td>Sand and silt</td>
<td></td>
</tr>
<tr>
<td>Dilpur</td>
<td>Upper Pleistocene</td>
<td>Continental loess and reworked loess</td>
<td>20-50</td>
</tr>
<tr>
<td>Nagum</td>
<td>Shupiyan/Middle Rampur/PleistoceneKrungus</td>
<td>Yellow silt, grey clay, calcareous layers and sand with conglomerates in the marginal areas Environment: Terrestrial, braided stream and lake deltas</td>
<td>40-135</td>
</tr>
</tbody>
</table>

---

**Unconformity**

| Methowain | Grey clay, silt, lignitic | 400 |
| Pliocene-Upper | mud, sand and conglomerate Environment: Lake delta with braided stream sub environment |
| Pliocene-Lower | |

| Hirpur | Rembiara | Conglomerate | 200 |
| Pliocene-Middle | Environment: Alluvial fan, braided stream |
| Pliocene-Lower | |

| Dubjan | Grey clay, silt, lignitic mud, lignite and green sand Environment: Lake delta | 600 |
| Pliocene-Lower | |

---

* After Bhatt, 1989

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The post-Siwalik uplift (HOM-4) also activated the southern margin of the Himalaya as a result of which the deposition of Dun Gravel in the intermontane valleys took place. Large scale fans developed on the southern face of the emerging mountain, which can be traced for considerable distance under the Ganga Alluvium.

3.11 Sedimentary Cycle-XI (Late Pleistocene to Holocene)

During Late Pleistocene-Holocene times, the uplift of Himalaya continued due to isostatic adjustments and related epeirogenic movements as the Himalaya attained its present geomorphic proportions. Accumulations of fluvio-glacial deposits, loesses, lacustrine clays and river terraces/alluvium were the main deposits in different parts of the Himalaya, whereas the alluvial and lacustrine deposits were the prime deposits in the planes of Punjab and Ganga Basin. Evidences of neotectonic activity along the pre-existing structural planes (both longitudinal and transverse) have been noticed and shall be discussed elsewhere in this Volume.

4 ASSOCIATED GEOLOGICAL AND TECTONIC EVENTS

Based on the stratigraphic information presented in the preceding section, an attempt has been made to reconstruct the evolutionary history of sequences exposed in the Himalaya, and also to identify different tectonic events (table-12).

TABLE 12
MAJOR GEOLOGICAL AND TECTONIC EVENTS

<table>
<thead>
<tr>
<th>Sedimentary Cycles</th>
<th>Major Geological Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>XI</td>
<td>(d) Formation of soil;</td>
</tr>
<tr>
<td></td>
<td>(c) Neotectonic activity along major longitudinal and transverse faults continued triggering earthquakes, landslides etc.;</td>
</tr>
<tr>
<td></td>
<td>(b) Thick alluviation in Ganga Fore deep, river terraces, fluvio-glacial and lacustrine deposits in the Himalaya;</td>
</tr>
</tbody>
</table>
(a) Tilting of terraces; occasional overthrusting of Dun Gravels and Upper Siwalik over alluvium

Isostatic uplift of Himalaya continued 50-100 x 10^3 yrs

(e) Development of present 'Fore Deep' and drainage in Punjab and Ganga Plains; deposition of fanglomerates on outer margin of the Himalaya extending deep into Ganga Valley; deposition of glacial moraines;

(d) Deposition of Dun Gravels;

(c) Uplift and tilting of Lower Karewa leading to development of angular unconformity with the Upper Karewa;

(b) Folding of the Siwaliks;

(a) Himalaya attained its present geomorphic proportions

---Himalayan Orogenic Movement (HOM-4) (0.8-0.5 Ma)---

IX

(1) Emergence of Pir Panjal range and formation of "Karewa Basin" in Kashmir and deposition of the Lower Karewa;

(k) Uplift of Central Crystalline axes and exposure to erosional agencies contributing high grade metamorphic minerals (e.g. kyanites, sillimanite) as heavy minerals to the Upper Siwalik in Frontal Zone

---Himalayan Orogenic Movement (HOM-3)---

(j) Migmatisation and intrusion of granites around 3.5 + 1 Ma;

(i) A phase of hypabyssal acid magmatism in age range of 9 + 2 Ma;

(h) Development of Molasse basins in the Frontal zone, and in between the rising Zanskar and Ladakh/Karakoram ranges;

(g) Uplift of Himalaya upto Main Boundary Fault (MBF), currently forming boundary between Palaeogene and Neogene Folding of Palaeogene sediments;

(f) 2nd Himalayan Orogenic Movement (HOM-2) accompanied by intense acid plutonism and metamorphism around 20 + 5 Ma;

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(e) Periodic uplift continued with deposition; reactivation of older 1St. order structural elements; southward movement of thrust sheets also continued; period of plutonism and migmatization around 27 ± 2 Ma;

(d) Formation of fore deep in front of rising Himalayan bounded by Main Boundary Fault - MBF₁ - (MBT = Krol Thrust = Murree Thrust) in the north and "Foot Hill Fault (MBF₃) in the south. In this foredeep deposition of thick pile of brackish water sediments (Murree-Dharamshala Formation) took place;

Uplift and thrusting of older basements over their cover rocks. All major pre-existing structural planes were also reactivated;

(b) Large scale regression of sea from Higher Himalayas and to its north leading to periods of non-deposition and erosion;

(a) Folding and uplift;

---Himalayan Orogenic Movement (HOM-1)---

VIII

(i) Collision of Indian Burmese and Asian plates commenced in middle Eocene (40 - 45 Ma)

(h) Uplift associated with each phase of acid plutonism;

(g) Periodic acid magmatism, migmatisation and resetting of mineral ages took place in 99 ± 4, 80 ± 3 and 60 ± 5 Ma culminating with 45 ± 5 Ma;

(f) Eocene transgression was much more widespread than that of Upper Cretaceous covering large parts of Lesser and Higher Himalaya;

(e) Deposition of marine sediments without associated volcanism unconformably over the emerging Ladakh range north of Indus Suture Zone between 110 - 45 Ma;

Indus Suture closed around 65 Ma, but Shyok Suture Zone remained active until much later period;

(c) Extrusion of Indus Ophiolites (110 - 65 Ma) along with associated melange in Indus Suture Zone; Khardung Ophiolites in Shyok Suture Zone 63 ± 8 Ma); and Abor Volcanics (94 - 66 Ma)

(b) Middle Cretaceous Marine transgression covering large part of Himalaya;

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(a) Opening of Indus Suture and commencement of subduction of Indian Plate underneath Asian Crustal Plate in the north, and subduction of Indian Plate under Burmese Plate in the northeast.

VII
(d) Marine conditions persisted in Higher Himalaya and regression of sea took place at the end of Early Cretaceous;
(c) Appearance of Upper Gondwana Flora in parts of Nepal and submergence of part of Himalaya;
(b) Phase of mineral resetting in metamorphic rocks and migmatisation around $160 \pm 14$ and $154 \pm 6$ Ma; and a volcanism in Indus Suture Zone in $157 \pm 3$ Ma;
(a) Lesser Himalaya remained a positive area;

VI
(g) Epeirogene movement leading to temporary withdrawal of sea;
(f) Stability of basin in Higher Himalaya where marine conditions prevailed with deposition of carbonates;
(e) Limited regressions and transgressions also alternated;
(d) Phases of acid magmatism, mineral resetting and thermal event around $250 \pm 10$ Ma, $190 \pm 12$ Ma; phases of basic and acid magmatism seems to be alternating in quick succession;
(c) Evidences of rifting associated with basic volcanism, possibly connected with the fragmentation of Gondwanaland are present; widespread basic volcanism both subaerial and submarine in $285 \pm 25$ Ma; $228 \pm 10$, and $188 \pm 1$ Ma age range;
(b) Widespread transgression in Lesser Himalaya and associated deposits after melting of glaciers due to warm humid climate; and appearance of Glossopteris flora;
(a) Widespread glaciation (?) and regression;
(e) Widespread acid magmatism and intrusion of Leucogranites associated metamorphism and mineral resetting around $330 \pm 30$ Ma and uplift leading to regression;

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(d) Marine conditions prevailed in Higher Himalaya with periodic transgressions of sea due to fluctuations of basin floor connected with periodic epeirogenic movements in Early Carboniferous;

(c) Maximum development of Rhacopteris flora. Appearance of vascular plants in Early Devonian;

(b) A phase of basic intrusions is recorded around $410 \pm 10$ Ma; and acid plutonism around $440 \pm 15$ Ma;

(a) Land conditions prevailed in Lesser Himalaya due to widespread regression;

IV

(d) Uplift and widespread acid magmatism and metamorphism in Himalaya during $525 \pm 50$ Ma;

(c) Rapid evolution of life diversification and development of hard parts in animals and appearance of calcareous algae;

(b) Stable platform conditions prevailed with period of extensive phosphatogenesis; carbonate formation with evaporites in localised areas;

(a) Transgression with accumulation of diamictites and boulder beds.

III

(e) Regressive phases due to uplift in provenance area;

(d) Intrusion of granites around 1000 and 725 Ma; and metamorphism in $850 \pm 30$ Ma;

(c) Synsedimentary volcanism is almost absent. However, phase of basic intrusions (dykes/sill) is recorded around $700 \pm 10$ Ma;

(b) Deposition of thick pile of stable to unstable platform deposits with occasional development of Evaporite facies. Basal conglomerate is generally present where contact with lower cycle is exposed;

(a) Many transgressions and regressions;

II

(b) Crustal movements; block uplifts associated with syntectonic granitic intrusions and metamorphism in age range $1090 \pm 65$, $1300 \pm 70$ and $1590 \pm 65$ Ma; and rifting/basin developments with synsedimentary volcanism (only one date $1190 \pm 35$ Ma is available);
Deposition of thick pile of carbonates with algal stromatolites of lower and middle Riphean affinity and occasional phosphorites. It is preceded and succeeded by accumulation of quartzite-shale volcanic association indicating deposition in active extensional areas. Sulphide occurrences are innumerable. Base of sequence not clearly decipherable. Could also be transitional;

Period of uplift and erosion

(b) Three phases of acid plutonism/migmatisation and metamorphism is recorded around 1600, 1850 ± 100 Ma and 2200 ± 125 Ma;

(a) Deposition of thick pile of sediments undergone polyphase deformation and regional metamorphism from green schist to amphibolite facies. Granulite facies is absent.

Archaean absent or not exposed

An exercise has also been made to recognise the imprints of global tectonic events present and/or preserved within different sedimentary cycles identified in the Himalaya (Table-13).

**TABLE 13**

**TECTONIC STAGES IN EVOLUTIONARY HISTORY OF SEDIMENTARY CYCLES**

<table>
<thead>
<tr>
<th>Sedimentary cycles</th>
<th>TECTONIC STAGES (TS) AND OROGENIC MOVEMENTS (OM) WITH AGES (IN MILLION YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Himalaya</td>
</tr>
<tr>
<td>XI</td>
<td><strong>HIMALAYAN TECTONIC STAGE</strong></td>
</tr>
<tr>
<td>Isostatic uplift</td>
<td>5-10x10^4 yrs</td>
</tr>
<tr>
<td>Time Interval</td>
<td>Event Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>--X--</th>
<th>HOM-4</th>
<th>5-8 x 10^8 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Himalayan</td>
<td>YOUNG</td>
</tr>
<tr>
<td></td>
<td>OM-2</td>
<td>ALPENIDS TS</td>
</tr>
<tr>
<td></td>
<td>(1.5-2)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IX</th>
<th>HOM-3</th>
<th>(3.5 ± 1.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rodahian OM</td>
<td>(3.5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HOM-2</th>
<th>(20 ± 5) Himalayan</th>
<th>Savian OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM-1</td>
<td>(25)</td>
<td>(25)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>------</th>
<th>HOM-1</th>
<th>(40-45)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YANSANIAN</td>
<td>TS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VIII</th>
<th>Sutures closed</th>
<th>Yanshanian</th>
<th>Laramidian</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OM-3</td>
<td>(57-60)</td>
<td>OM (65)</td>
</tr>
<tr>
<td></td>
<td>Yanshanian</td>
<td>OM-2</td>
<td>(100-105)</td>
</tr>
<tr>
<td></td>
<td>subduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OM-1</td>
<td>(160)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VII</th>
<th>Stable conditions</th>
<th>Epeirogenesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Magmatism</td>
<td>Yanshanian</td>
</tr>
<tr>
<td></td>
<td>OM-1</td>
<td>(160)</td>
</tr>
<tr>
<td></td>
<td>OLD</td>
<td>ALPENIDS TS</td>
</tr>
<tr>
<td></td>
<td>Late</td>
<td>Cimerian OM</td>
</tr>
<tr>
<td></td>
<td>Nivedian</td>
<td>OM (155)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>VI</th>
<th>Unstable to stable</th>
<th>Indonesian</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Platform</td>
<td>OM-1 &amp; 2</td>
</tr>
<tr>
<td></td>
<td>Basic volcanism</td>
<td>(215-230)</td>
</tr>
<tr>
<td></td>
<td>Yiningian OM</td>
<td>(275 ± 5)</td>
</tr>
<tr>
<td></td>
<td>Alleghenian</td>
<td>Pfalzian OM</td>
</tr>
<tr>
<td></td>
<td>OM</td>
<td>(248)</td>
</tr>
</tbody>
</table>

<p>|   | Stable | HERCYNIAN |
|   | Platform | TS |</p>
<table>
<thead>
<tr>
<th>Era</th>
<th>Event Description</th>
<th>Time Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Acid Plutonism &amp; Sedimentation</td>
<td>(300)</td>
</tr>
<tr>
<td></td>
<td>Tianshanian &amp; Sudetian</td>
<td>(330 ± 30)</td>
</tr>
<tr>
<td></td>
<td>CALEDONIAN &amp; Acadian</td>
<td>(325)</td>
</tr>
<tr>
<td></td>
<td>Qillianian CALEDONIAN</td>
<td>(390-400)</td>
</tr>
<tr>
<td></td>
<td>Acadian TS</td>
<td>(410)</td>
</tr>
<tr>
<td></td>
<td>Gulangian CALEDONIAN</td>
<td>(450)</td>
</tr>
<tr>
<td></td>
<td>Salarian OM</td>
<td>(500-510)</td>
</tr>
<tr>
<td></td>
<td>Assyntian OM</td>
<td>(525 ± 50)</td>
</tr>
<tr>
<td></td>
<td>Xingkaian OM</td>
<td>(530)</td>
</tr>
<tr>
<td></td>
<td>Assyntian OM</td>
<td>(570-580)</td>
</tr>
<tr>
<td>III</td>
<td>Stable Shelf Chengji-condition Plu-</td>
<td>(700)</td>
</tr>
<tr>
<td></td>
<td>tonism &amp; metamorphism (725)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jinningian OM</td>
<td>(725)</td>
</tr>
<tr>
<td></td>
<td>Sibaoan OM</td>
<td>(1100)</td>
</tr>
<tr>
<td></td>
<td>Zhongyucan Karelian Hudsonian OM</td>
<td>(1500-1600)</td>
</tr>
<tr>
<td></td>
<td>(1600 Ma)</td>
<td></td>
</tr>
</tbody>
</table>

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The review and analysis of data presented in Tables 12 & 13 indicate that the sedimentary record of the Himalaya represents almost a complete record of Earth's history from Proterozoic to Recent times.

5 CONSTRAINTS OF PREPARING GEOLOGICAL MAP

Attempts have been made to present a coherent account of the stratigraphy in the Himalaya with details of litho-columns where worked out. The data on stratigraphic measurements is very scanty and available only in certain sectors. Besides, strike mapping is yet to be completed. The boundaries of various cycles are often tectonised or not recognised. Thus, with the inflow of additional and critical information, improvement and refinement in stratigraphy and correlations made herein is inevitable.

As major part of the Himalaya is constituted of Proterozoic sequences, which to a great extent are represented by metasediments (metamorphosed from green schist to upper amphibolite facies), granitic gneisses and granites of various ages, the absence of systematic and adequate geochronological data is a major constraint. This has led many Himalayan Geologists to use grade of metamorphism as primary tool for correlating the sequences. Consequently many rock sequences just on their grade of metamorphism were equated with the Central Crystallines of Kumaon and Garhwal Himalaya though on gross litho-association, enclosed biota(?) and dated magmatic episodes they may be younger. An attempt
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has been made towards resolving this problem. Satisfactory solution should await extensive geochronological work and extensive search and study of pre-Cambrian biota in favourable lithofacies.

Till mid-seventies the fossil records in Himalaya were known to be restricted in a few belts viz. the Tethyan Sequence, the Tertiary Belt, isolated Eocene exposures over different sequences, Tal Shell limestone of Cretaceous age and a few exposures of rocks of Permo-Carboniferous age in Lesser Himalaya. In the absence of proper fossil records, age assignments to all other formations was dependant on their stratigraphic position relative to Blaini Boulder Bed and its supposed equivalents, which was correlated with the Talchir Boulder Bed (Permo-Carboniferous stage) of Gondwana Super group. Since the find of Early Cambrian trilobites, brachiopods, small shelly fossils and other fossils from the rocks of Tal Formation (considered earlier as Jurassic-Cretaceous in age) and early ostracods, coelentrates, algae and shelly fauna from Krol Formation the picture of Himalayan stratigraphy has sufficiently changed. In addition, upper Proterozoic biota has also been recovered from various sequences, specially in the western sector of the Himalaya, which were hitherto considered as unfossiliferous. These finds provided an opportunity to have a totally new perspective to the problem of establishing stratigraphy in the Himalaya. This has greatly helped in solving some of the problems and better understanding of the stratigraphy. But a constraint remains as very little data is available to resolve age relations of many other unfossiliferous sequences. Systematic search and study of pre-Cambrian biota must be pursued to date and establish inter-regional correlation which is otherwise difficult because of polyphase deformation and tectonic translation of various sequences. Precise radiometric dating of synsedimentary volcanic flows would be needed to fix chronostratigraphic placements.

Sedimentary environment during different cycles have been commented upon under description of individual cycles. It is seen that but for narrow stretch along Indus and Shyok suture zones, the litho assemblages, sedimentary features/structures, fossil contents in the Himalayan sequences indicate deposition in a shallow sea under stable and unstable platform conditions. Even in Carboniferous and Permian times, when the Tethyan Geosyncline according to earlier prevalent view had originated after the Hercynian Orogeny, the sediments deposited show alternating plant and marine fossil bearing beds or plant bearing beds and lava flows all indicating near coastal basin conditions. Also an earlier view that the Cambrian and Lower Palaeozoic sea was restricted north of the Great Himalayan Range (Central Crystal lines) does not appear to hold good any more in view of fossil finds in the Tal Formation. Thus, the Lower Palaeozoic Phulchauki

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Group in Kathmandu area need not necessarily be considered (as per existing and prevalent view) as part of northern Tethyan sequence having come to present position as an allochthonous mass. It could just be authochthonous to parautochthonous. A similar argument could also be advanced for Kashmir Nappe and needs careful reconsideration.

Mapping in the Himalaya had been carried out at different times with the varying concepts. This has resulted in the preparation of maps which lack uniformity and differ in geological details. Integrating these maps with those containing updated lithological and palaeontological data along with measured stratigraphic columns at times becomes hazardous as liberal generalisations are made. Some of the revisions made, based on deductive logic alone, and incorporated in plate I may, therefore, appear to be too imaginative and conjectural but could not be avoided. However, these may have to be verified by studies in the critical areas during second generation mapping.

6 STRATEGY FOR FUTURE STUDIES

With a view to reconstructing a coherent picture of geological evolution of the Himalaya multidisciplinary concerted programmes, with fair amount of inputs from geology, geophysics, geochemistry, geochronology and isotope geology, will have to be designed along carefully selected sections ("transacts") across the Himalaya commencing from northern edge of Indian Shield. The major thrust of the work should include:

(a) Systematic geological studies along measured stratigraphic sections;

(b) Systematic search and study of biota from favourable lithofacies in the entire geological column;

(c) Dating of magmatic episodes and their thermal histories, their relationship to metamorphic facies, palaeo-thermal regimes, tectonic episodes;

(d) Dating of periodic uplift of Himalaya, its relationship to development of sedimentary basins (including Quaternary Basins) and lithostratigraphic sequence and formation of bedded economic mineral deposits;

(e) Geomorphic evolution of the Himalaya and Neotectonism; development of drainage system and imprints of periodic uplift in the sediments of Gangetic Alluvium;
(f) Detailed geochemical inputs (major, minor, trace element) are needed for all types of magmatic, metamorphic, sedimentary sequences to get an insight into the processes of magma generation, emplacement, metamorphism provenance of sediments and mineralisation prospects;

(g) Intensive and extensive geophysical inputs to attempt studying deep intra- and infra crustal structures underneath the Himalaya and their relationship to structural fabric; seismotectonics, neotectonics and seismicity. This will also help study deep structures and delineate extension of tectonic/ structural features of the Shield area underneath the Himalaya.

Proper integration and synthesis, evaluation and interpretation of the data generated would facilitate proposing model(s) of Himalayan evolution for eventual testing by deep drilling.

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METAMORPHISM AND MAGMATISM IN THE HIMALAYA

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ABSTRACT

The Himalayan tectogene is the product of a protracted period of stratigraphic, structural, metamorphic and magmatic development. The bulk of the Himalayan rocks is Proterozoic in age, and they record imprints of polymetamorphism. Although the principal phases of metamorphism of these rocks is Mesozoic to Cenozoic, it is possible that older events are preserved as vestiges. The Metamorphic Facies Map of the Himalaya, presented in this paper, is a composite map, depicting the regional facies distribution, and showing that greenschist to amphibolite facies domains are restricted to the Proterozoic sequences. A paired metamorphic belt of low-P/T and high-P/T is present in the Ladakh suture zone while most of the Tethyan sequence is very low grade. One of the problems of Himalayan metamorphism pertains to the mechanism by which the Tethyan Phanerozoic and Cenozoic sequences escaped regional metamorphism while their substrate has been metamorphosed and migmatised in the Mesozoic-Cenozoic times. The other problem is the inverted metamorphism whose satisfactory explanation is not yet available. One of the plausible explanations involves the Main Central Thrust (MCT) which modified the thermal structure and whose 'hot-iron' effect produced the metamorphic inversion at the base of the MCT.

The Himalayan granitic activity has a large time span. Apart from the Mesozoic-Cenozoic granitoids of the Higher and the Trans-Himalaya, the Proterozoic sequences contain granitoid bodies that have yielded Middle to Late Proterozoic and Early Palaeozoic ages. The Proterozoic granitoids are often thrust-bound, and they may represent tectonic wedges of the basement of the metasedimentary cover sequences. The subduction-related tectonic setting for the Trans-Himalayan batholiths does not obtain for the Higher Himalayan granite plutons whose relation with the Himalayan metamorphism and tectonics is not clearly known. The Proterozoic basic volcanics are essentially tholeiitic (Mandi-Darla) to calc-alkaline (Daling) which would signify the

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different geotectonic regimes of the Proterozoic phases of basin opening and closing in the Himalayan region. Palaeozoic rift-related basic volcanics are present in Kashmir (Panjal), Sikkim (Gondwana) and Arunachal Pradesh (Abor), although the latter has a young (Cretaceous-Eocene) component. The suture zone in the Himalaya contains ophiolite with its various magmatic components in Ladakh and Shyok regions.

1 INTRODUCTION

The concepts and ideas on the evolution of the Himalaya are many, and they have changed with the availability of new data and introduction of new approach to the interpretation of young mobile belts. The Alpine geosynclinal models are inadequate for direct application to the Himalaya because of inherent constraints, and hence, these were modified by invoking large-scale basement involvement. It is realised that much of the geologic and tectonic attributes of the Himalaya can be accommodated in plate tectonic models, and that the evolution of the Himalaya must incorporate aspects of a high degree of crustal shortening to account for the large distance of drift of the Indian Plate. Indeed, recent studies in the various fields of Himalayan geology, including metamorphism and magmatism, have indicated that the uniqueness of the Himalaya lies in its mode of origin via plate convergence, extended to the ultimate stage of plate collision and even beyond to underplating.

The Himalayan tectogene is thus considered a classic example of continent-continent collision system. Much of the tectonic setting, metamorphic attributes and magmatic sequences of the Himalaya are considered to be the response of an advanced stage of intracontinental subduction that followed the collision of the Indian and the Asian plates. Except for the Tethyan zone the bulk of the rocks of the Lesser and the Higher Himalaya is composed of crystalline sequences of variable Precambrian ages whose significance to the Cenozoic evolution of the Himalaya is uncertain. These contain an evolutionary history in the Precambrian whose linkage with and control on the Cenozoic history of the mobile belt are also not clearly known. Because of these uncertainties and constraints tectonic modelling of the Himalaya has suffered from inadequacies. Various models have been proposed, but many of these are not well constrained by relevant data. The plate tectonic models are, however, strongly favoured and are deeply entrenched in the literature, albeit there are many differences in detailed aspects among the various plate tectonic models because of constraints set by lack of adequate data on geochronology, geochemistry and tectonostratigraphy.
Metamorphic and magmatic aspects are important components of tectonic models. These aspects are, however, not well-constrained for the Himalaya, yet the existing information is useful in providing an idea about the significance of these aspects on tectonic modelling and also to identify the constraints of these models.

2 METAMORPHISM

The tectonostratigraphic development of the Himalaya and the imprints of major deformation and metamorphic events allow for identification of several longitudinal zones in the Himalaya. The complex geologic setting of South Tibet continues in the Karakoram-Shyok region where the sedimentary sequences of various ages that have undergone a complex syn- and post-collisional metamorphic history, are cut by Mesozoic and Cenozoic plutonic rocks. The Trans-Himalayan batholith (the Ladakh pluton) extends along the northern flank of the Himalaya and consists of calc-alkaline intrusives ranging in age from 100 to 40 Ma. The main Himalayan suture, the Indus-Tsangpo suture zone, lies to the south of this immense Cordillera-type batholith. The Himalaya proper, lying to the south of the Indus-Tsangpo suture is divided into two major units. The Higher Himalaya is made up of a thick sequence of Cambrian to Eocene sediments in the Tibetan Tethys zone and they overlie Proterozoic metamorphic rocks of the Central Crystalline zone. The rocks of the Higher Himalaya are separated from those of the Lesser Himalaya by the Main Central Thrust (MCT), although the exact position of the MCT has been debated in recent years. The Lesser Himalaya comprises low-grade Proterozoic to Cenozoic metasediments. To the south of the Lesser Himalaya and separated from it by the Main Boundary Fault (MBF) are the Sub-Himalayan Murree and Siwalik sediments.

There is no published metamorphic facies map of the Himalaya, except for regional metamorphic maps of the Eastern Himalaya (Sinha Roy, 1977, 1981) and the Himachal Pradesh (Bhargava and Chopra, 1981). The Metamorphic Facies Map (Plate-1), compiled from available information from various sources is a preliminary one and is subject to refinement. This map also shows the distribution of the major granitoid bodies of different ages. It is evident that the metamorphic facies distribution follows a pattern that is likely to have been controlled by tectonic development, particularly by the major dislocation zones such as the MCT which appears to be a deep crustal feature. The zonal boundaries are folded by NE-SW and NW-SE regional folds in the Western Himalaya, and dominantly by N-S and E-W regional folds in the Eastern Himalaya which belong to the last generation, and available evidences indicate neither imbricate thrusting nor isoclinal folding of the metamorphic zones.
Himalayan metamorphism is essentially Barrovian with minor contact metamorphic signatures around major plutons. Misch (1949) described zonal metamorphism reaching up to kyanite grade and migmatite formation around the Nanga Parbat massif. The metamorphism in the Karakoram is complex and polystadial. Although the early phases are related to plutonic activity, the main Barrovian sequence in the Karakoram region is possibly Eocene, and may be associated with the emplacement of the Trans-Himalayan batholith. On the Metamorphic Facies Map the Karakoram-Shyok area is shown to be anchimetamorphic to lower greenschist facies which includes both the ophiolite ensemble and the sedimentary sequences of the Shyok suture zone.

The rocks of the Indus suture zone are in the greenschist facies with patches of blueschist facies rocks in the ophiolitic melange zone, thus providing an example of paired metamorphic belt. Frank et al. (1977) reported blueschists along the Paskhyum Thrust near Kargil. Blueschists have also been reported from areas east of Lats (Virdi et al., 1977; Jan, 1985). Glaucophane from blueschists of the Swat area to the west of the Nanga Parbat syntaxis has yielded dates of $100 \pm 20$ Ma and $67 \pm 12$ Ma (Maluski and Schaeffer, 1982), thus constraining the age of suturing.

In Kohistan the lower structural levels of the ophiolite zone contain granulite facies rocks (Jijal Complex) (Barnicoat and Treloar, 1989), but such a situation has not yet been recognised in the Ladakh area. Berthelsen (1953) reported eclogite within the gneisses of Jobashisha nala in Rupshu, but no recent work has been carried on these rocks. The Tethyan sequences of the Spiti and Zanskar basins are essentially anchimetamorphic, but lower greenschist facies assemblages have developed at lower structural levels near the Central Crystallines. One of the major problems of Himalayan metamorphism pertains to the absence of appreciable metamorphic imprint on the Tethyan sequences (Cambrian to Eocene) in contrast to the underlying Central Crystallines that have been metamorphosed to Amphibolite facies in Tertiary time. An explanation for this feature has been sought in normal faulting at the contact of the Central Crystallines and the Tethyan sequence that allowed the latter to escape syn-tectonic Himalayan metamorphism (Barnicoat and Treloar, 1989). This explanation, however, needs validation for the Tethyan sequence setting all along the Himalaya.

In the rocks of the Central Crystalline Zone and in the Lesser Himalayan metamorphites progressive Barrovian zonal sequences showing an inverted disposition can be recognised. Inverted metamorphism, meaning an increase in the metamorphic grade in the higher structural levels, is a characteristic feature of metamorphism of the Central Crystalline rocks and a part of the
Lesser Himalayan metamorphites. The foothill belt of the Siwaliks, and the Murrees are nonmetamorphic in character. The rocks of the Lesser Himalayan parautochthonous belt, namely, the Gondwana in the Eastern Himalaya and the Krol-Tal-Subathu sequences in the Western Himalaya, both of the frontal belt as well as of the Window zones (Eastern Himalaya), are either anchimetamorphic or in the lower greenschist facies. A lower greenschist facies assemblage of chlorite + biotite and upper greenschist facies assemblage of biotite + garnet + staurolite have developed in the Lesser Himalayan metamorphites, but these are too narrow to be depicted on the scale of the Metamorphic Facies Map, and hence, these two facies domains are shown under greenschist facies. Similarly, it is possible in many areas, namely, in the Almora Crystalline belt and in Sikkim-Darjeeling area, to separate the lower amphibolite facies (staurolite-out + kyanite) and the upper amphibolite facies (K-feldspar + sillimanite + anatectic melt) but since the lower amphibolite facies domain is narrow and is copiously developed, it is shown together with the upper amphibolite facies under Amphibolite Facies.

In the Western Himalaya the metamorphites of the Higher and the Lesser Himalaya exhibit greenschist to upper amphibolite facies metamorphism. Although the definition of the MCT is problematic on the west of the Sutlej river, this dislocation zone marks the boundary between the greenschist facies and the amphibolite facies in the Garhwal Himalaya. The Almora klippe is essentially in the amphibolite facies with a central zone of greenschist facies rocks in the southeast that continue into Nepal, and a zone of upper amphibolite facies in the northwest.

The Jutogh thrust sheet is in the lower amphibolite facies while its substrate is in the greenschist facies, thus showing an inverted metamorphic sequence. The Jutogh thrust sheet in its higher tectonic levels contains upper amphibolite facies assemblages. The Jutogh rocks, traced from the type area, are tectonically concealed beneath the amphibolite facies rocks of the Vaikrita Group that occupies a tectonic position similar to that of the Central Crystallines near Karcham in the Sutlej Valley (Bassi, 1989). As the amphibolite facies rocks are truncated at the Vaikrita thrust (=MCT) this thrust in the Kulu area is between lower and upper greenschist facies rocks. Amphibolite facies rocks reappear in the Central Crystallines of the upper reaches of the Chenab river and around the Kishtwar window. The relationship of metamorphic facies with the MCT in the area is problematic because the MCT might be located within the greenschist facies terrains to the south of the Chamba basin. The amphibolite facies rocks of the Central Crystalline zone of...
RELATION OF METAMORPHIC ZONES WITH MCT

Fig. 2.1

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southern Zanskar is probably tectonically juxtaposed against the greenschist facies rocks representing an island arc-ophiolitic terrace of Dras-Kargil areas.

In the Eastern Himalaya the greenschist facies assemblages, represented by the Daling sequence, is delimited in the north by dislocation zone (MCT-I of Sinha Roy, 1988) at the base of the tectonised slivers of the Lingtse Gneiss and in the south by the thrust (MCT-II of Sinha Roy, 1988) at the contact of the Gondwana rocks (Fig. 2.1).

This greenschist facies stack pinches out in Central Bhutan where lower amphibolite facies Thimpu Gneiss (shown under Amphibolite Facies on Metamorphic Facies Map) has encroached the foothill zone. At the lowest structural level of the Daling thrust sheet near MCT-II in the Sikkim Window zone, moderate-pressure and low-temperature metamorphism characterised by transitional glauconphanitic actinolite in metagraywacke has been reported by Sinha Roy (1975, 1977b). This metamorphism is considered to be due to thrusting deformation in low-temperature lower greenschist facies domain.

The greenschist facies rocks reappear in western Arunachal Pradesh, and they lie between the foothill Gondwanas and the amphibolite facies Central Gneisses, intruded by Tertiary granite plutons. The Bomdila Gneiss, yielding 1500 to 500 Ma age dates, are considered to be tectonised composite pluton of a possible basement complex (Sinha Roy, 1978) which is surrounded by the greenschist facies rock sequences. The Lohit thrust separates the Tidding ophiolite (?) zone in the upper greenschist facies and the Mishmi massif comprising dominantly of diorite and granodiorite and suspected enclaves of upper amphibolite facies rock sequences.

2.1 Age of Himalayan Metamorphism

It has been generally recognised that the rocks of the Lesser Himalaya and of the Central Crystallines are polymetamorphic in character. Since the bulk of these rocks is Proterozoic, they are likely to contain metamorphic imprints of different ages that are difficult to identify on the basis of available data. Metamorphic facies mapping in the Himalaya is beset with problems arising out of polymetamorphic characters of the rocks, and also of the difficulty in recognising the exact time relations between metamorphic parageneses and deformation sequences and their chronology. Although a number of studies have attempted to relate metamorphism with folding phases in relative terms, the significance of the polymetamorphic characters on the tectonometamorphic evolution of the Himalaya has not yet emerged. The facies maps of any Himalayan
terrain is likely to depict a composite picture of the metamorphic imprints of different ages. However, the pervasive and the most easily recognisable metamorphic mineral assemblages, on whose basis the Metamorphic Facies Map has been prepared, are likely to be the products of Mesozoic-Cenozoic Himalayan metamorphism. This conclusion has the support of the available data on mineral ages and on the timing of emplacement of granite plutons which are mainly Tertiary and a few Cretaceous.

While some workers (McPowell and Conaghan, 1973; Frank et al., 1973) consider all the recognisable metamorphic episodes to be Himalayan, others (Mehta, 1977; Thakur and Pande, 1972; Sinha Roy, 1974; Acharyya, 1979) opined that at least the first recognisable metamorphism in the Lesser Himalayan crystallines is Precambrian. Le Fort et al. (1986) suggested that sillimanite grade metamorphism was attained by the Vaikrita (Central Crystalline) rocks in limited area probably along the extensional tectonic zones in Lower Palaeozoic time, while Sinha Roy (1977a) suggested that the Lesser Himalayan rocks contain vestiges of Hercynian tectonometamorphic imprints.

The arguments in support of Himalayan metamorphism being essentially Cenozoic are as follows. A gradual decrease in the grade of metamorphism takes place from the Precambrian Central Crystalline rocks, showing staurolite to sillimanite grade metamorphism to the Middle Jurassic Tandi Group showing green-schist facies metamorphism. These metamorphic zones are not generally affected by pre-Tertiary isoclinal folds and dislocations.

The presence of schistose xenoliths within Palaeozoic granites (Bassi and Chopra, 1983) and the occurrence of slate and phyllite pebbles of the Himalayan basement rocks in the Precambrian Manjir Conglomerate (Thakur and Pande, 1972) and in the Permian Rangit Pebble Slate (Sinha Roy, 1974) would suggest an older metamorphic event. From the available evidence it would appear that the metamorphic sequence of the Lesser Himalaya and the Central Crystallines had been reworked a number of times, the latest being the Cenozoic event that produced the mappable metamorphic facies pattern. Careful metamorphic mapping accompanied with geochronologic work may delineate older metamorphic terrains, particularly within the Central Crystallines.

2.2 Inverted Metamorphism

Inverted metamorphism, a noteworthy feature of the Himalaya, has drawn the attention of many workers who suggested different explanations for this feature. The inverted metamorphic sequence was recognised in the Jutogh thrust sheet (Pilgrim and West, 1928) and was also worked out by Ray (1947) who
mapped the inverted zonal sequence in the Darjeeling Himalaya. This feature was explained by a huge recumbent fold (Pilgrim and West, 1928; Ghosh, 1956). Recumbent folding of the metamorphic zones and extensive areas of inverted stratigraphy are not recognised, and hence, post-metamorphic inversion is not likely to have occurred.

Another explanation involves high-level injection of granitic magma and consequent metamorphism of the rocks with the grade decreasing down the structural level (Auden, 1935). One of the constraints of this explanation is that the granites of the Higher Himalaya are not responsible for any significant metamorphism, and also that the regional metamorphism as obtained in the Himalayan rocks cannot be produced by the effect of granite injection.

Another explanation involves the presence of multiple thrust sheets. In Himachal Pradesh this explanation has been offered on the basis of thrust-sheet stack recognisable in that region (Bassi, 1988; Naha and Ray, 1970). Although down-grading of metamorphic paragenesis has taken place in some thrust zones. In most cases, however, disruption of the metamorphic zones and the presence of dislocations at zonal interfaces are not recognised which makes this explanation untenable as the prime cause of the metamorphic inversion (Das Gupta, et al., 1979)

In recent years the MCT has figured centrally in the explanation for the inverted metamorphism. Some workers have considered that the inverted zones are a consequence of the transient inversion of the isotherms during movement along the MCT. This so called hot iron model invokes a nappe of hot Central Crystallines over the cold Lesser Himalayan rocks with the isotherms that were folded by thrusting (Le Fort, 1975). This model has subsequently been refined, and one of the suggestions is that although the upward increase in the metamorphic grade seen below the MCT is a result of "hot iron" effect, the downward decrease in grade seen in the Central Crystalline is the result of a retrogression of the earlier assemblages. Shear heating is generally discounted as a significant effect. Although the MCT is generally considered to represent a ductile shear zone of about 3-5 km wide in Nepal (Hubbard, 1989), syn-to post-tectonic metamorphism and the spatial relation of the metamorphic zones with the definable thrust plane, the sole of the MCT-zone, argue in favour of the thermal event being causally linked with the MCT deformation (Sinha Roy, 1981a).

The distribution of the metamorphic assemblages in relation to the major tectonic features of the allochthon of the Lesser Himalaya would suggest post-collisional two-stage intracconti
THERMAL MODEL OF INVERTED METAMORPHISM IN THE HIMALAYA

STAGE-1

100°C
200°C
300°C
400°C
500°C
600°C

MCT Underthrusting Initiated

STAGE-2

100°C
200°C
300°C
400°C
500°C
600°C

Rapid MCT-I underthrusting

STAGE-3

100°C
200°C
300°C
400°C
500°C
600°C

Shear-heating superposed

STAGE-4

CZ
High-P, Low metamorphism
SZ - Sillimanite zone
GZ - Garnet zone
BZ - Biotite zone
CZ - Chlorite zone

Erosion level
Central Crystallines
Granite pluton

Lesser Himalayan nappe emplacement along MCT-II

(Modified after Sinha-Roy, S. 1988)

Fig. 2:2

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nental thrusting, MCT-I at the Central Crystalline-Lesser Himalayan boundary, and MCT-II at the allochthon – paraautochthon boundary (Sinha Roy, 1982a, 1988) [Fig. 2.2].

2.3 Constraints of Himalayan Metamorphic Geology

The nature and significance of polymetamorphism of the Himalayan rocks are not clearly known. Exact dating of the different metamorphic episodes has not yet been carried out, especially through mineral dating by Sm-Nd methods. Except for some isolated areas, the spatial relations between the metamorphic isograds and their linkage with the tectonic grains such as folds and dislocation zones are uncertain for most of the facies series of the different phases of metamorphism. The relations of facies series development with thrust tectonics are not clearly known, especially in remote areas where detailed mapping has not yet been possible. Delineation of intersecting isograds of different generations and dating of these metamorphic events would provide important components of tectonic modelling of the Himalaya.

The problem of inverted metamorphism is yet to be satisfactorily resolved. The cause-effect linkage of inverted metamorphism with the MCT would imply a very rapid movement along the thrust and rapid exhumation immediately following thrusting, because otherwise the inverted metamorphic assemblages would have been destroyed by further heating. It is not yet known if this constraint is satisfied by the rate of movement along the MCT and by the rate of morphogenic uplift of the Lesser and the Higher Himalaya.

3 MAGMATISM

Magmatic events play a significant role in tectonic modelling of mobile belts because the different igneous rocks of these belts serve as fingerprints of the various stages of tectonic development. Generation and emplacement of magma of various compositions in the Himalayan terrain is related to the tectonics of both crustal and sub-crustal regimes, to crustal interactions over a protracted period of time and to the various stages of collisional and post-collisional events.

3.1 Acid Magmatism

The granitoids of the Himalaya, depending on their disposition, can be grouped under different tectonic belts (Srikantia and Sharma, 1976; Bhandari and Singh, 1979; Sharma, 1983), and thus bear significance for the tectonic evolution of the respective belts. As revealed from the available geochronology, most of the granitoids seem to have undergone variable degrees
of mobilisation. This feature would suggest that the Himalayan tectogene is a reworked mobile belt involving many tectonomagmatic domains and incorporating a complex history of geologic evolution.

3.1.1 Distribution in Space and Time

The classification and distribution of the granitoids based on their tectonic disposition from north to south are discussed below. On the Metamorphic Facies Map the important granitoid bodies are shown under three principal age slots, namely, Proterozoic, Palaeozoic and Mesozoic-Cenozoic.

The Trans-Himalayan granitoids are the Karakoram, the Ladakh-Deosai and the Gaik granitoids. The Karakoram granitoid is dated between 25 to 8 Ma (Desio et al., 1964; Casnedi et al., 1978). The Ladakh granite, south of Skardu, has yielded Rb-Sr age of 48 Ma. Both these plutons vary from granite to granodiorite in composition. The Gaik granite has yielded Rb-Sr whole rock age of 253 ± 13 Ma (Trivedi et al., 1982a). The Trans-Himalayan granites are generally I-type and are considered to have been formed from magma derived from an oceanic crust and contaminated by continental contribution in a subduction setting.

The Tethyan granitoids occur as minor pegmatitic bodies intrusive into the Ordovician Thango Formation (Bhargava et al., 1978) and into the Tournasian Lipak Formation (Raina and Bhattacharyya, 1971) in the Lahaul region. The Kangan granite, intrusive into the Kashmir basin rocks, is 570 ± 11 Ma old (Trivedi et al., 1985).

The Higher Himalayan granitoids are mainly confined to the Central Crystalline zone, referred to as the VaiKritis in the Western Himalaya. There are two types of granite, namely, tourmaline-rich and biotite-rich granites. The former is represented by the Leo Pargial pluton in Kinnaur and the Badrinath pluton in Garhwal. Both these plutons are possibly 100 Ma old (Bassi, 1988). The biotite granite is represented by the Jispa, Barashigri, Rhotang, Rakcham, Kedarnath and Munsiari plutons. These granites have yielded Rb-Sr whole rock ages ranging between Upper Proterozoic and Lower Palaeozoic, except for the Munsiari granite which is 1890 ± 155 Ma old.

The granites contained in the thrust sheets of the Lesser Himalaya include Kaplas, Dalhousie - Mandi - Karsong, Chor, Champawat, Ranikhot, Almora, Amritpur bodies and also the mylonitic gneisses of Gahr (Baragaon) and Lingtse (Sikkim). These granitoids have shown ages ranging from 1430
to 2250 Ma for Baragaon (Bhanot et al., 1980), 1275 ± 12 Ma and 1139 ± 46 Ma for Bhilliganga (Bhattacharyya et al., 1980), 1170 ± 120 Ma and 1860 ± 65 Ma (Trivedi et al., 1982), 1075 ± 28 Ma for Lingtse gneiss, Sikkim (Paul et al., 1982), 1012 ± 29 Ma for the deformed granite of Bhutan Lesser Himalaya (Sinha Roy and Sengupta, 1986), 500 ± 12 Ma (Bhanot et al., 1975), 500 ± 20 Ma (Jaegar et al., 1971) and 456 ± 16 Ma (Bhanot et al., 1978) for the Mandi-Dalhousie granite.

The Window zone granitoid complexes are exposed in the Kishtwar and Larji-Rampur windows. In the latter area they are known as the Bandel and the Jeori-Wangtu complexes. The Wangtu complex has yielded an age of 2030 Ma (Bhanot et al., 1980) and the Bandal of 1840 ± 70 Ma (Frank et al., 1973) and 1229 Ma (Bhanot et al., 1975). These were regarded as intrusive bodies within the Rampur Group by Sharma (1977). Bhargava and Ameta (1987) interpreted these as mobilised basement complexes. All these complexes are mainly two-mica granites, belonging to S-type. Contrary to earlier view, the Lingtse granite gneiss of Sikkim Himalaya, has been shown to represent a mylonitic gneiss, tectonically emplaced along ductile shear zone through reworking of the basement for the Proterozoic Daling-Buxa cover sequences (Sinha Roy, 1980).

3.1.2 Relation to Stratigraphy and Structure

As enumerated above the different tectonostratigraphic units of the Himalaya contain granitoids of characteristic composition and age. This is of significance for the evolution of the Himalaya in that the stratigraphic and structural controls of acid plutonism are reflections of the tectonic development.

The Precambrian basement that supports the Tethyan sediments was granitised around 600 Ma (Sharma, 1983). This conclusion is based on 580 ± 9 Ma age of the Rohtang migmatitic gneisses and on the presence of xenoliths of kyanite-sillimanite bearing psammitic gneisses within the Kinnar-Kailas granite (675 ± 70 Ma). The metamorphism of the Precambrian Tethyan sediments appears to have gradually decreased in the highest structural levels.

The crystalline basement of the Lower Himalaya on which the parautochthonous sediments were believed to have been deposited is now represented by Jutogh-Munsiari-Daling-Darjeeling thrust sheets. Augen gneisses (Wangtu, Dhakuri, Munsiari, Chipulkot and Lingtse) of Early to Middle Proterozoic age are common at the base of these thrust sheets. These gneisses are the earliest record of acidic magmatism in the
Himalaya, but their tectonic setting and structural state would suggest their emplacement as tectonic wedges through basement reactivation (Sinha Roy and Sengupta, 1986). The deformed granite sheets of the Eastern Himalaya show the development of various types of mylonite, signifying ductile deformation at basement-cover interface (Sinha Roy, 1980). Goechemistry and Sr isotope data of the Lingtse gneiss suggest its derivation by melting of crustal material and graywacke to variable degrees (Sinha Roy and Sengupta, 1986). The Jutogh-Munsiari rocks contain younger (Ca. 500 Ma) intrusive granites (Champawat, Almora and Ranikhet). Another intrusive phase is represented by 311 ± 6 Ma old leucocratic microgranite (Mandi granite).

3.2 Basic Volcanism

An understanding of the nature and distribution of the basic volcanics is crucial in deciphering the basin evolution, and in working out the origins and destruction of rift and oceanic troughs. In the Himalaya a study of the basic volcanics distributed in different tectonostratigraphic units is important because multistage basin evolution and the migratory nature of crustal deformation zones are expected to be reflected in the basic volcanic suites of different ages. These suites from north to south are as follows.

The Trans-Himalayan basic volcanic suites include the Dras and the Shyok volcanics, both forming parts of subduction sequences. The Dras volcanics have an island arc affinity and has accreted on to the Indus ophiolite belt in the Cretaceous. The Tethyan basin basic volcanics include the Panjal and the Pho volcanics of Kashmir, Chamba and Zanskar-Spiti basins. These Upper Carboniferous to Lower Permian basic volcanics vary in composition from spilite to tholeiite basalt and are response of Upper Palaeozoic rifting in the Himalayan region. The geochemical affinity of the Panjal volcanics is debated. Pareek (1973) and Patwardhan et al., (1970) emphasised their spilitic nature. Bhatt and Zainuddin (1982), on the other hand, considered the Panjal volcanics as Sr-depleted ocean-floor tholeiites, and also continental tholeiites. Minor basic volcanics occur in the Precambrian Batal Formation, and locally in the Triassic Lilang Group in parts of the Zanskar range. They would represent brief periods of extensional tectonics in the Tethyan basin. The window zone basic volcanics are interstratified with the Banjar and the Manikaran Formations in Rampur, Tejam and Pithoragarh areas.
In the Lesser Himalaya the oldest basic volcanic suite having tholeiitic characters (Taran, 1979) occurs at the base of the Shali (Mandi-Darla), Deoban-Tejam-Pithoragarh carbonate belt. The Mandi-Darla volcanics have yielded Rb-Sr whole rock ages of 1487 ± 45 Ma (Kakkar, 1986). The Proterozoic Daling sequence of Sikkim contains bimodal basic and felsic (ignimbrite) volcanic suite at the base (Sinha Roy, 1987). The geochemistry of the suite indicates that the felsic volcanics are calc-alkaline while the basic volcanics have MORB characters. An island-arc setting has been postulated for the basal Daling sequence of Sikkim which was deformed by end-Proterozoic tectonic activity, probably representing a Caledonian event in the Himalaya (Sinha Roy, 1987)

For the basic and ultrabasic rocks within the thrust sheets and enclaves in the granites, the examples are provided by the Jutogh (Bhargava, 1972, 1975, 1977, 1980; Bhargava and Sharma, 1973; Bhargava and Shafiq, 1978; Srikanthia et al., 1975) and the Vaikrita rocks (Bassi, 1988) which enclose amphibolite bodies. Ultrabasic (lherzolitic) enclaves are found especially within the granitoid bodies, associated with the Vaikrita rocks and in the granitoids of the Miyar nala and Merdi areas.

In the Window zones of Sikkim the Gondwana sequence contains interlayered basic volcanics which are characterised by high contents of TiO₂, K₂O, P₂O₅ and incompatible trace elements (Sinha Roy and Furnes, 1978). The chemistry is compatible with a small degree of partial melting under high pressure of a titan-phlogopite bearing peridotite mantle. The geochemistry appears to be consistent with basic volcanism being associated with the initiation of continental rifting in the Palaeozoic in the Eastern Himalaya (Sinha Roy and Furnes, 1978). In the foothills of the Eastern Himalaya and in the Sikkim Window zone the Gondwana (Permian) sequence contains mica lamprophyre intrusives that are supposed to be mantle derived, and correlative of the Peninsular Indian lamprophyres (110 Ma, cf. Sarkar et al., 1980).

An important basic volcanic suite (Abor volcanics) occurs in the Siang district of Arunachal Himalaya. This suite seems to be a differentiated one with dominant basaltic component and minor andesitic and felsic components (Gupta and Misri, 1981). Contrary to the earlier idea which considered these volcanics to be solely of Palaeozoic age on the basis of their relationships with the Tertiary Yingkong Formation (Tripathi et al., 1981) considered the Abor volcanics to be partly Palaeozoic and partly Tertiary in age. Some workers believe that the Abor volcanics represent Late Mesozoic (Cretaceous) rifting in the region.
3.3 Ophiolite Sequence

The Trans-Himalayan Indus suture zone is the site of well-developed ophiolitic melange. Ophiolite sequence has also developed in the Shyok belt.

The ultramafic rocks associated with pillow lavas, marine sediments and basic rocks are exposed within the Indus ophiolite belt which represents obducted masses of the neo-Tethys oceanic crust. K-Ar dating of basalt from the southern ophiolitic melange of Chiktan nala near Budhkharbu gave an age of 77 ± 1 Ma (Sharma, 1983). Recently Brookfield and Reynolds (1981) reported K-Ar age of 82 ± 6 Ma for hornblende from syenite that intruded metamorphosed ophiolitic melange and the Dras volcanics near Kargil. The Indus ophiolite is mainly associated with the Sangeluma Group forming about 5-10 % of the sequence, and outside the Indus suture zone it occurs as nappe at Shilloking in Zanskar and Jungbwa-Mallajoher in Kumaon. The ophiolite comprises an assemblage of serpentinite, herzburgite, lherzolite, dunite, diopsidite, diabase, gabbro, anorthositic gabbro, dolerite and plagiogranite (Srikantia and Razdan, 1980). All the ultramafic rocks are more or less completely serpentinised. The dunite of the Dras area is however, comparatively fresh, but it is rimmed by serpentine-magnesite melange. The ophiolite sequence is highly dismembered. Ultramafics, gabbro and the mafic rocks occur together at the same tectonic levels. On the basis of the ophiolitic complexes an island-arc setting has been suggested for the Ladakh Himalaya (Ravi Shanker et al., 1982; Srimal et al., 1982) while the island-arc and marginal-sea couple seems to have accreted to South Tibet through the consumption of the neo-Tethys (Sinha Roy, 1981b, 1982b).

The volcanics of the Shyok ophiolite belt (Srimal, 1986) represent a great thickness of felsic volcanics, ignimbrite, volcanic breccia and basic volcanics. The latter is interbanded with shale, siltstone, limestone, containing Hippurites and Orbitolina of Middle Cretaceous age. The felsic volcanics exposed near Khardung represent the younger phase of calc-alkaline volcanism associated with calc-alkaline plutonism. This explosive volcanism took place during Eocene-Oligocene and covered a large part in the north of the Ladakh range.

3.4 Constraints of Himalayan Magmatism

The magmatic rocks play an important role in tectonic modelling. In the Himalaya granitoids of different ages occur at various tectonic levels whose petrogenesis is linked with tectonic evolution of the respective terrains. The knowledge of the petrologic types of the granitoids and their ages are not

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well-constrained, and hence, the relation of these rocks with the tectonic evolution is uncertain. The relationship of the granitoid bodies with the multistage metamorphic evolution of the Himalaya is not clearly known. The available age-ranges of the granitoids signify their multi-stage emplacement, but the degree of remobilisation of the same source material in the production of granitoid bodies at different tectonic levels is not known. This problem is linked with the question of emplacement of possible basement wedges within the thrust-stack as suggested for many tectonic zones in the Lesser Himalaya. A detailed study on thrust mechanics and basement-cover relations together with petrogenesis of the granitoid bodies of the Lesser Himalaya yielding Proterozoic ages would throw light on the extent and nature of basement mobilisation. Similar studies for the Palaeozoic and Mesozoic-Cenozoic granitoids would yield significant information for relating the granite genesis to geotectonic development of the terrane.

The basic volcanics occur in two contrasting tectonic domains of variable ages. The older setting is in the Lesser Himalaya where the Proterozoic suites might signify products of rifting related to a tectonic history not yet clearly documented in the Himalaya. As suggested in some studies, it is possible that some of these volcanic suites might lead to identification of end-Proterozoic (or Early Palaeozoic)? (Caledonian) tectonic imprints in the Himalaya. These suites together with the granitoids need precise age-dating for arriving at firm conclusions on their time relations with tectonic evolution, and their geochemistry need be studied in detail for understanding their tectonic significance. Similarly, the Middle Palaeozoic basic volcanics are possible indicators of Hercynian distensional tectonics in the Himalaya. These rocks together with the Palaeozoic granitoids need further study to decipher the nature and extent of influence of Hercynian tectonics in the Himalaya.

The recent suggestion of Cretaceous and Tertiary age for the Abor volcanics has posed a problem for the Eastern Himalayan frontal belt development. It is not known if a part of this volcanic suite is an extension of the Peninsular Gondwanic or Rajmahal-Sylhet Trap elements. If that is the case, then it would have important implications for the tectonic modelling for at least this part of the Himalaya.

The ophiolitic assemblages of the Indus-Shyok subduction zones have not been worked out in as much detail as to permit characterisation of the Himalayan collision tectonics with obduction dominated suture zone of telescoped island arc-marginal basin setting. Although the ages of some components of ophi-
olitic rocks giving the timing of their formation are known, there is a need to fix the timing of their obduction-related emplacement. This aspect is important because it will constrain the tectonic development in a time-frame, and throw light on the temporal setting of collision between India and Tibet, and the disappearance of neo-Tethys.

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STRUCTURE AND TECTONICS OF THE HIMALAYA

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ABSTRACT

The Himalayan tectogene, recording a multistage development, can be divided into four principal longitudinal tectonic belts on the basis of their characteristic geologic attributes. The Karakoram belt is the northern most which is followed in the south by the ophiolitic melange and the plutonic zone of the Indus-Shyok Belt, followed in the south by the Main Himalayan Belt which contains the complex fold-thrust tectonostratigraphic stack. The Frontal Fold Belt is the southernmost belt which contains essentially the Tertiary rocks of the foreland basin. Most of these tectonic belts are bounded by prominent dislocation zones. The Main Central Thrust is the most significant tectonic zone whose location and significance are debated. The bulk of the rocks of the Main Himalayan Belt is Proterozoic and they contain structures of polyphase deformation and imprints of polymetamorphism. The possibility of the existence of vestiges of pre-Himalayan structural and metamorphic imprints is recognised. The Frontal Fold Belt is a schuppen zone to the north bounded by the Main Boundary Thrust (MBF1).

On the basis of Lithostratigraphy, available geochronology, floral and faunal controls a palaeogeographic evolution of the Himalaya has been suggested. The recognisable sedimentation and orogenic events in the Himalaya have been correlated with the major global events, especially those recognisable in China.

The different tectonic models for the evolution of the Himalaya have been briefly enumerated to bring out the diversity that exists in the approach.

1 INTRODUCTION

The Himalaya has drawn the attention of a large number of investigators for over a century who have endeavoured to work out the structural and tectonic patterns. The results of these investigations have added to the knowledge and understanding of one of the complex orogenic belts but these have also contributed to and
created a host of other problems that are still unresolved. One of the peculiarities of the Himalayan tectogene is the involvement of a great tectonostratigraphic stack of older rocks of Precambrian age in the younger orogenic movement of Mesozoic to Cenozoic times. This has led amongst others to the problem of recognition of the response of the pre-Himalayan geologic evolution of these rocks during the various tectono-magmatic cycles. Although the stratigraphic record of the Himalaya spans Precambrian to Cenozoic times, it is difficult in most cases to find a continuous stratigraphic column because of multiple stages of deformation and tectonism.

On the basis of the available records it is impossible to recognise multiple deformation sequences and their structural responses in the different tectonostratigraphic units. It is also possible to recognise, different tectonic episodes that are possibly linked with the various sedimentation, magmatic, metamorphic and deformation episodes. These aspects have important bearing on the building up of the tectonic models for the evolution of the Himalaya.

2 TECTONIC BELTS

The Himalaya and the adjoining parts of Ladakh and Karakoram in the northwest and Mishmi Hills in the east can be divided into four east-west trending linear tectonic belts each having distinctive geologic attributes. In the northwest all the tectonic belts take a turn to the southwest to form the "western syntaxis" whereas, in the eastern part of the belt it assumes southeast trend. These tectonic belts from north to south are (Plate III).

North
Karakoram Belt (KB)

-----Shyok Suture-----

Indus-Shyok Belt (ISB) and Lohit Complex Belt (LCB)

-------Indus-Tsangpo/Tidding Suture-------
Main Himalayan Belt (MHB)

-----Main Boundary Fault------(MBF)

-----Frontal Fold Belt ------(FFB)

South

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2.1 Frontal Fold Belt

It is southernmost tectonic belt and is made up essentially of Tertiary and Quaternary sediments, constituting the Subathu, the Murree and the Siwalik Group of rocks overlain by alluvium. The former three sequences rest on the Proterozoic basement. Indian shield elements towards south. This belt is limited in the north by a tectonic surface which separates it from the pre-Tertiary rocks of the MHB. Depending upon the structural interpretations, this tectonic surface which is a north-dipping fault, is designated the Murree Thrust in the Jammu region (Wadia, 1931), the Krol Thrust in the eastern part of the Himachal Pradesh and the Main Boundary Thrust (MBT)/Main Boundary Fault (MBF) in parts of Garhwal and Kumaon, Nepal, Darjeeling, Bhutan and Arunachal Himalaya.

The outcrop width of the belt is variable. It has a maximum outcrop width of about 85 km in the western sector in areas lying between Long. 74° E and 78° E but it decreases gradually eastward to about 1 km. To the east of U.P. Himalaya only a part of the Siwalik Group is seen in parts of Darjeeling, Bhutan and east of the Dihang river in Arunachal Himalaya. The belt is involved in the Western Syntaxial Bend and assumes north-south trend in areas west of Muzaffarabad and runs parallel to the Jhelum river in Pakistan, whereas in the east it abuts against a major NW-SE trending Roing Fault (= Mishmi Thrust, Nandi et al., 1975) east of Long. 96° E.

Structurally and stratigraphically, this belt could be divided into three zones, each separated by a tectonic surface. These zones, from north to south are:

**North**

Main Himalayan Belt (MHB)

MHB-1 (Murree Thrust=Krol Thrust=Main Boundary Fault, ONGC)

Zone-I Murree Formation

---MBF-2 (Main Boundary Fault, GSI)

Zone-II Siwalik Group

---MBF-3 (Foot Hill Fault)

Zone-III Alluvium

**South**

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In order to avoid confusion in nomenclature and for the sake of simplicity, the tectonic planes have been referred to as the MBF-1, MBF-2 and MBF-3. All the three tectonic planes appear to limit in the north sedimentation of Murree, Siwalik and Ganga alluvium, respectively and thus may be boundary faults. However, due to intimate folded and faulted relations between the different stratigraphic units especially in the northern part of the fold belt, this belt assumes the characters of a Schuppen zone.

The MBF-3 is parallel to MBF-1 and has not been mapped continuously. At places, it forms the northern boundary of the alluvium with the Siwaliks. This tectonic plane has been variously named as the Foothill Fault (Kaladhungi) or the Himalayan Front Fault (Valdiya, 1988). It appears to be the youngest tectonic plane running parallel to the main trend of the Himalaya. Neotectonic activity has been recorded along this plain at several places.

The fold patterns of the three zones are different. In Zones I and II the folds are open, low plunging with axial trace running parallel to the Himalayan trend. The intensity of folding increases close to MBF-1 and MBF-2 where the folds become tight and at places, the limbs are inverted. There is a development of a number of parallel to sub-parallel reverse faults within each tectonic zones which include the Bilaspur Thrust in the Western Himalaya and the Tipi Thrust in Arunachal Pradesh.

Zone-III exhibits broadly homoclinal northerly dips to broad rolling dips in the northern part close to MBF-3. In the western sector between Jammu and H.P. occur several detached outcrops of Proterozoic dolostone- quartzite- slate ensemble of Riasi- Bilaspur- Sataun belt. These are considered as inliers of the basement rocks emplaced along high angle reverse fault or represent basement topography. Eocene fossiliferous shale and limestone are commonly associated as rims of these outcrops. Presence of Laterite/ Bauxite capping at the contact of these limestone and Eocene beds in parts of J&K and H.P. is taken to represent unconformity surface by many workers. These are alternatively interpreted as tectonic outliers with tectonised Subathu along with these overriding the Murree Thrust. A similar feature has also been recorded from the Kumai Hills of the Darjeeling area where the Siwalik rocks are overlain by tectonic outliers of Permian Gondwanas and Proterozoic Daling-Buxa rocks.
2.2 Main Himalayan Belt

It is the most complex tectonic belt which occurs between the FFB in the south and the ISB in the north. The MBF-1 marks its southern boundary with the former whereas the Indus Suture separates it from the latter. It abuts in the east against the Lohit Complex along the Tidding Suture (Tidding Lineament c.f. Acharyya, 1982), whereas in the west it continues to Pakistan. The belt is made up of all the lithostratigraphic units ranging in age from Proterozoic to Quaternary. Quite a few unconformities have been located from various places within this belt (Ravi Shanker et al., This Volume). A group of workers attempt to identify and correlate these breaks in sedimentation with the orogenic stages and related movements of global significance, some of which led to complete withdrawal of sea from the area due to uplift in the basin whereas other phases of movement have their imprints in the form of fluctuations in sedimentation and are, thus, possibly epeirogenic.

Since the deformation associated with the last Himalayan tectonic phase, is pervasive related to collision of the Indian plate with the Tibetan (Eurasian) plate, structures developed during the earlier tectonic phases got superimposed and modified. It is, therefore, difficult and at places practically impossible to identify and map the earlier structural elements. However, a synthesis of the data on fold patterns, available in different isolated and far apart areas, has helped identification of the fold patterns of the Proterozoic sequences (Table-1). Likewise, the emplacement of Tertiary granites and migmatisation during the Himalayan Orogeny has modified and at places obliterated evidences of pre-existing metamorphism and reset the mineral ages to Tertiary. The fact of Phanerozoic sequences escaping the Tertiary metamorphism is yet to be satisfactorily explained.

Within the MHB, the most important tectonic plane is the Main Central Thrust (MCT), the field delineation of which, however, has been a subject of controversy. The MCT was first identified in Kumaon between the high-grade metamorphites, the Central Crystallines, and the low-grade metasediments, now referred to as the Garhwal Group by Heim and Gansser (1939) where it is a north-dipping fault. With this definition it is traceable upto south of Rohtang Pass. From here for some distance westward the MCT is not clearly decipherable further in the west, however, it reappears and has again been mapped near Atholi in the Chenab Valley and traced to Suru Valley where it is cut off by the Kishtwar Fault. In Kishanganga, the tectonic
plane making the northern boundary of the Kashmir basin with the Nanga Parbat metamorphites, north of Salkhala, may mark its further westward extension.

In the central sector, in parts of Nepal, it has also been mapped at a similar tectonic position, but when traced further east in parts of Darjeeling and Sikkim, the plane is not well defined and its position varies from place to place. One group of workers (Srivastava and Raina, 1980) consider the MCT to be the tectonic plane between the Kanchenjunga Gneiss and the Chungthang/Paro Formations. It may join with the tectonic plane between Thimpu and Paro Formations (Jangpangi, 1978), passing north of Paro to south of Thimpu in Bhutan. However, in the Geological Map of Bhutan (1983) this tectonic plane has not been shown. With an off-set in the south along Long. 90° E, it continues further in the east of Arunachal Pradesh, demarcating the tectonic boundary between the Sela Group in the north and the Bomdila Group in the south. It abuts against the the Tiding Suture in the Dihang river west of Tuting. The other dislocation plane, which is considered to be the MCT, is the plane separating the Paro/Chungthang metasediments and the Dal-ing Group at the base of the Lingtse Gneiss (Acharyya and Ray, 1977; Sinha Roy, 1982a, 1988). It appears to join with the MCT described above in central Bhutan, separating the Phuntsholing Formation and the Paro Formation.

In the structural interpretations of the Himalaya Ray (1974), Ray and Acharyya (1976), Acharyya and Ray (1982) have visualised a concealed Palaeogene basin over which the entire MHB is thrust-over as an allochthonous mass (Fig. 3.1b). Similar interpretation was put forth by Auden (1973) for the Garhwal area of western Himalaya between MCT and Krol Thrust (Fig. 3.2b). Recent palaeontological finds assigning late Precambrian-Early Cambrian age to Blaini-Krol-Tal sequence in western sector lend support to structural interpretations which go against the existence of Krol and Garhwal nappes (Fig. 3.2a: Mehdi et al., 1972; Kumar and Dhaundiyal, 1979; Kumar, 1982). The structure of the Darjeeling-Sikkim sector could also alternatively be explained (Fig. 3.1a), against the cross section drawn by Acharyya and Roy, (1977).

There is yet another interpretation (Sinha Roy, 1988) which does not recognise the MCT as a single tectonic plane, but as two planes, one at the contact of the high-grade gneisses and the low-grade metamorphites (MCT-I), and the other (MCT-II) at the contact of the rocks of Daling Group and the Gondwana of foothills, though views on the contrary also exist.
GENERALISED GEOLOGICAL CROSS SECTION OF GARHWAL HIMALAYA
(ALTERNATIVE STRUCTURAL INTERPRETATION)

(a) (After G. Kumar)

(b) (After AUDEN, J. B.)

CC - Central Crystalline; G - Garhwal Group, GQ - Rautgare Fm, Gd - Tejam Fm, Gb - Beting Fm, Ga - Bajnath
Crystalline Formation, S - Morar Chakrata; Simla State C - Chandpur Fm; N - Nagthat Fm,
D - Dudatoli Alamara Fm; BKT - Blaini-Krol-Tel; Boulder Slate, Shell Limestone - Subathu Sw - Swalik Group;
M - Martoli Fm; R - Rolam Fm and younger Sedimentary Gr - Granite

Fig. 3.2 G. Kumar, S. Sinha Roy & K. K. Ray
Similarly, the position of the MCT is interpreted differently in different sectors in the NW Himalaya. One Group of workers join it with the "Jutogh Thrust" in the Simla region and visualise joining it with the "Panjal Thrust" (Panjal Fault, cf. Calkins et al., 1975; Jangpangi et al., 1986). Valdiya (1988) on the other hand, identifies another tectonic plane within the Central Crystalline (Heim and Ganssø, 1939), the Vaikrita Thrust, as the MCT which at places merged with or overlaps the MCT as defined above. The extension of MCT as Jutogh Thrust has however been questioned by some workers.

Another important tectonic plane in MHB is the North Almora Thrust (NAT), which was first identified as the tectonic boundary between the Garhwal Group and the northern boundary of the Almora Crystallines in Kumaon Himalaya (Heim and Ganssø, 1939). The latter rock sequence has been interpreted as tectonic outlier of the Central Crystallines, and thus the NAT is considered to be the trace of the MCT. In this structural interpretation the southern boundary of the "Almora Klippe" was the South Almora Thrust (SAT). Kumar et al., (1974) and Saxena (1974), however considered the Almora Crystallines to be autochthonous and opined that the NAT is a major tectonic plane separating the Garhwal Group and the Jaunsars from Almora Crystallines and that it is a steeply dipping fault with dips varying from 45° southerly to vertical or even with dips toward north.

At the northern boundary of the Central Crystallines, a tectonic plane, the Dar Martoli Fault, was recognised by Kumar et al., (1972). This tectonic plane was later referred to as the Malari Fault or as the Trans-Himadari Thrust (Valdiya, 1979;1988). Profuse Tertiary tourmaline granite and aplite are present all along this tectonic plane.

Besides MCT and NAT, the other tectonic planes are athwart or sub-parallel to the Himalayan trend. These are the SAT, the Tons Thrust, Duwadhar Fault, Singtali Fault (Garhwal Thrust, Auden, 1934), Panjal Thrust, Giri Thrust etc. Among these, the Tons Thrust, Duwadhar Fault and the Singtali Fault are all steeply south-dipping faults. The SAT (Heim and Ganssø, 1939), which forms the southern boundary of the Almora Crystallines, according to the nappe concept, forms the southern limit of the Almora Crystalline Nappe (Fig 3.2b) and thus, is the southern trace of the NAT (Heim and Ganssø, 1939 & others). In its eastern extension, it is sub-parallel to and in close proximity of the MBF-1, and is traceable into Nepal. In other structural interpretation wherein the Almora Crystalline is considered to
be autochthonous, the SAT when traced westward would abut against and end up in a strike-slip fault (Kumar et al., 1974; Saxena, 1974; Kumar, 1981) (Fig. 3.2a).

Within the Almora Crystalline, there is another tectonic plane, the Upradi Thrust (Vashi and Merh, 1975) which has been considered to be the SAT. It separates the almandine amphibolite grade metamorphites from the greenschist facies rocks of the Almora Crystalline (Manila Phyllite, Kumar et al., 1974). However, its lateral extension on either side is not clearly discernable.

The Panjal Thrust (Wadia, 1931) is a steep northerly dipping reverse fault (Heron, 1936) which separates the Nummulitic Rajpura Formation of the Autochthonous Belt of Wadia (1931) and the Bafliaz volcanics (Dogra Slate, Wadia, 1928) of the Kashmir Nappe, running almost sub-parallel to MBF-1. It was first identified in the Poonch area. In the west, it merges with MBF-1, southeast of Muzaffarabad, reappears in the Pakistan beyond the syntaxial bend and has been referred to as the Panjal Fault (Calkins et al., 1975). Southeastward, its tectonic position or even its existence has been disputed. Recent work (Jangpangi et al., 1986) has shown that it is traceable to the north of Ramban (Srikanthia and Bhargava, 1974), and further in the east to the Himachal Pradesh where its continuity is obscured by alluvium, but it may merge with MBF-1.

There is another fault within the the autochthonous folded belt, occurring between MBF-1 and Panjal Fault. It has been named as Sudh Mahadev Fault (Jangpangi et al., 1986). It separates the Rajpura Formation (Eocene) and the Upper Proterozoic Gamir-Baila at Sudh Mahadev, it is parallel or sub-parallel to MBF-1, merging with it in the north of Batote in NW, and in the east of Duniyara in the SE. In fact, this plane was considered to be the extension of the Panjal Thrust in Poonch area by Wadia (1931) and followed by subsequent workers. Its existence was questioned by Sharma et al. (1978), west of Batote. The Tons Thrust, Dudhwar Fault, and the Singtali Fault (Garhwal Thrust, Auden, 1937 in the Garhwal region) are east-west trending south dipping reverse faults.

In addition to the NW-SE trending faults and thrusts, there are a number of cross faults, trending in NNW-SSE to NNE-SSW, viz., the Kishtwar Fault in J&K, Sundernagar Fault in HP, Dwarahat Fault in Kumaon, the faults in Bhutan and the Bame-Fault in Arunachal Pradesh. Excepting the Bame Fault all these cross faults appear to be right lateral; some are pre-MBF-1 whereas others, post-MBF-3. The Kishtwar Fault is a N-S trending right lateral fault which cuts off the Kashmir basin in the Warwan valley and in the east the Central (Suru)
Crystalline abuts against it. It appears to abut against the Indus Suture in the north, whereas the southern extension has not been mapped beyond south of Kishhtwar. The Sundarnagar Fault has been interpreted to account for the swerve in the strike from a general NW-SE in the western block to NNW-SSE to N-S in the eastern block. It appears to have affected the FFB and as such could be much younger. The fault in the Spiti valley separates the Phanerozoic sequences of the Spiti-Zanskar basin from those of Kinnaur.

Amongst other N-S trending faults are the fault in Bhutan and the Bame Fault in Arunachal Pradesh, which have affected other tectonic features. The Bame Fault is connected with the Eastern Syntaxis and appears to be related to the refolding of rocks due to collision of the Burmese Plate with the Indian Plate during post Lower Eocene times but prior to development of MBF-1 and deposition of Siwalik (Fig 3.3) (Kumar in press).

Besides the above major N-S trending faults, the cross faults appear to be limited extent. These faults have offset the MBF-1, MBF-2 and MBF-3 at several places throughout the FFB. There are a few E-W trending faults such as the Alaknanda and Jhelum Faults which have also affected the earlier NW-SE trending folds.

A review of the data on the folds of various scales indicates that it is insufficient to arrive at a comprehensive picture of the folding of the Himalayan rocks. In certain sectors, detailed structural analysis has been carried out which has helped in identification of folds of different geometry and chronology (Table 1). The data on dating of the different deformation events are not available. Some fold patterns appear to characterise the structural style of the Proterozoic sequences.

The available data indicates that folds of multiple deformation exist in the MHB. Of these, the first three (F₁ to F₃) folding phases seem to be restricted to the Proterozoic sequences, although there are wide variations in the degree of development of these folds and their relative chronology in the different tectonostratigraphic units of the MHB.
GENERALISED GEOLOGICAL CROSS SECTION OF ARUNACHAL HIMALAYA

(a) WSW

SUBANSIRI RIVER

MCT

A

BAME F.

2bqz

2bmv

2bqv

2bv

2a

2c

2e

B

SIANG RIVER

ROING THRUST

TIDDING SUTURE

LOHIT THRUST

10c

10d

10a

10b

(b) N30°W

TALIHA

MCT

C

MBF

D

S30°E

G. KUMAR, S. SINHAROY & K. K. RAY

Fig. 3-3

1. Selo Group, 2 - Bomdila Group, 2a - Khetabari, 2b - Tenga (qtz - Quartzite, mv - metavolcanic), 2c - Rupa, 2d - Dirang fms., 2e - Ziro gneiss, 3 - Lumlo Fm., 4 - Miri Fm., 5 - Bichom + Bharali fms., 6 - Abor Volcanics, 7 - Yingkiong Fm., 8 - Siwalik Group (Ba - Dofla - Subansiri fms., 8b - Kimin fms.), 9 - Alluvium + river terraces, 10 - Lohit Complex (10a - Yang Sang Chu Fm, 10b - Tidding Fm, 10c - Mishmi Granodiorite)

(After G. KUMAR)
### TABLE-1
GEOMETRY OF FOLDS WITHIN DIFFERENT SEDIMENTARY CYCLES AND THEIR RELATION WITH MAIN DEFORMATIONAL EVENTS AND METAMORPHISM

#### Phases Of Deformation

<table>
<thead>
<tr>
<th>Cycle</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
</tr>
</thead>
<tbody>
<tr>
<td>F&lt;sub&gt;1&lt;/sub&gt; folds:</td>
<td>F&lt;sub&gt;2&lt;/sub&gt; folds:</td>
<td>F&lt;sub&gt;3&lt;/sub&gt; folds:</td>
<td>F&lt;sub&gt;4&lt;/sub&gt; folds:</td>
<td>F&lt;sub&gt;5&lt;/sub&gt; folds:</td>
<td></td>
</tr>
<tr>
<td>Tight Iso-clinal folds with long limbs, occasionally recumbent</td>
<td>Moderately tight to tight, open, asym-folds.</td>
<td>Open asym- metric, oc-warps with occasionally northern overturned, plunge rounded hinge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phases of Deformation</td>
<td>Cycle</td>
<td>D1</td>
<td>D2</td>
<td>D3</td>
<td>D4</td>
</tr>
<tr>
<td>------------------------</td>
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<td>----</td>
<td>----</td>
</tr>
<tr>
<td>F&lt;sub&gt;1&lt;/sub&gt; folds:</td>
<td>Tight Iso-clinal folds with long limbs, occasionally recumbent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D&lt;sub&gt;1&lt;/sub&gt;</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>/</td>
</tr>
<tr>
<td>D&lt;sub&gt;2&lt;/sub&gt;</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>D&lt;sub&gt;3&lt;/sub&gt;</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>D&lt;sub&gt;4&lt;/sub&gt;</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>D&lt;sub&gt;5&lt;/sub&gt;</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>/</td>
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</tr>
</tbody>
</table>

Geol. Surv. Ind., Spl. Pub. No. 26
The major phase of the Himalayan deformation produced the major faults, thrusts and ductile shear zones whose relations with the folding phases is not clearly understood. Some workers relate the recognisable first folding phase with the thrusting deformation, while others consider the second or third folding to have culminated in the emplacement of the thrust sheets. Limited strain analysis on the thrust sheets (Sinha Roy, 1979) indicates that the thrusting deformation was accompanied with large amount of extensional strains and that the thrust generated essentially in a flattening strain regions. This situation is consistent with the pervasive stretching lineation, trending almost N-S, that gives the direction of maximum elongation paralleling the direction of tectonic transport (Sinha Roy, 1982a).

A series of folds (F₁) varying in trends from NW-SE in the western part, almost E-W in the Central and to NE-SW in the eastern sector have affected the entire sequence ranging from Proterozoic to Eocene of this belt, and also the FFB. These are considered to be transverse structures having been controlled by the Indian shield structures during evolution of the Thrust system (Valdiya, 1975; Sinha Roy, 1976). This folding phase is likely to be related to the Himalayan orogeny per se. In general, the axial planes of these folds dip towards north with some variations in places such as in the northern part of the Garhwal synform. There is another NE-SW and N-S trending fold set (F₂), which is also present in the FFB. These have affected all the earlier structures and are thus the youngest. It is possible that F₁ and F₂ are conjugate cross-fold structures at least in the Sikkim-Darjeeling region (Sinha Roy, 1976b).

2.3 Indus- Shyok Belt

This belt is sandwiched between the Karakorum Belt in the north and the MHB in the south. It is essentially made up of Early to Late Cretaceous to Tertiary sediments and associated ultramafic, mafic, intermediate and acid magmatic rocks. However, imprints of earlier geologic history (Upper Palaeozoic onwards) are known in the Shyok belt.

On the basis of structure, sedimentation pattern and associated magmatism, the belt can be divided into three zones, each separated from the other by tectonic planes.
The Indus suture and the Shyok suture zones have more or less similar lithologic associations. The initiation of sedimentation in this belt appears to be slightly earlier than in the corresponding basin in the MHB and it was sometimes during late Early Cretaceous (Shanker et al., 1982). The presence of *Orbitolina* in the Indus belt and its absence in the MHB has been interpreted to reflect the presence of a barrier between these two belts since the later part of Lower Cretaceous (Shanker et al., 1982). Mathur (1983) however on the basis of a close faunal affinity with MHB basin, considers both to belong to the same faunal province.

The emplacement of ophiolites in this belt (Zone I and III) has been a subject of debate. The Zone-I was considered as an *Ophiolitic melange* (Gansser, 1974), a view which was followed by most workers. Srikantia and Razdan (1985) consider the ophiolites as tectonically emplaced within the sediments of the Sangeluma Group. The occurrence of Silakong ophiolite nappe (Srikantia and Razdan, 1981) in the Zanskar mountains over the Eocene rocks within MHB, is a significant evidence in favour of tectonic emplacement during post-Eocene period.
The folds associated with the first deformation in Zone-I are open to tight, often isoclinal with axes trending NW-SE to WNW-ESE and having moderate plunge on either sides (Thakur and Virdi, 1979). The other folds are cross-folds, trending NNE-SSW. The south-dipping (45°-60°) Pashkyun Thrust along which the ophiolitic Sangeluma/Sumdo Formation is thrust over the non-ophiolitic Indus Group may have developed at a much later stage. In Zone-III, the age of the ophiolite has been debated. Rai (1983) suggested an Upper Palaeozoic age. Frank et al. (1977) and (Gansser, 1977, in Rai, 1983) considered the Shyok Suture to be older (pre-Cretaceous) to the Indus Suture. Srimal (1986) suggested a model involving successive rifting, collision and accretion of Gondwana fragments along the southern margin of the Asian plate commencing from late Palaeozoic (early Carboniferous) and culminating with the Indus Suture. Thakur (1983), on the other hand, considered the Shyok suture to be tectonically compressed marginal basin.

The calc-alkaline volcanics of Zone-II, are correlatable with those of south Tibet where it is considered to be lower Cretaceous in age and the Ladakh granitoid batholith with the Gandise magmatic belt of southern Tibet (Yinji Xiang, 1983). The Indus Formation of this belt has been variously interpreted either as the Indus-Xigase arc-trench gap sediments of Cretaceous age (Thakur, 1983), or as continental deposits of Tertiary age (Oligocene-Miocene), overlying the basement of the Ladakh granitoid (Srikantia and Razdan, 1985).

In the eastern part, the Lohit granodiorite complex and Tidding Formation, trending NW-SE, have been interpreted to be a part of the Burmese plate, Tidding Suture (Acharyya, 1982), separating them, from the MHB. This belt can be subdivided into sub-belts, the Tidding Zone and the Lohit Granodiorite Complex, separated by the Lohit Thrust. Dykes of serpentinite and ultramafites are associated with the Tidding Zone and are considered either pre-Permian (Dhoundial et al., 1971) or pre-Cretaceous (Nandi, 1982). This belt is in tectonic contact along the Mishmi Thrust with the Assam Tertiaries (Nandi, 1973). A reappraisal of the stratigraphy and structural data suggests a younger age for the Tidding Suture which is post-Lower Eocene and pre-Siwalik (Mid-Miocene), and the serpentinite bodies are thus considered of this age (Kumar, MSS) and do not probably indicate an ancient subduction as suggested by Nandi (1982). This belt of high grade metamorphites with serpentinite has been considered to join with the Mogok metamorphic belt of Burma (Nandi, 1983).
2.4 Karakorum Belt

It is the northernmost lithotectonic belt on which very limited information is available (Gregan and Pant, 1983; Chowdhary, 1983; Srikantia et al., 1982; Bose et al., 1983; Sukh Dev et al., 1983; Bhandari et al., 1983). Although the general geological history, commencing from Permo-Carboniferous, appears to be similar to that of the MHB as deduced from the fauna and flora during the Mesozoic, these are distinctly different and appear to belong to a different province (Thakur, 1983). The metamorphites of the Pangong Tso Formation which forms the basement for the Upper Palaeozoic and the younger successions, may be older than what was proposed by Gregan and Pant (1983).

The data on structure are scanty. Folds of three generation are identifiable in the Pangong Formation. The F1 folds are isoclinal, trending NE-SW and F2 folds are open and are coaxial with F1 and at places, at a low angle to F1. F3 trends NW-SE (Chowdhary, 1983). There are a number of faults running parallel to the NW-SE trending folds. The F3 folds are recognisable only in the Upper Palaeozoic and younger sequences.

2.5 Palaeogeographic Evolution of the Tectonic Belts

The bulk of the Himalayan rocks are made up of Proterozoic metasediments which formed the basement for the Phanerozoic sequences, and hence, they are likely to contain vestiges of pre-Himalayan palaeographic history which has been superposed by the different stages of Phanerozoic and Cenozoic history.

The available radiometric data, though meagre and at times conflicting, have to some extent facilitated the correlation between magmatism and orogenic events, and major hiatuses in sedimentation. The hiatuses reflect orogenic movements of different intensities which brought about significant changes in palaeogeographical and faunal distribution. This has helped identification of the orogenic phases and correlation with the events of global importance. This approach as applied to the Himalaya (Kumar and Singh in press) is based on the one proposed by Wang (1986). The hiatuses in sedimentation in the Himalaya can be correlated with those on global scale, specifically to those in China.
According to one view, a wide ocean between Laurasia and Gondwana land was conceived during Palaeozoic which closed in Cretaceous with northward drift of the Afro-Arabian and the Indian plates beginning from Permian. The collision boundary is marked by ophiolites what is now known as Indus-Tsangpo Suture. According to another view the collision boundary between India and Eurasia may lie in the north of combined Indo-Tibetan block (Kaila and Hari Narain, 1981), coinciding with the southern boundary of the Tien Shan-Nan Shan mobile belt. According to Chang (1983) the wide Tethyan ocean did not exist in Early Palaeozoic and probably never existed at all. This conclusion is based on the faunal similarities in the Late Pre cambrian and Ordovician along the northern margin of the Gondwana-land and China.

It is presumed that the Proterozoic platformal rocks of the Indian Shield extended into the Himalayan region and got involved in various orogenic episodes. This Proterozoic sedimentation phase would represent the Luliangian/Vindhyan phase which culminated in the intrusion of granites dated around 1896 my.

The sediments of the next Jinningian phase are characterised by quartzite-basic volcanic + carbonate association. The carbonate sequences contain well-developed stromatolites, comparable to those recorded from Lower and middle Riphean of the Siberian platform. The orogenic movement, comparable to the Siabaoan of China, is perhaps responsible for regional metamorphism accompanied by syntectonic granites dated around 1100-1300 m. y. (Bhanot et al., 1976; Pandey et al., 1982). The uplift of the basin perhaps resulted in the development of a ridge of the Central Crystalline and migration of the basin southwestward in northwestern Himalaya (Kumar et al., 1965; Mehdi et al., 1972; Kumar, 1982). The sedimentation appears to have continued into Upper Proterozoic when granites dating around 750-800 my were emplaced and complete withdrawal of the sea took place.

The Chengjiangian orogenic movements resulted in a widespread marine transgression. It is during this period, that the northern part of the Central Crystalline was also submerged and the geanticlinal ridge became prominent. In the area between Rohtang Pass and east of Atholi in the Chenab valley, this ridge did not exist. The main depocentres were in the present areas of the Spiti, Zanskar and Kumaon, north of the geanticlinal ridge and from Kashmir, to near Nainital in Uttar Pradesh, in the southern basin.
the characteristic lito-association is diamictite beds associated with grey to dark grey shale, quartzite and thin limestone in the basal part, carbonate-evaporite facies in the middle and and the silliciclastics in the upper part. Associated with the association are beds of gypsum and phosphorite. It is during this phase, a rapid biological evolution leading to the appearance of calcareous algae, soft bodied animals, and animals with hard parts occurred towards end of Proterozoic and beginning of Phanerozoic around 580 my. Further diversification and evolution took place in the Cambrian. The trilobites, brachiopods and poriferids made their appearance. The Xiangkian orogenic activity resulted in complete regression of sea and intrusion of granites dated around 500 m.y. It thus marked the end of Caledonian.

The Gulangian orogenic movements during the middle part of lower Ordovician brought a marine transgression. Unlike the previous phase, the marine transgression was limited to Kashmir and in areas north of the Central geanticlinal axis. The fauna and flora, recorded in south Xizang (Tibet) in areas north of Mt. Everest (Yim Ji et al., 1983) appear to belong to a province different from that of the Kashmir-Zanskar-Spiti-Kumaon belt. This suggests that this Orogenic movement led to the formation of two basins, separated by ridge located somewhere in western Nepal. The other areas remained as landmass, excepting in areas around Kathmandu in Nepal. It is during this phase that important evolutionary changes were brought about in plant life. The Upper Devonian vascular plants made their appearance (Singh et al., 1982). The *Rhaeopteris* flora of Lower Carboniferous age are also recorded. The sedimentary cycle records a number of regressions and transgressions during Upper Devonian and Lower Carboniferous. The regressive sediments enclose continental flora where as the transgressive phase is evident from the fauna. The movements, mainly epiorogenic in nature, were precursor to Tianshanian orogenic movement leading to withdrawal of the sea.

The widespread marine transgression that occurred during (?) Upper Carboniferous marks the beginning of the Indoasian phase which is related to the Yiningian orogeny. The Upper Carboniferous unconformity was recognised by many workers as the Hercynian gap. There is no indisputable record of Upper Carboniferous fossils, and there is a possibility that this marine transgression occurred during Lower Permian marking the beginning of Gondwana sedimentation. This transgression was restricted to the outer fringe.
in the southern Kumaon (Lesser Himalaya) close to MBF-1. The magnitude of unconformity varies from area to area. In the southern domain the sediments rest over Middle to Upper Proterozoic sequences whereas in the northern domain and Kashmir Lower Palaeozoic sequence forms their basement. This transgression is also recorded in the Karakorum belt where its sediments rest over the Pangong metamorphics. Fluctuations of the basin are recorded throughout the phase. The appearance of continental facies in association with marine one during Lower Permian basic volcanism and return of marine facies during Upper Permian could be related to the Indosinian orogenic movement-1. However, the Upper Permian transgression was not as wide spread as the Lower Permian one and it was restricted to Kashmir and Spiti-Zanskar areas. The accompanying changes in environment brought about mass extinction of the invertebrates at the advent of Mesozoic. The Triassic saw more stability resulting in large scale precipitation of carbonates throughout Kashmir and Spiti-Zanskar-Kumaon belt. The Lesser Himalaya continued to remain a landmass till the end of this phase. Some epeiorogenic movements related to Indosinian orogenic movement-2 saw temporary withdrawal of sea during Lower Jurassic and resumption of marine conditions during Upper Jurassic in the Higher Himalaya and deposition of continental Upper Gondwana in the Lesser Himalaya in Nepal (Sakai, 1983). The Indosinian orogenic movement-3 was responsible for the total withdrawal of sea at the end of Lower Cretaceous.

The next Yanshanian phase is the most important and crucial phase in the Himalaya. The event led to the collision of the Indian Plate with the Eurasia. In the Indian plate, the development of two basins took place on the southern and the northern borders of the uplifted central mass due to Yanshanian orogenic movement-1 in Upper Cretaceous. The development of continental facies in the southern basin (MHB) and also in the ISB, and resumption of marine sedimentation till Middle Eocene may be due to epeirogenic movements related to Yanshanian orogenic movement-2 in Early Eocene. The complete withdrawal of the sea during Middle Eocene may be related to collision of the Indian and the Eurasian plates.

As a result of N-S directed stresses of Himalayan orogenic movement-1, the Eocene sea disappeared and the rocks were folded and led to reactivation of some of the earlier tectonic planes. This resulted in the formation of a foredeep on the southern side of the rising MHB block which was the sites for the deposition of the Murree sediments during
Oligocene to Early Miocene time. The periodic upliftment continued leading to Himalayan orogenic movement-2, which is accompanied by acid plutonism and metamorphism around 20 ± 5 my. As a result of this movement a part of the Murree sediments close to MBF-1, was folded and a basin developed for the deposition of molassic Siwalik in the frontal zone and of the Liyan sediments in the ISB. The Himalayan orogenic movement-3 saw further uplift and shallowing of the Siwalik basin leading to the deposition of conglomeratic Upper Siwalik. It is accompanied by intrusion of granites around 3.5 my. The deposition of the Lower Karewa in Kashmir basin, north of the Pir Panjal range, may be the result of this phase. The final Himalayan orogenic movement-4 dated around 0.8 - 0.5 m.y. saw tilting and uplift of the Lower Karewa close to the Pir Panjal range and deposition of the Upper Karewa.

3 MODELS OF TECTONIC EVOLUTION

The Himalaya is a part of the global Mesozoic-Cenozoic mobile belt whose evolution has not followed similar course all along its extent. As a consequence of intrinsic difference in the development of the tectonostraphies and in the pattern of crustal interactions the individual segment of the Alpine-Himalayan belt has evolved through individual course of events whose responses are imprinted in their tectonic, metamorphic and magmatic attributes. Major part of the Mesozoic-Cenozoic mobile belt has developed via an interaction of actively subducting oceanic plate against accreting continental crustal plates, displayed throughout the Circum-Pacific borders. Some believe that this type of Circum-Pacific interaction extends into the Indonasian arc upto the Indo-Burman ranges. Beyond this, between the Himalaya in the east and the Alps and the Atlas in the west, the interaction has been conceived through the convergence of two continental crustal plates separated by oceanic crust which subducted beneath passive Eurasian continent due to advancing Indo-African plate as a result of the opening of the Indian ocean. This continent-continent interaction led to the consumption of an oceanic crust to various degrees along its length leaving behind trails of ophiolitic sutures. A number of geoscientists further refined this basic concept through introducing the interplay of a large number of microcontinents in the process of convergence and eventual collision. Large scale overthrust movements in this Mesozoic-Cenozoic mobile belt and piling up of one above the other is common as a rule rather than exception. However, within this broad framework less deformed autochthonous to paraautochthonous blocks have been identified or interpreted.
The Himalaya, being an integral part of this Mesozoic-Cenozoic mobile belt, displays most of these general characteristics of tectonic evolution. However, it does have its own peculiar attributes which isolate it from the other parts and provide an identity to it. Its unique feature is the development of a 2500 km long high mountain chain at the leading edge of the continental plate and the involvement of the continental crustal material along with cover sequences ranging in age from Late Proterozoic to Early Cenozoic.

Almost complete development of the stratigraphic record in the Himalaya from the Proterozoic to the Recent has been explained by major episodic block movements with attendant folding and reversal of stratigraphic sequences in some linear zones (Eremeniko and Dutta, 1968; Kumar, 1982). The palaeogeographic evolution of the tectonic belts, discussed above is based primarily on the consideration of block movements and basin evolution in the Himalayan region. Large scale horizontal translations along low angle thrusts have played very insignificant to marginal role in this scheme of tectonic evolution of Himalaya.

As a precursor to the plate tectonics in the Himalaya, the concept of the Himalayan Tethyan Geosyncline and its continuity with the Alpine system was advocated (Petrushvsky, 1971). It has been suggested that only a small part of the Himalaya was formed from a Geosyncline whereas the main mountain chain represents the reactivated areas of the Indian shield. In this scheme it is considered that the southern part of the main Himalayan belt represents the reworked Proterozoic platform while the Tethyan Geosyncline was superposed on this platform. The influence of Caledonian deformation in the closing of the Late Precambrian Geosyncline in the western Himalaya has also been stressed by some workers. Hercynian tectonism in the main Himalayan belt has been advocated by some from the evidence of Early-Palaeozoic sedimentary record and from the presence of superposed deformation structures (Shanker, 1972). It is a matter of debate whether or not the Himalayan isopic zones are supposed on and are essentially concordant with the older Hercynian ones. It is possible that the Hercynian distensional tectonics gave rise to a central Himalayan ridge (geanticline) that played a major role in bringing about the lithostratigraphic diversity between the northern Tethyan domain and the southern main Himalayan domain (Sinha Roy, 1976b). Faunal affinity of the marine Mesozoic sequences between the northern and the southern domains and local Cenozoic transgression across the Central ridge would indicate that this ridge was unstable and was involved in the various phases of reactivation. During the Himalayan orogeny the
sedimentary sequences of the eugeosynclinal furrow in the Tethyan domain formed flysch nappe, split into several diverticulated sub-nappes. Farther to the south, on the northern flank of the Central Crystalline miogeanticlinal axis, the Mesozoic stratigraphy is involved in decollement (Sinha Roy, 1972). In this model (Fig. 3.4) the crystalline thrust sheets of the Himalaya are considered to have been derived from the central geanticlinal ridge (Sinha Roy, 1976b).

Invoking the classical geosynclinal concept (Ray, 1974; Ray and Acharyya, 1976; Acharyya and Ray, 1982), the Himalaya has been explained as a three tier tectonic pile-up (Fig. 3.5). The Indian crustal basement has completely downwarped, being overlain by a Palaeo-Mesozoic shelf to Palaeogene shelf geosynclinal sedimentary column concealed by the exposed Himalayan rocks above the Main Boundary Thrust (MBT), which acted as a sole for bringing large scale, piled-up, thin-skinned thrusts from South Central Tibetan homeland, overstepping the ophiolite-flysch bearing geosynclinal Indus-Tsangpo belt. In this model the major Mesozoic-eugeosynclinal magmatic and metamorphic events have been interpreted to have taken place at the homeland areas of the nappe system. Even in the concept of plate tectonic model this nappe system is considered to be the result of advancement of the accreted Eurasian plate. The Indus-Tsangpo suture marking the interplate oceanic crust would continue into the central Burmese ophiolite belt below the nappe cover which over-rides the Indo-Burmese isopic zone. Later imbrications have caused partial dismembered outcropping of ophiolite across the Lohit-China section. As per this view the nappe system generated in the homeland during Early Palaeogene propagated southward by gliding till Late Neogene and possibly even onto the Recent times in the foothill fold Belt at least in Eastern Himalaya.

This makes the Himalaya as one of the largest klippe of the world constituting the loftiest young mountain range. The analogous model has been proposed for the Appalachian (Cook et al., 1979, 1983).

The tectonic evolution of the Himalaya has been illustrated in a number of plate tectonic models (Powell and Conaghan, 1978; Crawford, 1974; Sinha Roy, 1976; Thakur, 1983). Tethys ocean has figured centrally in these models, and in recent years the concept of Tethys has changed in that a two-stage Tethys evolution has been recognised. The Palaeo-Tethys was considered to have been consumed at the site of the Kun Lun while the Neo-Tethys, that existed as a shallow sea during the Palaeozoic and the early part of Mesozoic opened into an oceanic trough when Tibet (a microplate correlative of the Lut block) was detached from the
I - Early Proterozoic Sequence
2 - Late Proterozoic Sequence
3 - Early Palaeozoic Sequence
4 - Late Palaeozoic Sequence
5 - Triassic Sequence
6 - Cretaceous Sequence
7 - Eocene Sequence
0 - Ophiolite

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1 - Early Proterozoic Sequence
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7 - Eocene Sequence
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Direction of nappe transport, arrow-base = 'homeland', arrow-head = location of nappe
Uplift
Late Mesozoic-Cenozoic
Granitic activity
Possible Eocene transgression in Himalayan domain
Hercynian Unconformity

(Modified after Sinha-Roy, S. 1976b)
GEOTECTONIC SECTION ACROSS HIMALAYA: DARJEELING-SIKKIM-NYENCHENTANGHLA SECTOR

LEGEND

Granite (T)
Granodiorite (B)
Granitoid (K & T)
Ophiolite zone ($K_2$, $K_1$)
E-P2
E-P1
AnE

Fig. 4-5
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Structure & Tectonics
Greater India (Sinha Roy, 1981a; 1982b). This has precipitated a problem in the recognition of the northern boundary of the Indian plate which was conceived along the Tienan by Crawford (1974) and Kaila and Harinarain (1981). The Palaeozoic to Mesozoic distensional tectonics in the northern margin of the Greater India caused both drifting of Tibet and opening of a linear trough in the Himalayan region which gave rise to a Himalayan microcontinent (Sinha Roy, 1978 a, b) which in fact was the geanticline in the geosynclinal model discussed earlier. The neo-Tethys oceanic crust was subducted in stages, the initial subduction beneath south Tibet produced the Nyenchel Thangla Cordilleran fold belt and at a later stage an island-arc and marginal basin couple was formed (Fig. 3.6) in the Dras-Shyok-Ladakh belt (Sinha Roy, 1982b). This couple was deformed and ophiolitic melange was emplaced in the Indus-Tsangpo suture zone. With continuing spreading in the Indian ocean after the continental collision and locking in the Himalaya, intracontinental underplating took place along the MCT ductile thrust zone (Bird, 1978), located probably at the southern margin of the Himalayan microcontinent (Sinha Roy, 1981b). This Intracontinental subduction was responsible for the inverted metamorphic sequences and the Cenozoic granite plutons in the Himalaya (Le Fort, 1975; Sinha Roy, 1988). The MCT seems to have been locked and with south directed orogenic polarity in the Himalayan region, a new intracontinental dislocation zone developed along the MBT which is considered to be destined to evolve as the MCT (Sinha Roy, 1982b).

As would appear from the above discussion on the tectonic evolution of the Himalaya there are quite a few alternative and contrasted models proposed for explaining the peculiarities of this mobile belt and for accommodating its unique characters. Although the description of these models is not exhaustive, they would indicate the diversity in approach for explaining the origins of this mountain chain. These models need refinement through further studies and data input through deeper probing by geophysical and drilling techniques besides conventional geological and geochemical work. These models hold promise for generating eventually a unified and viable tectonic model that would not only explain the geologic complexity satisfactorily and meet the constraints of tectonic evolution of the Himalaya but would also provide conceptual as well as factual orientation to the search for the mineral and hydrocarbon accumulations.

4 ACKNOWLEDGEMENTS

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PLATE TECTONIC MODEL OF EVOLUTION OF THE HIMALAYA

Devonian

Permian

U. Triassic

Jurassic

U. Cretaceous

L. Eocene

U. Eocene

Miocene

Pleistocene-Recent

Legend: • Ophiolite □ Sedimentary sequences ——— Transitional Crust △ Island Arc

(Modified after Sinha-Roy, S. 1981a, 1982b)

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NEOTECTONIC ACTIVITY
IN THE HIMALAYA

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ABSTRACT

The scattered and scanty data base on the neotectonic activity in the Himalaya has been reviewed and codified corresponding to different phases of deformation and tectonic adjustments during the Quaternary times. The categorisation has been done with a view to offer input in geoseismological research as well for assessing the evolutionary trends of the Himalaya in the Quaternary period.

A generalised map depicting the tectonic features, which were formed during the Quaternary period as well as those along which rejuvenation has been recorded or apprehended during this period has been prepared and presented. The data obtained from Geodetic monitoring of some of the tectonic lineaments depicting contemporaneous adjustments have also been synthesised.

1 INTRODUCTION

It is recognised that the Himalaya is undergoing continuing crustal adjustments. It follows, therefore, that the relationship of these adjustments with the tectonic framework explaining neotectonic manifestations would help in a rational assessment of the stress fields as well as the tectonic history and evolution of the Himalaya.

Neotectonics is a term which conveys different connotations to the various branches of earth sciences and seismologists. Hence it becomes imperative to define the scope of this term to avoid ambiguity and misinterpretations. In the geological literature the term Neotectonics was initially proposed by V.A. Obruchev (in Fairbridge, 1968) to mean the branch of Earth science which is devoted to the movements of earth's crust that have taken place during the Neogene and Quaternary periods, and played a decisive role in the formation of the contemporary topography. This definition is, however, not universally accepted. Particularly seismologists prefer to restrict the period of neotectonic activity to Holocene and later parts of Quaternary.

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For the purpose of constraints in Tectonic modelling of the Himalaya, it is felt appropriate to define the term Neotectonic activity as follows:

The episodic crustal adjustments and movements including slow secular creep, with or without ground rupture during the Quaternary period (beginning from about 1.92 million years till date) are described as neotectonic activities.

An appraisal and assessment of the available data on neotectonic activity would help in identification of areas of stress accumulations and strain release during the contemporary and Quaternary periods which when back-worked could establish the authenticity of tectonic model/models for the evolution of the Himalaya. Second important utilitarian aspect of such an appraisal is to identify areas where secular creep is taking place with or without the possibility of ground rupture. This in confirmation with source mechanism studies of discrete earthquake events would help to understand better the areas susceptible to risk and provide direction to the enigmatic question of earthquake prediction.

2 APPRAISAL OF NEOTECTONIC ACTIVITY IN THE HIMALAYA

From the Himalayan region only scattered and isolated records of neotectonic activity are available and data base is relatively more for the Northwest Himalaya where evidences have been recorded, systematically mapped and documented during the course of geotechnical investigations of various river valley projects.

Efforts have been made to codify and logically represent the evidences of neotectonism on the geological map (Plate IV) with the purpose of identifying the genetic relationships of these manifestations with established tectonic lineaments and episodic uplifts in the Himalaya during the Quaternary period.

From the appraisal of the data on the relative geological ages of activity, strength of evidences recorded and the utilitarian aspects particularly seismological consideration, the Neotectonic activities have been categorised into: (i) Younger Neotectonic episodes; (ii) Older Neotectonic episodes and (iii) Undifferentiated geomorphic evidences.

Younger Neotectonic Episodes include tectonic features affecting Holocene and late Pleistocene deposits; secular continuous movements and sudden, discontinuous (seismic) movements in the Orogenic regions. The discontinuous contemporaneous movements like the earthquake effects and source mechanism studies are not included in this write up. Older Neotectonic Episodes include tectonic features which have affected the Eo-Pleistocene deposits.
like the Upper Siwalik Boulder Beds. Besides there are undifferentiated and indirect geomorphic evidences of neotectonic activity.

The above categorisation keeps in view the utility of the map for seismological interpretations. In the seismological jargon, there are different classes of tectonically active faults like, (i) Active faults defined as contemporary displacements or adjustments; (ii) Active faults of high seismic potential affecting the Holocene deposits of age less than 11,000 years; (iii) Active faults of low seismic potential affecting the Pleistocene sediments. The first category would satisfy the above classes of tectonic lineaments and could be conveniently utilised for seismological interpretations and research. The other categories are aimed to give an input of Quaternary tectonics which, when extrapolated, could give clues to postulate models for evolution of the Himalaya.

A brief category-wise appraisal of the recorded neotectonic activity is given below:

2.1 Younger Neotectonic Episodes

The movements along some of the outer Himalayan thrusts and faults bringing older rocks in juxtaposition with late Pleistocene or Holocene silts and clays, landslide debris and river borne material, have been recorded at a number of places. Many of these tectonic adjustments have been caused by rejuvenation of older tectonic lineaments during the Holocene and late Pleistocene periods.

2.1.1 Movements Along Thrusts

2.1.1.1 MBF₁ (Krol/Shali Thrust)

This thrust which has brought the pre-Tertiary rocks in juxtaposition with the Tertiary rocks has shown eloquent evidences of rejuvenation in the Holocene and late Pleistocene periods at a number of locations. In Sihunta areas in Chamba district of H.P. the Shali thrust has been interpreted to have rejuvenated in Recent to Sub-recent times as it overlaps the Tundi tear which has brought the Dharamsala beds against the Upper Siwalik boulder conglomerates (Swamy, 1979-80). Though on direct evidences it would fall in category of Older Neotectonic Episodes but the carbon dating of samples along Krol thrust from near Motla has given late Pleistocene age and thus classified in this category.
Fig. 4.1 - GEOLOGICAL SECTION DEPICTING OVERRIDING OF RIVERBORNE MATERIAL BY SHALI ROCKS ALONG SHALI THRUST AND SUBSEQUENT BLOCK GLIDE, JOGINDERNAGAR H.P. (AFTER NARULA)

Fig. 4.2 GEOLOGICAL SECTION SHOWING LATE NEOTECTONIC ACTIVITY, KALA-AMB AREA. (1) TALUS (2) SUB-RECENT DEPOSITS. (3) NAHAN SANDSTONE AND CLAYSTONE. (4) SUBATHU SHALE AND SANDSTONE. (5) NANDHALLI SLATE AND QUARTZITE. (AFTER KRISHNASWAMY, JÄLOTE AND SHOME)

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Evidences of recent activity along this thrust have also been recorded in Mandhokhar Khad and Neri Khad near Jogindernagar, H.P. (Narula, 1971). In this area the Shali rocks have overriden the landslide debris in the exposed sections. The explorations conducted by drilling as well as exploratory drifting has also proved this overriding. It has also been interpreted that because of continued uplift, the overthrust block has glided overlapping the landslide debris as well as the Shali thrust (Fig. 4.1).

The homologue of this tectonic feature in the Kumaon and Garhwal Himalaya have also indicated recent tectonic adjustments. Jalote (1966) has reported overriding of Palaeozoic Chandpur phyllites over the Dun gravels all along the trace of Krol thrust between Dehradun and Rishikesh.

Auden (1942), on the basis of occurrence of lakelets between villages Bakan and Danda and series of landslides in the Choraro Ka-Khala and Khain-Ka-Khala had interpreted that the recent movements along Krol thrust and Nahan thrust could be responsible for these morphotectonic features. The extension of this tectonic lineament further east in Amboa-Sataun section has demonstrated direct evidences of neotectonic activity near Bhatrog and Janjli villages the Infra Krol carbonaceous shales have overridden the cemented gravel beds for distances of 60 m and 20 m, respectively. Similar evidences have in Kala Amb area been picked up in Dopaharia Khala and Dauli Rao (Jalote & Jalote, 1978). Subsurface explorations conducted for Yamuna Hydel Project have indicated that black, gypsiferous clay shale has overridden sub-Recent scree and landslide debris (Fig. 4.2) indicating rejuvenation along Nahan thrust or a branch of the same in the geologically recent times (Krishnaswamy et al., 1970).

Further east neotectonic activity in the form of dissection of fan deposits of Logar stream, a tributary of Gaula river along the Main Boundary Thrust, has been interrupted (Chibber, 1984). Because of this activity the south block of the fan has risen resulting in change in the course of this stream from south towards west (Sharma and Tangri, 1983).

In addition to the above direct evidence, other geomorphic evidences have been reported to suggest that this feature has rejuvenated in recent times (Valdiya, 1986)
In Bhutan Himalayan foot hills, the Main Boundary Fault displaces the highest terrace in Jia Bar nadi and valley near Dalim, which suggests neotectonic activity along this lineament (Biswas et al., 1979)

2.1.2 Active Thrusts in the Lower Himalaya

2.1.2.1 Srinagar Thrust, Tehri Garhwal, U.P.

The photo-interpretation, matching of terraces and nick point studies conducted by Mehta, Shome and Narula (1967) indicated that NW-SE trending thrust dipping at varying angles in the Southern quadrant has been active in recent times, though direct evidence of overriding of older formations over the Holocene and late Quaternary sediments could not be picked up. The geologic surveys have, however, demonstrated that contemporaneous movements along this thrust are taking place.

2.1.2.2 Manora Thrust, Nainital Area, U.P.

Hukku et al. (1974) interpreted that the Lower and Middle Krols have been brought in juxtaposition with the younger Quaternary deposits along the Manora thrust which could be traced from Ratanpani nala in the east to Khurpatal in the west. It has been reported that dragging of the rocks of overlying block also suggest significant strike slip component of movement along this feature.

2.1.3 Thrusts in the Siwalik Domain

2.1.3.1 Riasi Thrust

The Precambrian Sirban Dolomites have overridden the Mio-Pleistocene Siwalik group of rocks along a thrust exposed along the foot of Vaishno Devi range. Doubts about this tectonic lineament being seismically active were first raised by Auden (1944) and later by Krishnaswamy (1961).

In the vicinity of Riasi, Srivastava (1965-66) identified evidences of neotectonic activity along this thrust and has observed that Sirban Dolomites have overridden the Siwalik boulder beds in Dugla Nala section while in Aghar and Mari Nala sections the dolomite scree is exposed at steep angles which were interpreted as having been caused by rejuvenation of Riasi thrust.
However, Narula (1971) collected evidences of recent activity along Riasi thrust in the form of 0° tilt of river terrace south of Riasi thrust and 40° to 50° inclined terrace on the northern side of the thrust and overriding of the dolomites over the terrace material (Fig. 4.3). In addition, a number of normal as well as reverse faults transverse to the trace of the thrust were recorded from the terrace material in the vicinity of this thrust. These transverse features could have genetic relation with the stresses field responsible for the Riasi thrust.

Fig. 4.3
SKETCH GEOLOGICAL SECTIONS SHOWING NEOTECTONIC ACTIVITY ALONG RIASI THRUST, RIASI J & K. 1. TALUS 2. PARTIALLY CEMENTED SCREE/FANGLOMERATES. 3. TERRACE DEPOSITS. 4. SIWALIK SANDSTONE/CLAYMALE 5. CRUSHED SIYAN DOLOMITE. 6. SIYAN DOLOMITE (a) DEPICTS OVER-RIDING OF TERRACE DEPOSITS BY SIYAN DOLOMITES (b) DEPICTS TILTING OF RIVER TERRACE AT VERY STEEP ANGLES IN THE BLOCK ON HANGING WALL SIDE. (AFTER NARULA)
The Markanda Thrust has brought over Siwaliks in juxtaposition with the upper Siwalik boulder beds. Shome and Dayal (1966) while carrying out explorations by drilling at the Giri Power House site encountered sub-Recent silts and clays with pebbly horizons below the lower Siwalik sandstone and clay shales representing a low angle reverse fault of Recent geological age (Fig. 4.4a). The extension of mapping in the area proved that this fault in its strike continuation joins the Markanda thrust exposed in Markanda river section near Dhaduwala (Fig. 4.5). This thrust has even deposited top soil cover in Morar Kakhala east of Mairi (Fig. 4.4b).

Fig 4.4  NEOTECTONIC ACTIVITY ALONG MARKANDA THRUST.
(a)GEOLGICAL SECTION AT PROPOSED POWERHOUSE SITE, GIRI HYDEL PROJECT.
(b)GEOLGICAL SECTION ACROSS MARKANDA THRUST FURTHER EAST OF THE ONE SHOWN AS IN (a). (AFTER SHOME AND DAYAL)
Fig. 4.5 GEOLOGICAL MAP OF GIRI PROJECT AREA SHOWING NEOTECTONIC ACTIVITY

(After Shome, Mandal and Dayal)

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2.1.3.3 Sarpduli- Dhikala Thrust

In the Ramganga river section, a lineament demarcating the contact of the upper Siwaliks with overlying lower Siwaliks has been picked up in Dhikala- Sarpduli section. The nick point studies by Verma (1962) along the tributary streams cutting across the Sarpduli Dhikala thrust suggested a possibility of Recent activity along this feature, though direct evidences of the same to be younger than Pleistocene age could not be collected.

2.1.3.4 Satlita/Soan Thrust

In the vicinity of the Beas Dam project the Siwalik sand rocks have overridden boulder beds and locally this thrust had been named as Satlita thrust. The continuity of this thrust in the east has been named as Soan thrust north of Janauri anticline. Jalote (1962) reported that this tectonic lineament is of recent geological age, the evidences (like overriding etc.) of which were collected from the exploratory pits and trenches along the trace of this thrust (Fig. 4.6). These explorations indicated that Siwalik sandrocks have overridden the river terraces in the Sahan Khad and Khari Khad sections. In the strike continuation further east Karunakaran and Ranga Rao (1979) have reported that Soan thrust has been active in Recent times as evidenced from the involvement of the terraces of Soan river in tectonic movements.

Fig. 4.6 SUB-RECENT ACTIVITY ALONG SATLITTA THRUST
(AFTER JALOTE, S.P.)

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2.1.3.5 Foot Hill Thrust

The outermost thrust in the Himalayan Foot Hills is the frontal thrust/fault which has brought the Siwaliks in juxtaposition with the Gangetic plains. This fault is poorly delineated in most parts, except in the areas of re-entrants like Himachal foot hills, Dun re-entrant, Kalagarh- Ramnagar sector and Nainital foot hills; because of which apron of piedmont deposits. Evidences of overriding of Siwalik rocks over the gravel beds have been recorded near Mohand (Nakata, 1972), near Kalagarh (Verma, 1960) and near Subansiri Project, (Ashraf, 1983).

2.1.4 Recent Activity Along Transverse Faults

In the Himalayan Foot Hills a number of tear faults disposed transverse to the Himalayan trend have been recorded along many of which geomorphic as well as geological evidences demonstrating their being active during Recent to sub-recent times. Some of these features have registered dextral strike slip and others sinistral strikeslip. Some of the important tear faults in the outer NW Himalaya are the Ravi tear, Ropar tear, the Ghaghar tear, Yamuna tear, Ganga tear and the Kosi tear.

2.1.4.1 Yamuna Tear

Auden (1942) was the first to recognise the existence of this major tear fault on the basis of anomalous juxtaposition of the structures across Yamuna river. He had recognised a horizontal component of the order about 1050 m along this fault. Subsequently Krishnaswamy (1959), Agarwal Mitra and Sikka (1961), Chibber (1976) Shome and Mandwal (1979) have confirmed this N-S trending tectonic feature. Many of the above referred to authors have quoted evidences of this feature being active during recent times. Krishnaswamy, Jalote and Shome (1970) inferred that strike slip movement of the order of 30 cm took place during a period of 4 years. The repeated Geodetic surveys conducted by Survey of India across this feature have indicated horizontal movement of the order of 0.7 to 5-7 cm in the period (1965-1976) (Arur, 1982) which suggests that contemporary tectonic movements are taking place along this transverse tectonic lineament.

2.1.4.2 Ganga Tear

On the basis of geomorphic expression of setting outermost Siwalik hills along transverse feature interpreted along Ganga, it is interpreted that a tear fault must have
been responsible for this off setting and this feature had been assigned the neotectonic status. Chibber (1976-77) while carrying out investigations of Chilla Hydel Scheme recorded a steeply dipping fault along the hydel channel which has brought the upper Siwalik rocks in juxtaposition with the Dun gravels. According to Chibber this fault could be a branch of the Ganga Tear. This fault though involving Dun gravels has not disturbed the overlying present day river terraces.

Just east of this tear is the Mithawali fault which has brought lower Siwaliks in juxtaposition with the alluvium (Karunakaran and Rao, 1979). Another major dextral wrench fault is interpreted to be present along Kosi river. The geomorphic expressions in this area suggest that this fault could also have been active in Recent times. In addition to the outer tear faults described above some of the tear faults in Tertiary domain, along which neotectonic activity has also been reported are as under:

Sile tear fault, traced for a distance of 12 Km from Giri river in North to Bata river in south along which eastern block has moved towards north in comparison to the western block by about 1.7 Km (max.) (Fig.4.7) exhibits signs of neotectonic activity in the form of terrace level differences on its either side.

In Sihunta area of H.P. Simalghat tear and Tundi tear, with net horizontal slip of 80 m and 200 m respectively, have been assigned neotectonic status as these involve the upper Siwalik boulder beds (Swamy, 1979-80). Some evidences of neotectonic activity in lower and inner Himalaya along transverse features have also been recorded e.g. in Baspa Valley (Hukku & Dayal, 1966-69), in Bhagirathi valley (Mehta, Shome and Narula, 1967). Bhargava (Personal communication, 1989) has recorded evidences of Neotectonic activity in the form of folding of Recent sediments along tear faults and some indirect evidences like disorganised drainage east of Togosim, tectonic basins of Tsokar and Tso Morari lakes, truncated Valley of Chandra Tal etc. in Ladakh, Lahaul and Spiti Valley. Further systematic work in lesser and inner Himalaya may lead to further direct evidences of Neotectonic activity associated with different phases of Himalayan uplift.
2.1.5 Dating of Tectonic Lineaments

Radiocarbon dating of some of the tectonic lineaments along which carbonaceous material was encountered. The carbonaceous material along Krol thrust/Shali thrust has been dated as 30990 ± 1640 years in Dun Valley, U.P. (Jalote 1966); 20660 years from a sample along Krol thrust in Khair-Ka-Khola (Swamy, 1980-81); 38270 ± 2480 years from material near village Kamur; and 30900 ± 1300 years of material along Shali thrust near village Motla in Sihunta area H.P. (Swamy, 1980).

Similar late Quaternary ages have been obtained from carbonaceous material along transverse tears. The Sile tear in Giri Project area, which exhibits geological evidences of Neotectonic activity has yielded an age of 28100 ± 1850 years (Swamy, 1980-81).

The above data support the geological evidences of recency of movements along some of tectonic lineaments in the outer Himalaya. Incidentally all these ages are indicative of younger Quaternary period but are older than Holocene. Unfortunately, carbonaceous material of organic origin is not present along all the Neotectonic features, thus geochronological ages of all the features are not available.

2.1.6 Geodetic Surveys along Tectonic Lineaments

At a number of locations, the neotectonic features have been monitored by Geodetic triangulation and levelling surveys by the Survey of India at the instance of the recommendations of the officers of Geological Survey of India. These locations were chosen because the continued tectonic creep or adjustment along these features were of relevance to designing and execution of River Valley Projects. The relevant findings of these surveys have been summarised below:

The headrace tunnel of Maneri Bhali Hydel Project Stage-II had to negotiate Srinagar thrust which was suspected to be active during recent times (Shome, Mehta and Narula, 1967). In order to monitor continued adjustments along this feature Geodetic Surveys were conducted by Survey of India who have concluded that horizontal movement of the order of 4 to 5 cm has taken place from 1972-74 to 1977-78 while between 1977-78 to 1982-83, it is of the order of 7 cm to 14 cm. Vertical movement of 2 to 4 cm in these periods has also been recorded. It has been suggested that there is a possibility of localised strike slip movement along this thrust (Joshi Rajal and Hasija, 1987).
The Shanan Penstocks laid across the Shali thrust have been showing signs of distress on the hanging wall side of the thrust (Narula, 1970, 1971-72, 1980, 1988). It had been apprehended that contemporaneous tectonic creep along this feature could have been accentuating the unstable conditions of the penstock slopes. With this in view, Geodetic triangulation and precision levelling was conducted. These studies have indicated continued movements of the order of 1 to 5 cm in vertical and 0.5 to 4 cm in the horizontal direction between 1976 and 1978 (Arur and Rajal, 1981). Change in the horizontal vector direction on either side of the thrust has also been noticed.

The crustal movement studies across Ganga tear in U.P. have statistically confirmed horizontal movements of the order of 1.5 to 5.5 cm between 1978 and 1985. The horizontal movement vectors have depicted that eastern block of this tear has moved southwards with respect to western block (Arur and Hasija, 1986).

Levelling and distance measurements carried out in small networks across the MCT and the MBF in Central Nepal have indicated 5 micro- strains per year in the vicinity of upper MCT. It has been interpreted that if strain change is attributed to horizontal movements a left lateral sense of movement would have taken place along this tectonic structure. The levelling across MBT in Kerabari area has yielded tilting rate of 1 micro radian per year along the MBT (Omura, Yokoyama and Kubo, 1986).

The above Geodetic monitoring data is isolated and site specific and for clearly understanding the crustal movements across the Himalaya comprehensive work is necessary with larger networks along a number of sections.

2.1.7 Secular Episodic Movements

The Himalaya have an extremely youthful and rugged topography with deep river gorges and steep valley slopes. Five to six levels of terraces indicate many major uplift episodes in the Quaternary period. It has been interpreted (Khan, 1982) that there has been continued decrease in the rate of uplift from early to late Holocene as evidenced by divergent disposition of older terraces and convergence of younger terraces. These studies have been made in Alakananda Valley.
Based on the terrace level studies in Himalayan river regimes, episodic uplifts and subsidences in various tracts has been demonstrated by many workers, particularly in Siwalik domain. In Kangra Valley, Awasthi (1982) interpreted that along Balganga river, a tributary of Beas, differential uplifts took place in Holocene and late Pleistocene periods. Episodic uplift in the Pir Panjal range during Middle Pleistocene and later periods has been suggested by various workers, based on the morphotectonic set up prevailing in the Karewa sediments in Kashmir Valley.

It has also been interpreted that Doon Valley shows trend of uplift in Holocene period and the same is continuing. Precision levelling data collected in Dun Valley during pre and post Kangra Earthquake of 1905. The data reveals that a maximum of 15 cm uplift has taken place between 1904 and 1975 out of which 10 cm uplift took place consequent to the Kangra earthquake. After Kangra earthquake the rate of uplift works out to be only 1 mm per year. Another observation made is that the rate of uplift progressively decreases towards north and at Mussoorie it has become negligible from which it has been interpreted that a block between MBT in the north and Foot Hill Thrust in the south is undergoing continuous uplift (Rajal, Virdi and Hasija, 1986).

2.1.8 Vertical Movements in Indo-Gangetic Plains

Survey of India has run a number of high precision levelling lines across the Indo-Gangetic plains and repeated over the last 100 years or so. The analysis of certain selected lines (Joshi et al., 1989) has yielded vertical movement patterns. The lines selected by them were the Dhule- Saharanpur; Dhule- Bhadrak; Nagpur- Gorakhpur and Bharakh to Purnea. They have concluded that there is a general subsidence in the western sector, ranging from 1 mm/yr to 31.5 mm/yr, and uplift in the eastern sector, ranging from 1 mm/yr to 16 mm/yr. It has been inferred that the tilt is associated with tectonic processes.

These data base could be of great utility for visualisation of a tectonic model for the Himalaya.

2.2 Older Neotectonic Episodes

In defining this episode the lower age limit assigned is the base of Quaternary or the Neogene-Quaternary Boundary, an important stratigraphic problem, as various workers have put the boundary at different stratigraphic levels. For the purposes of compiling the Neotectonic map of the Himalaya, the older Neotectonic episode has been separated from the older tectonic
elements on the basis of involvement of upper Siwalik Boulder beds in the folding and faulting. Thus, in strictest sense of Quaternary stratigraphy, the tectonic episodes included in this category would be younger than the Neogene-Quaternary Boundary.

The regional geological mapping of Tertiary foot hills belt has revealed occurrence of belt of gentle folds containing broad en-echelon anticlinal folds at its southern margin, exposing mainly the upper Siwalik rocks (Karunakaran & Rao, 1979). These shortening structures involving the Quaternary sediments are included in this category of neotectonic movements. In addition to these shortening structures a number of tectonic lineaments, parallel to the Himalayan trend and transverse to it, have been picked up which have either overlapped the upper Siwalik boulder beds by thrust sheets or displaced beds by dextral as well as sinistral strike slip faults. The northern most thrust which has overlapped the upper Siwalik Boulder Beds at a number of locations is the Main Boundary Fault and the southern most structure is the Foot Hill Fault. Both these tectonic features have been included in the Younger Neotectonic episodes because these at many places have displaced even the Holocene deposits.

In the northwest Himalaya, the Himachal Tertiary Belt, opposite Punjab plains, is the widest and exposes maximum number of thrusts, namely the Darang thrust, Palampur thrust, Gambhar thrust, Barsar thrust and the Markanda thrust which have overriden the Quaternary sediments in addition to the MBF, which can be traced all along the Himalaya. In the Jammu foot hills, the thrust which involves the Quaternary deposits is the Riasi thrust which has brought Sirban dolomites in juxtaposition with Siwalik Boulder Beds and along its trace towards east Murree rocks overlie the same horizon and the thrust is locally named as Nandiki- Kishanpur thrust.

In the Uttar Pradesh foot hills, the wide Dehradun embayment exposes older Tertiaries in a small section near the MBF and Siwalik towards the south and major central portion is occupied by Dun gravels covering the older rocks and any tectonic feature associated with them as such no tectonic feature exhibiting older neotectonic activity is exposed in this embayment but further east one tectonic structure the Sarduli-Dhikala thrust bringing lower Siwaliks over Boulder beds falls in this category.

In the Nepal foot hills, the Siwaliks have been shown only as one unit with separating the Upper, Middle and Lower Siwaliks between meridian 80° and 82.50° and thus it is not possible to codify the neotectonic episodes. Between segments 83° to
84° and 85° to 88°—thrusting of Upper Siwalik Boulder Beds by older rocks, similar to the ones in NW Himalaya have been recorded.

In the northeastern sector, the MBF which has brought Gondwanas over the Dafla formation overlaps the Kimin formation in Dhansiri Valley indicating this feature to have activated in early Quaternary period. Another important tectonic feature of unequivocal Quaternary age is the Tipi thrust along which Kimin formation has been overridden by Dafla formation.

The regional analysis of the structures in the Himalayan Tertiary belt reveals that a number of transverse features have sculptured the configuration of the Tertiary basin. Many of such transverse strike slip faults, primarily showing conjugate dextral and sinistral sense of movement, have offset the upper Siwalik Boulder Beds and most of these control the major river courses at locations where three rivers debouch into the plains. These transverse features are of great significance in modelling the stress fields operative during the Quaternary period. The important transverse faults exposed in outer foot hill belt are depicted in the map appended with this write up. Most of these features have shown continued movements through the younger Quaternary as well as present day adjustments. The trend of these transverse features NNW-SSE and NNE-SSW in the western sector to NW-SE, NE-SW in the north eastern sector. The differential movements and changes in their trend are to be genetically related to the changes in stress fields but at the same time could even be attributed to an anticlockwise rotation of the Indian Plate in the Quaternary period.

2.3 Undifferentiated and Indirect Geomorphic and Archaeological Evidences

An important aspect of establishing neotectonic adjustments are the geomorphic evidences regarding changes in river courses caused by episodic uplifts and subsidences, abrupt drainage swings and development of river terraces and erosional terraced slopes in the mountain belt. This aspect would be covered in the write up on Geomorphology. Similarly extensive archaeological records are available on buried locales of past civilisations, many of which could have been related to neotectonic adjustments. This being a specific field of research, the documentation and interpretation of this data is beyond the scope of this write up.
3 DISCUSSIONS

In the outer Himalaya large scale regression of sea took place during Oligocene times which was followed by the first major uplift. This heralded the continental foredeep in which early Oligocene sediments were deposited in primarily, brackish water conditions. This basin was bounded by a tectonic lineament, which during the evolution of the Himalaya got modified and is presently recognisable as the MBF (locally named as Murree Thrust, Shali Thrust and Krol Thrust). The southern boundary of this basin would have been the foot-hill fault south of which the Murree, Dharamsala and Subathu Groups of rocks are not reported below the Siwalik Group of rocks in any deep structural wells drilled in the present Indo-Gangetic alluvium.

The next Himalayan orogenic impulse (HOM-2) resulted in shifting of the foredeep further south which was repository of Siwalik Group of rocks. The Siwalik basin overlapped rocks of various age group in different sectors and domains viz. Murree, Dharamsala or Subathu group of rocks north of Fort Hill Fault, Granitic complex in Punjab plains, Vindhayan Group of rocks in U.P. and Gondwanas further east. The differential uplift and transverse movements continued during the course of deposition in Siwalik domain modifying the basinal boundaries reflected by varying widths of basin in various sectors and many a times controlled by transverse faults. Contemporaneous transverse movements with the deposition are exhibited by the swings in structural trends like fold axes in the vicinity of the projected location of transverse basement faults.

In the Himachal Foot Hill belt the MBF takes a N-S swing from its general NW-SE trend through Mandi and Sundarnagar. This N-W swing could also be the result of transverse movements. It is interesting to note that the southward projection of N-S trend of MBF matches with the Ropar tear towards south and a N-S fault in pre- Tertiary domain in the north. The modification of the trend of MBF along transverse faults has been recorded at a number of places, though on a much smaller scale than recorded in Himachal Pradesh (Plate IV). Embayments of Tertiary basin exist at a number of places all along the Sub-Himalaya, particularly in the northwestern sector. It is possible that these embayments are controlled by transverse basement conjugate faults. In different blocks, bounded by these conjugate set of faults, the extent of movement would decide the spatial interblock configuration.

Subsequent to the deposition of Siwalik molasse, the Himalaya experienced another cycle of uplift after Lower Pleistocene time. The older Neotectonic structures were the result of tectonic
adjustments during this cycle of orogenic movements. The last phase of crustal adjustments which have continued till date resulted in the Younger Neotectonic Episodes.

The data generated till date on the neotectonism demonstrate that the most important Quaternary structure in the Himalayan foot hills is the Main Boundary Fault which could have been a fundamental fracture of even pre-Tertiary age and has got modified during the subsequent orogenic movements and is presently recognisable as a thrust which overlaps all the rocks right from early Miocene to the Siwalik Boulder beds of Upper Pleistocene age. Isolated evidences of strike slip component along the MBF have been displayed by opposite sense of horizontal movement vectors on either side of this feature monitored by geodetic surveys (Shanan, H.P.) conducted for establishing contemporary adjustments along this feature. The geological evidences collected and geodetic monitoring at a number of locations have indicated that tectonic adjustments along the MBF are continuing.

Another important tectonic feature of neotectonic significance, subparallel to the Himalayan trend, is the Foot Hill Fault which delimits the Indo-Gangetic foredeep. It is significant that though homoclinally northward dipping Siwalik rocks have been encountered below the Indo-Gangetic alluvium but the shortening structures in the Siwalik Group of rocks have only been recorded north of the Foot Hill Fault.

Tectonic features subparallel to the Himalayan trend are present as Schuppan belt between the MBF and the Foot Hill fault which display evidences of neotectonism. These thrust type of faults merge along the strike with the MBF and could thus be splays of the MBF.

These traverse faults occur as conjugate dextral and sinistral faults with changing attitudes and have been found active even onto the Quaternary. The changing attitudes of the conjugate fault sets seem to indicate changing parameters of the movement plan of the stress field in various sectors. A critical study of these, through space and time is suggestive of being related to anticlockwise rotation of the Indian Plate throughout the Quaternary period.

Isolated evidences of neotectonic adjustments along the tectonic features north of the MBF, both parallel to Himalayan trend and transverse to it, have been recorded which could be genetically related to the Quaternary phase of uplift. Geodetic monitoring along Srinagar thrust and MCT in Garhwal Himalaya and MCT in Nepal Himalaya, has established contemporary tectonic adjustments.
4 ACKNOWLEDGEMENTS

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5 REFERENCES


Neotectonic Activity


Neotectonic Activity


GEOMORPHOLOGY OF THE HIMALAYA

By
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ABSTRACT

The geomorphology of the Himalaya including the frontal foredeep to its south has been discussed based primarily on the study of remote sensing data. A Geomorphological Map on 1:5 million scale is also presented.

Himalayan terrain has been geomorphologically classified into seven units. Each unit is again re-grouped according to its mode of origin. Many geomorphic units have been found to transgress the broad stratigraphic boundaries of various lithounits. Though many prominent longitudinal structural planes/thrusts (like MBT and MCT) are not discernible from remote sensed geomorphological considerations but transverse fracture lines and lineaments are easily identifiable.

1 INTRODUCTION

The Himalayan Mountain System is a conspicuous landmass characterised by its unique crescent shape, high orography, varied lithology and complex structure. The mountain system is rather of young geological age though the rock material it contains has a long history of sedimentation, metamorphism and magmatism from Proterozoic to Quaternary in age. Geographically, it occupies a vast terrain covering the northern boundary of India, entire Nepal, Bhutan and parts of China and Pakistan, stretching from almost 72° E to 96° E meridians for about 2500 Km in length. In terms of orography, the geographers have conceived four zones in the Himalaya across its long axis. From south to north, these are (i) the sub-Himalaya, comprising low hill ranges of Siwalik, not rising above 1000 m in altitude in general, which may be regarded as the rising line of the Himalaya from the plains; (ii) the Lesser Himalaya, comprising a series of mountain ranges not rising above 4000 m in altitude; (iii) the Great Himalaya, comprising very high mountain ranges with glaciers, rising above 6000 m in altitude. It contains some of the renowned ranges (Deosai mountain, Ladakh range, Kailash range, Zanskar range, Pir Panjal range), and contains some of the highest peaks in the world.

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viz., Mt. Everest (8848 m), Kanchen Dzonga (8598 m), Manaslu (8156 m), Annapurna (8078 m), Dhaulagiri (8172 m), Nanga Parbat (8126 m), Nanda Devi (7817 m), Kamet (7756 m), Kula Kangri (7554 m), etc.; and (iv) the Trans-Himalaya, comprising very high moun-
tain ranges with glaciers, the Hindukush-Karakoram ranges proba-
bly constitute the Trans- Himalaya. Beyond the Trans-Himalaya or
the Karakoram ranges are high altitude mountain plains (with or
without prominent ridges) of Aksai Chin which pass into Pamir on
the NW and Tibet plateau on the ESE.

The above four orographic zones of the Himalaya are not
strictly broad morpho- tectonic units though tectonism must have
played a key role in varied orographic attainments of different
zones. Their conceived boundaries do not also coincide with those
of lithostratigraphic or tectonostratigraphic units. Because of
the involvement of a large number of parameters of variable na-
ture, the geomorphic units are expected to be diverse but cause-
specific, having close links with mechanism and history of sedi-
mentation, metamorphism, magmatism and crustal movements. Thus, a
lithounit or a group of lithounits, depending on its compe-
tence/incompetence and its sedimentary/ metamorphic/ igneous ori-
gin as also depending on the nature of forces (structure/ tecton-
ic) having acted upon it, is theoretically supposed to shape into
a landform of given geometry that may speak of the former's
genesis. It is because of these reasons, an attempt has been made
to work out the geomorphology of the Himalaya to see if such an
approach is able to throw any light on the tectonic modelling of
the Himalaya.

2 METHODOLOGY

Field-based geomorphological mapping and measurements of the
entire Himalaya is a herculean task and will take a long time for
systematic coverage. However, geomorphological mapping, with spe-
cific aims and objectives, have been conducted in many sectors of
the Himalaya, especially in river valleys, gorges, intermontane
structural valleys and foothill zones of interest and impor-
tance. The present study of demarcating the Himalaya into various
geomorphic units is primarily based on remote sensing techniques
with liberal input of actual ground truth and concerning geologi-
cal/topographic information contained in innumerable unpublished
Geological Survey of India reports and maps.

Geomorphological Map of India on 1:2 million scale, prepared
by the Geological Survey of India (in press) from Landsat 2 MSS
imagery forms the basis of the present study. However, suitable
modifications and/or additions have been effected by way of re-interpreta-
tion of Landsat 4/5 MSS imagery (on 1:1 million scale) in different spectral bands. Available SPOT and Landsat 5
TM imagery/FCC on 1:250,000/1:50,000 scale have also been scanned for the critical areas. The interpreted information on geomorphological classes/units besides structure and lineaments have been plotted on a mosaic of Landsat 4/5 MSS imagery (1:1 million scale) for the entire terrain. Afterwards, the entire data have been transferred on 1:2 million scale approved topo-base to prepare the Geomorphological map. This map has further been reduced photographically to 1:5 million scale for presentation purpose (Plate V). Needless to mention that reduction at various stages from 1:50,000/1:250,000 scale to 1:5 million scale has compelled omission of minor details and generalisation of mappable units. Geomorphic forms have mostly been erased to avoid crowding of the final map. Thus, accounts of some geomorphic units and forms that have found place in the write-up may not be seen on the map presented on 1:5 million scale (Plate V).

Degree of ruggedness, amount of elevation/ depth, nature of dissection, drainage density, texture and pattern, reflectivity in terms of brightness grey value/colour, slope characters, aspects of ridges, facets, relative relief, alignments of ridges/valleys, crest configuration, extent of denudation, etc. have been taken into consideration in classification of geomorphic units. Structural imprints like fold pattern and lineaments on landforms have also been studied. Needless to mention that the interpretation is based on monoscopic view of the terrain features in two dimensions only, thus lagging in proper perception on elevation. The drainage pattern and texture, and photographic tone and texture coupled with shadow effects have been used to compensate vertical dissection-cum-elevation perception. Based on such concepts, the Himalayan terrain has been geomorphologically classified into deeply/ moderately/ poorly dissected mountain ranges, mountain plains (with or without ridges), mountain masses, hill ranges, hill masses and valleys having well-defined drainage texture (coarse/medium/fine/very fine) and crest configuration (sharp/horn-peaked/round/subdued) or valley slope/head configuration (steep or otherwise). Such geomorphic units have again been regrouped according to their modes of origin, i.e., on the degree of influence of structure or denudation in shaping the landform units. Therefore, on one hand every geomorphic unit is essentially of structural origin and on the other every unit is resultant of denudation (i.e. of denudational origin). Thus, elements of structure and denudation have due weightage in identification of various geomorphic units mapped. Most of these units are significantly modified by denudation though their alignments/dispositions are essentially controlled by the imposing regional structure/tectonics. Other geomorphic units like river valleys, flood plains, terraces, fans, alluvial plains, etc., have also been classified according to their modes.
of origin. These are units of aeolian/ fluvio-aeolian origin; units of glacial/ fluvio-glacial origin; and units of fluvial/lacustrine origin. The latter three classes of geomorphic units are independent of structural connotation though they might occur at localities of structural significance or might have been affected by subsequent structure.

3 GEOMORPHIC CLASSIFICATION

The landscape which we see today has been shaped in the Quaternary period, especially by physical activities in glacial and post-glacial fluvial periods. Many terrain features diagnostic of given structural control and lithological significance must have since been obliterated/modified responding to exogenic process (fluvial/glacial/aeolian) to give rise to the sum total of present-day picture of the terrain. The generalised geomorphological account of the mountain system is, thus, obvious. The following geomorphic units have been recognised and mapped right from high mountain plains/Trans-Himalaya mountain range in the north to the northern boundary of the Peninsular craton in the south (Plate V).

3.1 Units of Structural Origin (S)

<table>
<thead>
<tr>
<th>Broad Class</th>
<th>Unit No.</th>
<th>Geomorphic unit (with geographic location)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain ranges</td>
<td>S1a</td>
<td>Deeply dissected, medium drainage textured, horn-peaked ridges with profuse cirques and valley glaciers (Karakoram range)</td>
</tr>
<tr>
<td></td>
<td>S1b</td>
<td>Deeply dissected, fine drainage textured, sharp crested ridges (Deosai-Ladakh ranges; part of Kun Lun mountain)</td>
</tr>
<tr>
<td></td>
<td>S1c</td>
<td>Moderately dissected, medium drainage textured, sharp crested ridges (Zanskar range; Dras and Zanskar river basin; Tethyan Himalaya)</td>
</tr>
<tr>
<td></td>
<td>S1d</td>
<td>Transverse deeply dissected, medium drainage textured, sharp crested ridges with glaciers (Parts of Great Himalaya including Pir Panjal ranges, Almora ranges, Kumaon Himalaya, Darjeeling Himalaya, Central parts of Nepal and Bhutan, Mishmi range)</td>
</tr>
<tr>
<td>Mountain S2</td>
<td>Moderately dissected, fine drainage textured, poorly oriented, sharp crested ridges</td>
<td>Mussoorie- Nagtibba ranges, Central Nepal, southern Bhutan, Arunachal Pradesh of Lesser Himalaya</td>
</tr>
<tr>
<td>Mountain S3a</td>
<td>Transverse, deeply dissected, very fine drainage textured, sharp crested, curvilinear ridges with snow-clad peaks and deep glaciated valleys</td>
<td>Northern Nepal and northern Bhutan, parts of China/Tibet</td>
</tr>
<tr>
<td>Mountain S2 plains with ridges (S2)</td>
<td>High altitude plains with poorly dissected, fine drainage textured, subdued, detached ridges</td>
<td>Chang Tang-Linzi Tang area of Aksai Chin</td>
</tr>
<tr>
<td>Mountain S3a masses (S3)</td>
<td>Poorly dissected, medium drainage textured, sharp crested, mountain mass with low relative relief</td>
<td>Ghizar- Gilgit- Indus river basin area</td>
</tr>
<tr>
<td>Mountain S3b</td>
<td>Deeply dissected, medium drainage textured, sharp crested, mountain mass with high relative relief</td>
<td>Nanga Parbat of Great Himalaya, Kishan Ganga area, north of Kashmir valley</td>
</tr>
<tr>
<td>Mountain S3c</td>
<td>Deeply dissected, coarse drainage textured, round crested, mountain mass, with moderate relative relief</td>
<td>Jhelum- Punch- Jambhir river area south-west of Kashmir valley; Lesser Himalaya</td>
</tr>
<tr>
<td>Mountain S3d</td>
<td>Moderately dissected, medium drainage textured, round crested, mountain mass with moderate relative relief</td>
<td>Rupshu-Tso Kar- Tso Morari region (south of Indus river); Tethyan Himalaya</td>
</tr>
<tr>
<td>Mountain S3e</td>
<td>Moderately to deeply dissected, fine drainage textured,</td>
<td>Natu La area of Sikkim-Bhutan</td>
</tr>
<tr>
<td>Hill ranges (S4)</td>
<td>S4a</td>
<td>Poorly dissected, fine drainage textured, sharp to round crested, linear ridges</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>S4b</td>
<td>Moderately dissected, medium drainage textured, round crested, linear ridges with steep valley side slope</td>
</tr>
<tr>
<td>Hill mass (S5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope facets (S6)</td>
<td>S6</td>
<td>Moderately dissected, fine drainage textured, valley side steep slope facets with sharp spur crests</td>
</tr>
<tr>
<td>Valleys (S7)</td>
<td>S7a</td>
<td>Intermontane broad valleys with or without glacial outwash plains</td>
</tr>
<tr>
<td></td>
<td>S7b</td>
<td>Low-lying, flat bottom, narrow spindle shaped valleys with fills</td>
</tr>
<tr>
<td></td>
<td>S7c</td>
<td>Deeply dissected, fine drainage textured, valley head with sharp crested spurs</td>
</tr>
</tbody>
</table>

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### 3.2 Units of Fluvial and Lacustrine Origin (F)

<table>
<thead>
<tr>
<th>Broad Class</th>
<th>Unit Geomorphic unit with diagnostic characters</th>
<th>Geographic location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low lying flats/plains (F1)</td>
<td>Fla Lacustrine plains</td>
<td>Mostly on high mountain plains of Aksai Chin; also on Karakoram range, in Ladakh, Tethyan Himalaya, Central Crystallines</td>
</tr>
<tr>
<td></td>
<td>F1b Present flood plains</td>
<td>Along major river valleys in Ganga Foredeep</td>
</tr>
<tr>
<td></td>
<td>F1c Older alluvial plains</td>
<td>Major parts of Ganga Foredeep</td>
</tr>
<tr>
<td>Infilled valleys (F2)</td>
<td>F2 Infilled valleys with or without alluvial ridges</td>
<td>Along major river valleys in Ganga Foredeep</td>
</tr>
<tr>
<td>Alluvial fans (F3)</td>
<td>F3a Piedmont cut and fill coalescing fan terraces (Upper F3a1; Lower F3a2)</td>
<td>Piedmont fan zones in Ganga Foredeep between Siwalik hills and alluvial plains</td>
</tr>
<tr>
<td></td>
<td>F3b Discrete fan surfaces</td>
<td>-do-</td>
</tr>
<tr>
<td>Riverine terraces (F4)</td>
<td>F4 Distinct riverine terraces above present flood plains</td>
<td>Along major river valleys in Ganga Foredeep</td>
</tr>
</tbody>
</table>

### 3.3 Units of Glacial and Fluviooglacial Origin (G)

<table>
<thead>
<tr>
<th>Broad Class</th>
<th>Unit Geomorphic unit (with diagnostic characters)</th>
<th>Geographic location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low lying flats/plains (G1)</td>
<td>G1 Glaciated low lying flats/plains</td>
<td>Mostly on high mountain plains of Aksai Chin; also on Ladakh and Karakoram ranges</td>
</tr>
<tr>
<td>Valleys (G2)</td>
<td>G2a Glaciated U-valleys and cirque valleys</td>
<td>On Karakoram, Ladakh, Deosai, Zanskar ranges; also in Tethyan Himalaya and Central Crystallines of Great Himalaya</td>
</tr>
</tbody>
</table>
3.4 Units of Undifferentiated Origin, Defining Foredeep Boundary (D)

<table>
<thead>
<tr>
<th>Broad Class</th>
<th>Unit Geomorphic Unit (with Geographic location Class No. diagnostic characters)</th>
<th>Geographic location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hills D</td>
<td>Undifferentiated geomorphic units bordering approximate southern limit of Ganga Foredeep</td>
<td>Parts of Peninsular Craton/Naga- Patkoi fold belt</td>
</tr>
<tr>
<td>Plains (D)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 DESCRIPTION OF GEOMORPHIC UNITS

Unit No. S1a (Plate V) encloses very high mountain ranges with profuse cirques and valley glaciers covering mainly the Karakoram mountain ranges of the Trans Himalaya. Its northern border with mountain plains (S2) of Aksai Chin is rather gradational, showing gradual change in topographic slope which merge with the flat topography of S2. Its southern contact with S1b is sharply demarcated by Indus-Shyok lineament system depicting narrow, deep river gorges. Its southwestern boundary with S3a is marked by deep, arcuate gorges of Ghizer-Gilgit river systems. The mountain ranges of this unit are deeply dissected and medium drainage textured with dendritic pattern. The major river channels/gorges, being longitudinal rivers, follow ridge-parallel courses. The ridges are horn-peaked and mostly aligned in NW-SE direction. The dominant lithologies in this are mainly granites, some sedimentary rocks and basic volcanics.

Unit No. S1b encloses high mountain ranges with glaciers and snow-covered peaks of Deosai mountains and Ladakh ranges. Its northern boundary with Unit No. S1a (Karakoram ranges) is well defined by Indus-Shyok lineament system and its southern boundary with Unit Nos. S1c (Zanskar ranges) and S3d (Tethyan Himalaya) is defined by the deep gorges of the Indus river (Indus Suture). Its northwestern boundary with mountain masses (Unit Nos., S3a and S3b) swerves into an arcuate fashion. The mountain ranges of this unit are deeply dissected and fine dendritic drainage textured.
The major river valleys/gorges being longitudinal are ridge-parallel, the ridges being mostly aligned in WNW-ESE direction. Crests of the ridges are sharp. It has transverse spur ridges. It is mainly underlain by younger granites, granitoids and ultrabasics. Metamorphics are also present. However, these varying rock types do not yield differential land forms identifiable on satellite imagery. A part of Kun Lun mountain at the north of mountain plains (S2) of Aksai Chin has also been mapped as Sib unit.

Unit No. Sib occupying mainly Zanskar mountain ranges and Indus and Zanskar valleys is moderately dissected. Its northern contact with Unit No. Slb is well marked by Indus river gorges (Indus lineament/suture) but its southern boundary with Unit No. Sld is not well defined, except with some minor stream knick points. The knick points of streams indicate structure-controlled, minor lineaments, may be a series of faults. This unit has strike-parallel ridges and drainage (longitudinal river valleys). This unit is developed mainly over Tethyan sediments. Thus, its look and character substantially differ from Unit No. Sib (Ladakh Range) on its north and Unit No. Sld (Central Crystallines) on its south. Its northwestern boundary with Sib appears to indicate closure of a fold which is probably affected by a N-S (NNE-SSW) fault along which the Zanskar river, with its northerly flowing tributaries, takes a sharp northerly turn to join the Indus river. However, the overall appearance of these mountain ranges appears to have been dictated by a regional fold having NW-SE axial trend. The ophiolites/melanges that occur along the Indus river typifying subduction zone along the Indus Suture are not distinct and are marked by the massive sedimentary pile of this geomorphic unit.

Unit No. Sld is the most prominent geomorphic unit in the Himalaya Mountain System. It runs continuously from Kashmir valley in the west to Mishmi hills in the east for about 2500 Km in length. Its average width is about 100 Km; the maximum being about 200 Km in a NE-SW direction near Simla. It houses some of the highest peaks of the world and the average elevation of the mountain ranges of this unit belonging to the Great Himalaya is above 6000 m. Its northern contact with Unit Nos. Slc and Slb is marked by some minor lineaments whereas that with Unit Nos. Slf (in Nepal/China/Bhutan) and S7a (in Nepal/China) is gradational and/or marked by break in topographic slope. Its southern boundary with Unit Nos. Sle, S4b and S3c is largely defined by strong relief difference as well as by break in topographic slope. Eroded steep escarpment and contact-parallel knicks in river channels indicate structural weak planes in sectors along the southern boundary. The conspicuous geomorphic anomalies in this unit are that (i) the individual mountain ridges are not continuous; (ii) the ridges are frequently dissected by trans-
verse courses of major river channels; (iii) in spite of being of very high elevation, this unit does not act as major watershed for rivers. This unit is traversed by a number of prominent lineaments, the major ones running transversely in N-S and NE-SW directions in the western part and in NW-SE direction in the eastern part. This unit is developed mainly over high grade metamorphic and granite/granitoid rocks with migmatites. Minor volcano-sedimentary rocks are also included within this unit. In the northeast corner of India, this unit takes a sharp bend towards south where a strong NW-SE linear gorge (Lohit thrust) delimits the granitoid block at Mishmi Hills on the north.

Unit No. S1e is conspicuously different from S1d, marked by a sharp fall in elevation from above 6000 m in S1d to about 4000 m in it. It is moderately dissected with sharp crested ridges. It has fine textured dendritic drainage pattern. Lower order streams from S1d merge in this unit to form higher order streams/rivers. The rivers are mostly transverse across the NW-SE, E-W and NE-SW sharp-crested ridges. This unit is frequently traversed by strong transverse lineaments which often offset the ridges. Its southern boundary with Unit No. S4a (Siwalik hills) is very sharp, often marked by local longitudinal lineaments of prominence indicative of faults/thrust. Ridge-parallel knicks of channels along its southern boundary also point to the existence of weak structural planes of faults/thrusts. Its western boundary with Unit No. S4b is rather gradational whereas its eastern boundary is marked by a syntaxial bend along Dihang river as also by the strong NW-SE lineament representing Lohit thrust. This unit is mainly developed over low grade metamorphic and sedimentary rocks. There are also some high grade metamorphics and granites in it.

Unit No. S1f mapped along Chinese border with Nepal and Bhutan is analogous to Unit S1d. This Unit with high mountain ridges and glaciers acts as the major watershed for rivers. The sharp-crested, curvilinear ridges of this unit are transversely dissected by fine textured dendritic drainage. It is developed over metamorphic and sedimentary sequence.

Unit No. S2 represents the high altitude mountain plains of Aksai Chin which passes into Tibet, a Plateau in ESE and Pamir in NW. Its southern boundary with lofty Karakoram ranges and northern boundary with Kun Lun mountain are rather gradational, showing gradual changes in relative relief and topographic slope. It is poorly dissected by fine textured drainage. There are few subdued ridges. This high altitude plain is extensively glaciated hosting glacial, fluvial and lacustrine plains and lakes.
Unit No. S3a represents a round-crested mountain mass with low relative relief. It has a massive appearance without well-defined ridges. Its almost arcuate boundary is defined by Ghizer-Gilgit river system on west and north and by Indus on east and south. The look of this unit, developed over mainly undifferentiated mafic and felsic intrusives and Deosai diorites, is completely different from mountain ranges of Unit Nos. S1a and S1b on its east.

Unit No. S3b hosting Nanga Parbat represents sharp crested mountain mass with high relative relief. The ridges on this mountain mass appear to be radially fanning out. It is deeply dissected and medium drainage textured. Its northern contact with S3a almost coincides with the Indus river course flowing from east to west. Its eastern contact with Deosai-Ladakh ranges of Unit No. S1b is marked by a south to north flowing tributary of Indus. Its southern boundary with Unit No. S3c, S7a and S1d is marked by break in topography. This unit is formed over mostly granites, granitoids, migmatites and other hybrid rocks. There are also some basic intrusives and metamorphics.

Unit No. S3c is a moderately dissected, coarse drainage textured, round-crested mountain mass with moderate relative relief. Though massive in appearance because of extensive denudation, this unit follows the regional structural trend of NW-SE. Its northern contact with S1d and southern contact with S4a are marked by distinct break in topographic slope. This unit is formed over soft sediments.

Unit No. S3d represents moderately dissected, medium drainage textured, round-crested high mountain mass with moderate relative relief. Its northern contact with Ladakh ranges (S1b) is marked by the deep gorges of the Indus river (Indus Suture), whereas its southern contact with S1c (Zanskar mountain) and S1d is rather gradational with break in topography. The northwestern end of this spindle shaped unit depicts a distinct fold closure. The rivers are mostly longitudinal being structure controlled. The bed rock of this unit is sedimentary sequences.

Unit No. S3e, occurring in Natu La area in Sikkim-Bhutan boundary, represents a moderate to deeply dissected, fine drainage textured, round created, mountain mass with the relative relief. having been surrounded by Central Crystalline mountain ranges of Unit No. S1d, with gradational contact, this unit differs from the former by the absence of well defined ridges in it. It is formed over metamorphic rocks.
Unit No. S4a constitutes very well-defined, low, linear hill ranges, running from Jhelum lineament in the West to Dihang-Brahmaputra in the East and separating high Himalaya from fans/alluvial tract of the Foredeep. The unit is poorly dissected by fine textured transverse drainage. The crests of the hills are sharp to round. The linear hill ranges of this unit are often offset by NW-SE and NE-SW trending fractures/ faults/ lineaments along which most of the major rivers flow out from high ranges to debouch on plains. Its northern contact with Unit Nos. S1e and S3c is marked by sudden break in topographic slope (with escarpment at places) and by appearance of higher order streams through joining of lower order streams from S1e/S3c. The rivers draining and dissecting this unit form ridge-parallel knicks at its northern boundary, which are indicative of longitudinal faults/ thrusts/ fractures. There are some trellis/ sub-trellis and semi-arcuate drainage pattern which indicate doubly plunging/ open folds suffered by rocks of this unit. This unit is developed over Siwalik sedimentary rocks.

Unit No. S4b represents linear ridges of sediments which are round-crested and moderately dissected with steep valley side slopes. The drainage texture is medium and the drainage pattern varies from parallel to trellis, being structure-controlled. Its contact with S1d is marked by steep escarpment and changes in abrupt drainage pattern whereas its contact with S4a is defined by eroded escarpment. The hill ridges of this unit conspicuously swerve from NW-SE orientation to N-S orientation.

Occurring north of Govind Sagar between Sutlej and Beas rivers, this small hill mass S5 has sharp crests and steep valley side slopes, and is poorly dissected by very fine drainage. It is formed over soft sedimentary rocks. Its contact with S4a and S4b units is marked by gradual fall in topographic slope with local escarpments.

Unit No. S6 is a slope facet developed along NE-SW flowing Tamur river in the eastern boundary of Nepal. It represents the Kanchen Dzonga lineament within the crystallines of Unit No. S1d. This unit is moderately dissected by fine textured drainage. It displays steep valley side slope facets and sharp spur crests.

Unit No. S7a represents intermontane broad valleys, with or without glacial outwash plains, disposed in conformity with regional structural trend of the host rocks. Such intermontane structural valleys have been developed in Kashmir, Kathmandu and in the upper reaches of E-W flowing Sutlej river on high altitude mountain plains around Mansarovar. These elliptical shaped valleys have flat bottom and deeply dissected valley walls. Centripetal drainage is obvious in this unit. The valleys located within older rocks are filled by Quaternary sediments.
Unit No. S7b constitutes the narrow spindle shaped, low-lying, flat-bottom valleys developed within or at the margins of Siwalik hills (Unit No. S4a). These valleys mostly occupy the centres of synformal fold structure. Their margins are defined by hillside slopes; northern slope is gentle and southern steep. These are filled mostly with boulders to gravels of Quaternary age. These are commonly known as Duns.

Unit No. S7c is a valley head with sharp crested spurs and it occurs along Chumbi valley at Sikkim-Bhutan border. It is deeply dissected and fine drainage textured. The unit is formed over crystallines.

Unit No. F1a constitutes low-lying flats and plains having irregular arcuate shape. These plains appear to contain Quaternary lacustrine sediments formed over former lakes. These lacustrine plains have been mapped on high altitude mountain plains of Aksai Chin, on Karakoram and Ladakh ranges and in Tethyan Himalaya.

Unit No. F1b is a low-lying flat representing the present flood plains of all major rivers in the Ganga Foredeep. The flood plains along with the river channels are controlled in many sectors by strong lineaments/faults. They also shift their courses within the alluvial plains.

Unit No. F1c is the extensive alluvial flat occupying the Ganga Foredeep. The sedimentary fill has its provenance in the Himalaya. Strong transverse lineaments and faults traverse this unit indicating active tectonic regime of the Ganga Foredeep.

Unit No. F2 represents the infilled valleys along the major rivers in the Ganga Foredeep. These infilled valleys, with or without alluvial ridges are in the earlier left out channels of the major rivers.

Unit No. F3 represents the alluvial fans constituting a unique landform developed all along the foot of Unit No. S4a (Siwalik hill ranges). Its contact with S4a is marked by break in topographic slope and by the appearance of higher order streams which form by merger of lower order streams coming out of S4a. These fans coalesce to form the piedmont zone (mapped as Unit No. F3a) which has been cut and filled subsequently to form two level terraces. The upper (and older) cut and fill terraces have been mapped as F3a1 unit and the lower (and younger) cut and fill terraces have been mapped as F3a2 unit. Where the two level terraces could not be mapped separately, the whole surface has been mapped as F3a. The discrete fan surfaces, which maintain their typical shape and have not coalesced with other fans, have been separately mapped as Unit No. F3b. Prominent NE-SW and NW-SE

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fractures/ faults/ lineaments often transversely cut across F3/ F3a1/ F3a/ F3a2 displacing them. Such lineaments often continue within S4a unit, offsetting the latter.

Unit No. F4 are riverine terraces developed above the present flood plains of the major rivers within the Ganga Foredeep. These terraces are longitudinal and contain younger fills representing Holocene sediments. The development of terraces is indicative of continued vertical cutting of the valleys during Holocene.

Unit No. G1 represents low-lying flats and plains formed due to glaciation. These are mapped on high altitude mountain plains of Aksai Chin (Unit No. S2) and also on Karakoram and Ladakh mountain ranges (Unit No. Slα and Slb), and on Tethyan Himalaya (S3d).

Unit No. G2a are mappable glaciated U-valleys and cirque valleys which, because of their typical shape, could be identified and mapped on satellite imagery. This unit has been mapped on mountain ranges and mountain masses of Unit Nos., Slα (Karakoram), Slb (Ladakh), Slc (Zanskar), and Sld.

Unit No. G2b represents fluvioglacial valleys developed mostly along high altitude valleys of the major rivers like Indus, Zanskar, Shyok, Sutlej, etc. These fluvioglacial valleys have been mapped on Unit Nos., Slα, Slb, Slc, Sld, S3a and S3d.

5 DESCRIPTION OF LINEAMENTS

A large number of prominent lineaments have been identified and mapped. These lineaments, mostly transverse and few longitudinal, affect the geomorphic/morphotectonic units transversely. Some others define the boundary between the units. These have been numbered on the map and described below.

Lineament No. 1 Mishmi Thrust, equivalent to MCT, trending NW-SE, separating Naga- Lusai mountain arc from Mishmi block.

Lineament No. 2 Lohit Thrust, within Mishmi block of geomorphic Unit No. Sld of Central Crystallines, trending NW-SE cutting across Lohit- Dihang rivers.

Lineament No. 3 Siyum lineament, within geomorphic unit No. Sle of Lesser Himalaya, trending N-S, near NW of Along. There are many minor lineaments around this major one.

Lineament No. 4 North Lakhimpur lineament, affecting Flb, F3a2, S4a and Sle, trending NW-SE, between Dibrugarh and Jorhat.

Lineament No. 5 Kameng lineament, NE of Bomdila, trending NNE-SW, affecting Sle and Sld units.
Lineament No. 6 Bomdila lineament, SE of Bomdila, trending WNW-ESE, affecting F3a1, S4a and S1d units.

Lineament No. 7 Kalaigaon lineament, north of Kalaigaon trending NW-SE, offsetting F3a1, S4a, S1e units.

Lineament No. 8 Dihang lineament, along Dihang river, NE-SW trending, continuation of MCT, abutting the Lohit Thrust.

Lineament No. 9 Sankosh lineament, trending N-S, within geomorphic unit No. S1d.

Lineament No. 10 Yadong Gulu lineament, S of Thimpu, trending NE-SW, within S1d unit.

Lineament No. 11 Tista lineament, along Tista river, trending NW-SE, affecting F3a2, F3a1, S4a, S1e and S1d units.

Lineament No. 12 Gangtok lineament, south of Gangtok, trending WNW-ESE, within S1d unit.

Lineament No. 13 Kanchen Dzonga lineament, east of Koshi river, comprising geomorphic unit No. S6, trending NE-SW, affecting F1b, F1c, F3a2, F3a1, S4a, S1c and S1d units for a stretch of more than 200 Km. Around Koshi fan, this lineament with two others (as may be seen on map) form the Monghry-Saharsa ridge.

Lineament No. 14 Dudhkoshi lineament, trending NE-SW, displacing F3a2, F3a1, S4a, S1e and S1d units.

Lineament No. 15 Motihari- Everest lineament, trending NE-SW, occurring around Aara- Muzaffarpur extending to high Himalaya, affecting F3a2, F3a1, S4a, S1e, S1d units.

Lineament No. 16 Malda-Kishanganj lineament, occurring along Mahananda river, trending N-S to NNE-SSW affecting F1b and F3a2 units.

Lineament No. 17 Gorakhpur-Baāti lineament, trending NE-SW, affecting F3a, S4a, S1e and S1d units.

Lineament No. 18 Ghaghra lineament, along Ghaghra river, trending NNW-SSE, affecting F1c, F1b, F2 and F4 geomorphic units. The southernmost point of this lineament ends at the NE extremity of Faizabad ridge which is NE-SW in direction and bound by two prominent NE-SW lineaments.

Lineament No. 19 Etah-Budaun Fault, trending NE-SW, affecting F1b and F3a geomorphic units.

Lineament No. 20 Moradabad Fault, trending NNE-SSW, affecting F1b, F1c, F2, F3a geomorphic units.

Lineament No. 21 Tanakpur Fault, trending NE-SW, affecting F3a1, S4a, S7b, S1e and S1d geomorphic units.
Lineament No. 22 Sharda lineament, trending NE-SW, displacing F3a, F3a1, S4a geomorphic units.

Lineament No. 23 Shikohabad-Fatehgarh lineament, trending ENE-WSW, affecting F1c, F1b and F2 geomorphic units. This lineament continues from the Indian Craton along a part of the Chambal river course.

Lineament No. 24 Sitapur lineament, trending ENE-WSW, affecting F1b, F1c, F2, F4, geomorphic units, and abutting against lineament No. 18.

Lineament No. 25 Rishikesh lineament, trending NE-SW, affecting and offsetting F1c, F3a, S7b, S4a, S1e and S1d geomorphic units. This lineament probably acts as the zone along which river Ganga comes out of Siwalik hills, tearing the latter.

Lineament No. 26 Yamuna tear, almost N-S trending, dislocating F3a, S4a and S7b geomorphic units.

Lineament No. 27 Mussoorie lineament, trending NE-SW, affecting F1c, F3a, S4a, S1e and S1d geomorphic units.

Lineament No. 28 Simla-Solon Fault, trending NE-SW, clearly displacing S1d, S1e and S4b geomorphic units.

Lineament No. 29 Kalka Fault, trending NNE-SSW, dislocating F3a, S4a, S4b, S7b geomorphic units and affecting S1e unit.

Lineament No. 30 Ropar Fault, trending NE-SW, dislocating F3a, F4, S4a and S4b geomorphic units.

Lineament No. 31 Hisar-Sangrur lineament, trending NNE-SSW affecting F1c, and F2 geomorphic units. This lineament is continuous from the Indian craton into the Ganga Foredeep.

Lineament No. 32 Delhi (Aravalli) lineament, trending NE-SW, affecting F1c and F4 geomorphic units. This lineament maintains the Aravalli trend.

Lineament No. 33 Chautang lineament, trending NNE-SSW, traversing the geomorphic unit No. F1c and following the abandoned channels of Yamuna river.

Lineament No. 34 Mukerian Fault, trending E-W, dislocating F3a, S4a and S7b geomorphic units. The river Beas transversely cuts across this lineament to flow from E to W at this point.

Lineament No. 35 Pathankot lineament, trending ENE-WSW, clearly displacing F3a, and S4a geomorphic units.
Lineament No. 36 Jammu-Srinagar lineament, trending N-S cutting across Kashmir valley and Pir Panjal ranges. It clearly displaces/offsets/affects geomorphic unit Nos. F3a, S4a, S3c, Sld, S1a and S3b respectively from south to north running for a distance of more than 150 Km.

Lineament No. 37 Jhelum lineament, trending N-S, along Jhelum river course, defining the syntaxial bend of the Western Himalaya.

Lineament No. 38 Anantnag lineament, trending NNE-SSW for about 200 Km, affecting Slb (Deosai-Ladakh range), Sld and S7a (Kashmir valley) geomorphic units. It just touches the southeastern end of geomorphic unit No. S3b (Mountain mass).

Lineament No. 39 Chamba lineament, trending NNW-SSE, affecting Sla, Slb, Slc and Sld geomorphic units, running across E-W flowing Shyok and Indus rivers for about 200 Km. It does not appear to have displaced the Shyok Suture or Indus Suture.

Lineament No. 40 Khalabse lineament, trending N-S, affecting Sla, Slb and Slc geomorphic units, running across Indus and Shyok rivers. Its northern end meets that of Lineament No. 39.

Lineament No. 41 Most prominent longitudinal (NW-SE) lineament, named Shyok-Indus-Tsangpo lineament, running for more than 2000 Km, controlling river courses of Shyok, Indus and Tsangpo (Brahmaputra) probably defines the leading northern edge of the Indian Plate. This lineament has two parallel components; one along Shyok river and the other along Indus river; the two meeting further east to form Indus-Tsangpo lineament.

Lineament No. 42 Chandrabhaga lineament, trending WNW-ESE, affecting geomorphic Unit No. Sld longitudinally. It probably demarcates the boundary between granites and high grade metamorphic rocks. It runs parallel to subparallel to Chandrabhaga (Chenab) river for a distance of over 150 km.

Lineament No. 43 Dharasmsala lineament, trending NNE-SSW, affects transversely the geomorphic unit No. Sld; cuts across E-W flowing tributaries of Chandrabhaga river.

6 DISCUSSIONS

The geomorphic units which have been grouped under those of structural origin are essentially morphotectonic units. The total entity of the Ganga Foredeep housing various geomorphic units of fluvial origin also represent a morphotectonic mega unit. All these units (including Ganga Foredeep mega unit) owe their present characteristics to dominant endogenic processes are dominant for other geomorphic units of lacustrine,glacial and fluvioglacial origin. Needless to mention that exogenic processes

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overwhelmingly control the present day changes in the morphology though endogeny in the form of neotectonism does partake in the ongoing alterations.

It has also been seen that, except for those of fluvial, lacustrine, glacial and fluvioglacial origin, the geomorphic units do not necessarily hold one-to-one relationship with bedrock geology. Geomorphic units of structural origin often cut across the lithological boundaries. Among the units of structural origin, S4a and S4b are uniquely controlled by lithology also apart from their structural control. This is because these two geomorphic units have been developed over homogeneous sequence of soft sedimentary rocks and which have not suffered deformation of tectonic orogeny to the extent other geomorphic units of structural origin have suffered. Geomorphic Unit Nos. S1c, S2 and S3d having been developed over thick piles of Palaeozoic-Mesozoic sediments, which have been little metamorphosed and which have not been affected by subsequent magmatism, bear evidence of lithological control also. The character of these geomorphic units of homogeneous lithology, therefore, has not been obliterated by large scale orogenic deformation. The imprints of fold structure of regional scale along NW-SE axial trends could be well picked up in Unit Nos. S1c and S3d. Similarly, Unit No. S5 having developed over Lesser Himalayan sediments continues to exhibit its lithological control along the regional structural trend.

It has been noted that longitudinal valleys have developed along the major river course of Indus, Zanskar, Shyok and Sutlej in high mountainous region in Unit Nos. S1a, S1b, S1c, S3d, and S7a. These indicate that these morpho-tectonic units of structural origin are essentially delineated and controlled by E-W/NW-SE trending regional fold axis (of N-S compressional force) and/or NW-SE trending thrust/subduction lineaments.

The other geomorphic units of S1d, S1e, S1f, S2, S3a, S3b, S3c, S4a, S4b and S5 are intricately transversely dissected by imposed drainage. It may, thus, be assumed that all these geomorphic units have been subjected to further/subsequent deformation of tectonic origin. A large number of NE-SW and NW-SE lineaments have been mapped cutting across these units, often offsetting and displacing the mountain/hill ridges. Some of these lineaments originate from alluvial plains of the Ganga Foredeep and affect the fan/ piedmont/ terrace zones in the same manner as these affect the Siwalik hills (S4a), Lesser Himalayan rocks (S1e) and Central Himalayan Crystalline rocks (S1d). Lineament Nos. 28 & 29, SE of Simla, are classical examples which show displacement of F3a, S4a, S4b, S1e and S1d units in the same fashion. Obviously, these transverse lineaments represent neotectonic episodes in
N-S stress field. Other such important NE-SW lineaments/fractures offsetting fans and Siwalik hills are lineament Nos. 17, 22, 25, 26, 29, 30, 35, 36 and 37.

The transverse river courses, while flowing across geomorphic units like S1d, S1e, S4a, etc., form ridge-parallel knicks at the contact between the units and again follow a transverse course. The ridge-parallel knicks of the channels and steep escarpments, marking the boundaries of these geomorphic/ morphotectonic units, may probably reflect 2nd/3rd order shears in roughly E-W direction which are in conformity of the Himalayan orogenic trend.

The two most important structural planes mapped in the Himalaya, viz. the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT) could not be picked up on geomorphological considerations. The rocks across these structural planes have been grouped under S4a, S1e and S1d units respectively, and the contacts between these units are well defined by vertical escarpments/ knicks in the river channels and appearance of different stream orders. However, contrary to expectations, strong E-W (NW-SE) lineaments are not discernible along the subsurface traces of these regional structural features.

7 CONCLUSIONS

The geomorphological considerations have added a discrete domain, viz. the foredeep zone in front of the rising mountain. With its thick pile of valley fills this mega unit is balancing the isostatic rise of the tectonic mountain mass. Sandwiched between the continental craton in the south and lofty mountains in the north, the foredeep has record of frequent incidence of earthquakes and innumerable evidence of other neotectonic activities in the form of shifting river channels, channel pattern, offsetting of fans, displacement of terraces, uplift of subsurface ridges, etc., all of which phenomena are intricately related to the mountain building processes and tectonism of the Himalaya.

Analysis of all these geomorphic units with tectonic/ neotectonic elements in them has supplemented to the understanding of the tectonic framework of the Himalaya. A general agreement between the geomorphic units and broad lithological groups (with normal stratigraphic/ tectonic boundaries) has been noted to exist. However, many geomorphic units, especially in the higher Himalaya, have been found to transgress the stratigraphic boundaries of various lithounits of different ages. Again, the long axes of various geomorphic units are in conformity with regional strike directions and trends of regional fold axes. Minor fold patterns, though conceived to certain extent by discrete drainage pattern in Siwalik hills, are not identifiable. Various thrust structures, especially nappes and windows, could also not be
picked up from remote sensed geomorphological considerations. This is probably because of (i) high amount of terrain ruggedness, (ii) intricate deep dissection of mountain/hill ridges, (iii) severe active denudation prevailing over rock masses irrespective of their ages and of their sedimentary/metamorphic/igneous modes of origin, (iv) welding of rock masses, and (v) last but not the least, scale limitation (ground resolution around 79 m) of remote sensed data products. Many lineaments, mostly transverse, are very well depicted and mapped. Some of those are undoubtedly of tectonic origin, representing deep-seated fracture lines having offsetted/terminated the hill/mountain ridges. Such prominent transverse lineaments/fracture lines add to the knowledge of fracture/fault systems of tensional origin in the Himalaya. Amongst the lineaments of compressional origin, the one which is conspicuously prominent has been mapped as the strong E-W megalineament representing the Indus-Tsangpo suture right from Shyok in the NW to Dihang in the East. The tectonic significance of the 2000 km long lineament thought to define the northern boundary of the Indian Plate is obvious. However, other two prominent tectonic lines, which play very important role in the geology of the Himalaya, could not be picked up as lineaments. These are the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT). Although geomorphological characteristics are discretely different and separately identifiable for rocks of (i) Neogene-Quaternary (Siwalik), (ii) Palaeogene (Murree/Subatha/Dagshai) - Palaeozoic (metasedimentary-volcanosedimentary sequence), and (iii) Proterozoic (high grade metamorphics and granites), their mutual contacts/boundaries, considered as thrust boundaries, are not disposed as linears like the strong lineament of the Indus-Tsangpo suture.

Geomorphological evidence, especially picked up as transverse lineaments/fractures/faults affecting various geomorphic units of the Ganga foredeep mega unit as also mountain/hill ridges, indicate that mountain building processes through northward translation/movement of the Indian Plate are still active.

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METALLOGENY IN THE HIMALAYA

By
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ABSTRACT

The metallogenic features of the known mineralised belts of the Himalaya and adjacent regions comprising four longitudinal tectonic belts, namely, Karakoram Belt, Indus-Shyok Belt, Main Himalayan Belt and Foot Hill Belt have been discussed. The metallogenetic episodes and their relationships with the tectonic regimes have limited bearing on the constraints of tectonic modelling of the Himalaya. Large metallic deposits of Andean or island arc types related to convergent plate boundaries of Meso-Cenozoic events have not been located in the Himalaya formed by continent-continent collision. Small deposits and sporadic occurrences of metallic minerals are mainly restricted to Proterozoic sequences evolved during pre-Himalayan (pre-Meso-Cenozoic) tectogenesis.

1 INTRODUCTION

Investigations for basemetal and related mineralisation have been carried out over a period of time along the stretch of the Himalaya from Kashmir in the northwest to Arunachal Pradesh in the northeast. Though many of the investigations have been taken up as off-shoots of regional geological, structural and petrological studies, some in the Lesser Himalaya have been studied in detail in the last three decades. Only one of the basemetal prospects thus explored has been developed into a small mine at Rangpo in Sikkim and a few others are still in the process of detailed studies.

Attempts have been made in the recent decades (Hawkins, 1972; Mitchell et al., 1982) to relate metallogenic episodes with global tectonic events. The identification of major metallogenic episodes and their spatial and temporal relationship with tectono-stratigraphic and magmatic evolution have thus supplemented to decipher constraints in tectonic modelling. Metallogenic signatures, however, being very sporadic and subordinate in nature in the Himalaya may not itself contribute significantly to such reconstruction, more so in a region where earlier minerali-
sation related to Proterozoic events has been affected by later folding and dislocation during Himalayan (Meso-Cenozoic) diastrophism.

However, an attempt is made here to scan the recorded mineral occurrences to analyse the role of metallogenesis in defining the constraints in the tectonic modelling of the Himalaya.

A broad review of the mineral deposits of the Himalayan Belt was presented in the Himalayan Geology Seminar (G.S.I., 1976). A brief description of mineral deposits of the Himalaya and strategy for future mineral exploration has been given in Wadia Centennial Lecture. Mukherjee (1983) and Dasgupta et al., (1976) tried to classify broadly the sulphide ore occurrences in different geological setups of the Himalaya. Ghose (1982) made an attempt to synthesize and correlate the broad and significant aspects of the evolutionary trend of the Himalayan Belt and their influence on the localisation of metalliferous occurrences of Proterozoic- Early Palaeozoic cycle in parts of Western Himalaya. Dalingian metallogeny with its strata bound syngenetic and later remobilised sulphide and tungsten occurrences of Eastern Himalaya as distinct from the Himalayan metallogeny has been distinguished and discussed earlier (Ray, 1976).

2 TECTONIC BELTS

The Himalaya and adjoining parts of Ladakh and Karakoram in the northwest and Mishmi Hills in the northeast comprising rock types of Proterozoic and Phanerozoic ages could be divided into four linear tectonic belts each separated from the other by mega-tectonic features such as Shyok Suture, Indus- Tsangpo/ Tidding Suture and Main Boundary Fault.

The entire Himalaya and adjacent parts from north to south could thus be sub-divided into the following longitudinal tectonic belts/ domains.

a. Karakoram Belt
b. Indus-Shyok Belt
c. Main Himalayan Belt
d. Foot Hill Belt

Karakoram Belt - This belt comprises Palaeo- Mesozoic sedimentary formations with metamorphics of unknown age and Tertiary Karakoram granitoid occurring towards north of Shyok Suture.
Indus-Shyok Belt - This tectonic belt is bounded by Indus-Tsangpo Suture on the south and Shyok Suture on the north and includes ophiolite-melange zone represented by Sangeluma Formation and associated basic and ultrabasic rocks and related Cordilleran I-type Ladakh granitoid pluton and overlying molassic Indus-Formation. This belt comprises rock types significant of the Meso- Cenozoic evolution.

Main Himalayan Belt - This tectonic belt bounded by the Indus Suture on the north and Main Boundary Fault on the south is represented mainly by Proterozoic volcanosedimentary- metamorphic- magmatic and granitoid rocks with overlying Phanerozoic rocks at places. The Main Himalayan Belt could be further subdivided into two broad units separated by Main Central Thrust (MCT). The Higher Himalaya occurring mainly to the north of MCT consists of medium to high grade metamorphic- migmatic- plutonic sequence comprising Central Crystallines and related rocks overlain by Phanerozoic Tethyan sequence. These are separated from rocks of the Lesser Himalaya by MCT, the latter comprising volcanosedimentary sequence of mainly Proterozoic age with localised sedimentation in Phanerozoic time and overlain at places by tectonic outliers and probable thrust sheets of metamorphic- migmatic crystalline sequence bounded by tectonic planes such as North Almora Thrust, South Almora Thrust, Jutogh Thrust, Panjal Thrust, Daling Thrust etc.

This belt shows imprints of Proterozoic crustal evolution having different episodes of penetrative deformation and associated metamorphism and plutonic activities. These features have been overprinted by Meso-Cenozoic reactivation during continent-continent collision and accompanying deformation, magmatism and metamorphism during Himalayan orogenesis.

Foot Hill Belt - This belt is situated on the south of Main Boundary Fault, Krol Thrust and Murree Thrust comprising sedimentary sequences of Neogene- Quaternary age represented by Murree-Dharamsala Group and the molassic Siwalik Group, showing effects of deformation only of uppermost Tertiary and Quaternary ages.

3 METALLOGENY IN SPACE AND TIME

Each tectonic belt as enumerated above, has its own characteristic metallogenic signatures. Characteristic features of the known mineralised belts are classified below according to their tectonic and geological set up with a view to understanding their significance in tectonic modelling of the Himalaya. Distribution of mineral occurrences/ incidences in the Himalaya is annexed in a table (Annexure-I). Metallogenic characteristics of important mineral occurrences are shown in the sketch Metallogenic Map of the Himalaya (Plate-VI).
Karakoram Belt - No important mineral occurrence is yet known from this belt, though Cordilleran I-type Karakoram granitoid batholith may be searched for disseminated Sn-W and Cu-Mo deposits.

Indus-Shyok Belt - Sporadic occurrences of chromite have been reported from the ultrabasic rocks associated with the Dras Volcanics from ophiolite-melange zone associated with the Sangeluma Formation. Some local high values of nickel have been reported at places. Some sporadic high values of platinum have also been reported around Dras- Thansgam area, near Kargil, Ladakh and there is a possibility of platinum group of metals associated with the dunite or serpentinitised dunite of this belt. Fluorite in pegmatite associated with Ladakh Granitoid Complex is also known. The ophiolite sequence within the Indian territory being a highly tectonised melange zone, chances of locating sizeable mineral deposits are not very good. Subduction related I-type Ladakh, Karakoram and Mishmi granitoid complex may perhaps represent possible locales of porphyry type Cu-Mo and Sn-W occurrence.

Main Himalayan Belt - Mineralisation of some significance in the Himalayan area is mainly restricted to the Main Himalayan Belt in the metamorphosed sedimentary and volcanosedimentary sequences of Proterozoic age. Mineralisation is broadly stratabound, parallel to bedding planes and formed earlier to recognisable earliest folds in most of the cases. However, there are evidences of remobilisation during later deformation with sulphides occurring also as veins and fracture fillings.

Significant occurrences of Pb-Zn or Cu-Pb-Zn + Au + Ag are associated with the metamorphosed volcanoclastic sequences. Small deposits of some significance of this type are: Pb-Zn-Cu in the Askot Crystallines at Askot, U.P., Pb-Cu-Zn, Cu (Zn-Pb) and Pb-Zn in the metamorphics of the Daling Group at Bhotang- Rangpo, Dikchu and Gorubathan in Sikkim-Darjeeling area respectively. Mineralisation appears to be volcanogenic stratabound types at these places. Magnetite occurs as an important accessory mineral in some occurrences and in others magnetite occurs as predominant mineral along with the sulphides such as at Gorubathan. Incidences/occurrences of sulphides are insignificant in the carbonaceous euxinic to sapropelic and evaporite sequences.

Sporadic occurrences of sulphide mineralisation are also associated with low grade metasedimentary and partly volcanogenic sequence of Proterozoic age in the paraautochthonous zones. Mineralisation in these zones is synsedimentary stratabound along with remobilised veins and occurs in orthoquartzite-carbonate sequence such as - sulphides of lead, zinc + copper in the Garhwal Group at Dhanpur, Pokhri, Bora Agar, Rain Agar, Shiskhani in U.P., in the Deoban Group at Kwanu and Amtiargad in Dehradun.

Incidences of antimony sulphide at Barashigri and Pokhri are seen associated with quartz-veins within the gneissic rocks and the age of this mineralisation is not known. Tungsten (scheelite, wolframite) mineralisation has been seen associated with quartz vein in Almora Crystallines, in slate at Mansong, Darjeeling and in pegmatites with phyllite-quartzite at Bungthang, Bhutan. Age of these epigenetic mineralisations is not known.

Mineralogy, geological environment and mode of occurrence of some of the significant metalliferous mineral occurrences are classified according to their geological environment and described in brief.

3.1 Polymetallic Sulphide Associated with Low to Medium Grade Metamorphic Rocks

Pb-Zn-Cu-As of Askot, U.P. Himalaya: The mineralisation is represented by veins, stringers, pockets and disseminations of galena, sphalerite, chalcopyrite and arsenopyrite with minor amounts of marcasite, bornite, chalcocite, pyrite, pyrrhotite and cubanite in the sheared epidote- chlorite- sericite- biotite schist belonging to the Askot Crystallines, which is one of the several detached doubly plunging synformal crystalline bodies of allochthonous nature in the Lesser Himalaya of U.P.

The complex polymetallic sulphide bodies of Askot area are stratabound but lensoid in nature and occurs in the form of specks, blebs, veins, stringers and richer lodes and pockets probably indicating replacement and fracture fillings. Pronounced wallrock alteration in the form of chloritisation, propylitic alteration, magnesia and silicification are seen in the mineralised zone indicating a genetic connection between the wallrock alteration and formation of sulphides (Ghose, 1976, 1982; Chattopadhyay, 1976). The stratabound and lensoid nature of the deposit associated with metamorphosed volcanoclastic rocks and probable green tuffs, the coexistence of Pb, Zn and Cu with arsenopyrite, higher concentration but lensoid nature possibly resemble Kuroko type of small deposit formed in submarine environment during Proterozoic. Widespread wallrock alteration seen in this deposit may indicate hydrothermal alteration during submarine volcanic-exhalative activity, modified by remobilisation at a later stage.
Pyrite-Pb-Zn of Buniyar, Kashmir Himalaya: The sulphide minerals are mostly represented by pyrite, galena and sphalerite with subordinate pyrrhotite, arsenopyrite, chalcopyrite and marcasite occurring as concordant streaks, blebs, stringers and disseminations parallel to bedding and major foliation planes within phyllite and chlorite-quartz schist. The ore bodies are mostly stratabound and associated with metavolcanic and tuffaceous bands. The laminated ore bodies parallel to stratification planes were subjected to first phase of folding along with the country rocks (Ghose et al., 1979, 1982) indicating that the ore formation took place prior to folding, suggesting synsedimentary volcanogenic origin for these ore bodies.

Pb-Zn of Gorubathan: Mineralisation of Pb-Zn + Co + Ag etc. as sulphides is associated with magnetite bearing cherty quartzite occurring within sericite chlorite cherty quartzite, chlorite schist and chlorite- sericite schist of the Daling Group. Magnetite is a ubiquitous common accessory. Metavolcanic rocks and chloritic tuffaceous schist are also associated with above rock types. Sulphide mineralisation shows fine laminations and a few load markings with a well developed rythmite development both within these as well as with associated metasediments. A characteristic feature is decrease of sulphide mineralisation with the increase of coarse grained high energy depositional tuffaceous beds or with presence of primary hematite (specularite). These sulphide beds strictly define and follow the primary bedding plane and along with associated rocks are deformed by early generation folds ($F_1$) with development of axial plane schistosity ($S_1$). Evidences of further modification is also described in the form of development of metamorphic texture.

Effects of remobilisation is scanty in the form of offshoot veins and stringers but a flowage of sulphide in the core of $F_1$ fold hinges with consequent attenuation in the long stretched out limbs is characteristic (Ray, 1975).

Zn-Pb-Cu of Rangpo: Mineralisation of Rangpo, Bhotang Mines is well known and is the only working mine in the Himalaya. This Pb-Zn-Cu + Au sulphide is also essentially stratabound within the sericite- chlorite phyllite and phyllonite of the Daling Group, associated with possible metavolcanic schist resting tectonically on quartzite- variegated slate- dark slate ensemble. The metabasics and chlorite schists host the mineralisation. The mineralisation shows metamorphic texture and mostly parallel to or even segregated independent of foliation in massive bands. A few relict parts, however, betray their primary syngenetic nature where fine rythmic laminations are found.
Cu-Zn of Dikchu: Sulphides of copper and zinc are also stratabound similar to Rangpo but are associated with higher grade metamorphic rocks represented by garnet biotite quartz schist. These are associated with metabasic and chlorite-muscovite-quartz schist of the Daling Group close to the contact of Lingtse gneiss. Metamorphic texture here is well developed marking the original syngenetic nature.

Copper-mineralisation in Zanskar: Sporadic sulphide mineralisation in the form of disseminations, veinlets and stringers, of chalcopyrite, galena and sphalerite occur in the crystalline rocks and overlying formations of the Late Proterozoic–Early Palaeozoic age of Zanskar area.

Mineralisation within the rocks of the Phanerozoic sequence of this belt is rare. Only sporadic incidences of sulphides have been located at places in Phe volcanics of Permian age.

3.2 Pb-Cu mineralisation in the epiplatform carbonate sequence in the Garhwal Group and equivalent formations

Sporadic occurrences of sulphide mineralisation in the carbonate sequence of the Garhwal Group in U.P. Himalaya, Sirban limestone in Riasi, J&K, Deoban Group and Buxa Formation evoked lot of attention.

Occurrence of base-metal sulphides of Pb + Zn at places and Cu also at some places are synsedimentary, stratabound and confined to narrow zone of silicified dolomite, magnesite and talc forming the upper horizon of the carbonate rich lithounits of the Garhwal Group of Proterozoic age in the U.P. Himalaya from Dhanpur in the northwest, to Bora Agar-Rain Agar in the Southeast (Ghose et al., 1976; Ghose, 1982). Indications of sporadic sulphide mineralisation are seen spatially over a long stretch in similar carbonate rich formations near its contact with a quartzite sequence. The extent of individual ore shoots are too small to be economically exploitable. Only the sulphide occurrence near Kwanu at U.P.–H.P. border has shown some lateral extension.

3.3 Base Metal Sulphide occurrence within Tethyan Palaeozoic sedimentaries and volcanogenic sequence

Cu at Gangkhola, Bhutan: Bedded base metal sulphide with mainly copper comprising chalcopyrite, pyrite, arsenopyrite, pyrrhotite and galena has been located in the manganosideritic carbonate sequence within sericite and carbon phyllite in the Maneting Formation of Tethyan sedimentaries of Lower Palaeozoic age in Gangkhola area of Bhutan.
**Other Sulphide occurrences**: Bedded baryte and polymetallic sulphide with mainly Cu has been reported from the dolomitic-arenaceous beds within the Lower Palaeozoic Garbyang Formation between Barmatiya and Milam area (Sinha and Mehrotra, 1979). Mineralisation of copper sulphide-pyrite-arsenopyrite have been reported from the underlying Ralam Formation.

**3.4 Epigenetic mineralisation as veins, stockwards**

Sporadic occurrences of synsedimentary Pb, Zn & Cu sulphides in the carbonates of the Garhwal Group, Sirban Limestone, Deoban belt, without a distinct and closer association of volcanic or intrusive rocks suggest their formation in platform environment, Pb-Zn sulphide of Gonekha, Bhutan-stratabound sulphide of Pb-Zn has been reported from carbonate horizons of the Paro Group associated with Central Crystallines.

(a) *Sb Mineralisation in Mohankhal-Pokhri Area*: Sporadic occurrences of antimony have been reported from Mohankhal-Pokhri area, U.P. Small pockets of stibnite associated with quartz veins occur in the granitoid gneiss emplaced within the schistose quartzite of the Garhwal Group. However, lateral extension of pockets and lenses have not been found. The sporadic occurrences of Sb as stibnite-quartz vein is related to epigenetic hydrothermal cavity fillings along joints and fractures.

(b) *Sb-Pb-Zn-Pyrite-Cu mineralisation of Barashigri, N.W. Himalaya*: Antimony mineralisation of Barashigri, H.P., is mostly confined to the peripheral zone of the granitoid-batholith forming a part of the Central Crystallines. The mineralisation is mainly polymetallic containing stibnite, galena, sphalerite, pyrite and chalcopyrite and occurs mainly as veins and cavity filling along fracture planes. The mineralisation is highly sporadic and inconsistent.

(c) *Sn-W mineralisation*: Tungsten mineralisation has been recorded from quartz veins in the phyllites of the Daling Group from Monsong area, Darjeeling (Ray, 1975). Scheelite has been found associated with quartz vein within garnetiferous schist of Almora Crystallines, U.P. Scheelite has also been recorded from Chitra area of Sikkim within Calc-Silicates of Paro Group (Ganguli et al., 1976). Tin-tungsten mineralisation has been located in tourmaline bearing pegmatite in the Higher Himalaya of Bhutan (Poulose, 1975).

**Foot Hill Belt**: This belt is bounded by Main Boundary Fault, Krol Thrust and the Murree Thrust on the north comprising sedimentary sequences of Cenozoic age represented by the Murree-Dharamsala Group and the Siwalik Group. No significant
mineralisation has been noted in this belt except occurrences of placer gold from conglomerate and gravel beds of the Siwalik Group and Sub-recent alluvium.

4 DISCUSSIONS AND CONCLUSION

Main constraints in the metallogenic modelling in the Himalaya are:

(i) Large metallic deposits of Andean type and Island arc type related to convergent plate boundaries of Meso-Cenozoic events have not so far been recorded in the Himalayan and adjacent areas formed by continent-continent collision.

(ii) Small deposits and sporadic occurrences located so far are restricted mainly to the Main Himalayan Belt comprising rocks of Proterozoic ages and thus inherited from pre-Meso-Cenozoic geological processes.

(iii) There are evidences of remobilisation of metallic minerals but even these occurrences are also confined to the pre-Phanerozoic rocks. However, the relative role of Caledonian and younger orogenies and their effects on the pre-existing mineralisation need detailed analysis.

(iv) Isotopic ages of most of the known ore bodies have not yet been determined. Though geochemical characteristic of a few deposits are known, detailed geochemical behaviour of most of the occurrences need systematic evaluation.

The base metal sulphide occurrences of some significance located so far in the Lesser and Higher Himalaya of the Main Himalayan Belt are largely stratabound and associated with meta-argillites and associated volcanogenic sediments and all are related to pre-Himalayan (pre-Meso-Cenozoic) tectonic grains, affected later by Himalayan folds and thrusts. The application of plate tectonic concepts to Precambrian geological formations of the Himalaya and identification of such tectonic regimes, though highly speculative may explain the tectonic framework of some of the Precambrian sulphide occurrences of the Himalaya.

The distribution of basic volcanics and igneous intrusives in different tectono-stratigraphic units and their relation to multistage basin evolution and recognition of palaeorift and palaeo-subduction zones may lead to better understanding of metallogeny in the Himalaya (Sinha Roy and Furnes, 1978). Volcanoclastic sequence of green tuff type of Askot area and associated polymetallic sulphide deposit (possibly Kuroko type) may be attributed to Proterozoic island arc setting. An island arc setting has been postulated for basal Daling sequence of Sikkim containing bimodal basic and felsic volcanics crushed by end Proterozoic
tectonic activity (Sinha Roy, 1987). Amphibolite bodies representing basic and ultrabasic rocks occur within the metamorphic thrust sheets at a number of places, but sulphide mineralisation related to these amphibolite bodies has not been reported. It is not certain whether some of these amphibolite bodies represent remnants of Proterozoic oceanic crust or are related to the magmatic phases of the Proterozoic tectonic history of the Himalaya.

Precambrian ensemble of the Sikkim-Darjeeling Himalaya with syngenetic exhalative volcanic-volcanogenic polymetallic sulphides in Gorubathan type pelagic to flyschiod sequence and stratabound sulphide bands associated with Paro type carbonate-quartzite-amphibolite association with later partial remobilisation have been attributed to Dalingian metallogeny of Precambrian ages. However, such remobilisation is believed to have taken place at the culmination of pre-Himalayan Precambrian orogenesis where tectonic, metamorphic and magmatic episodes were active (Ray, 1975 a, b).

The extent of all these mineralised zones is invariably small, low and the ore-bodies are lensoid in nature and are broken up (Mukherjee, 1983). This is due to extensive deformation by pre-Himalayan folding with thickening of ore lenses at fold hinges and thinning along sheared limbs, and later dislocation due to Himalayan thrusting. Existence of deposits of large extent is thus possibly not expected in the Himalayan belt. However, the identification of favourable tectono-magmatic regimes, as discussed here by integrated stratigraphic, structural, petrological, geochemical and geochronological studies may be useful in identifying new sites of mineralisation or proving extension of known occurrences.

5 REFERENCES


Ghose, Arabinda (1982). Late Proterozoic geological evolution in relation to Metallogenesis in parts of Western Himalaya in Symposium on Metallogeny of the Precambrian, IGCP Project-91, Bangalore, 71-78.


### DISTRIBUTION OF MINERAL OCCURRENCES/INCIDENCES IN THE HIMALAYA

**ANNEXURE - 1**

<table>
<thead>
<tr>
<th>Tectonic Belt</th>
<th>Locality</th>
<th>Rock formation</th>
<th>Mineralisation</th>
<th>Nature of mineralisation/mode of occurrence</th>
<th>Probable age</th>
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<tbody>
<tr>
<td><strong>I. INDUS-SIUYOK BELT</strong></td>
<td></td>
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<tr>
<td>Indus Belt</td>
<td>Dras Belt and Nicobar area, J &amp; K.</td>
<td>Dunite - harzburgite cumulates and serpentinitised ultramafics in ophiolite belt.</td>
<td>Chromite, local high values of Platinum and Nickel</td>
<td>Occurrence, Podiform and layered.</td>
<td>Meso-Cainozoic</td>
</tr>
<tr>
<td><strong>II. MAIN HIMALAYAN BELT</strong></td>
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<tr>
<td></td>
<td>Gongkholo, (Black Mountain), Bhutan</td>
<td>Mane Ting Fm. Manganosiderite bands within carbon phyllite-lithic wacke sequence</td>
<td>Cu</td>
<td>Small deposit, Strata bound</td>
<td>Lower Palaeozoic</td>
</tr>
<tr>
<td>2. Higher Himalaya</td>
<td>Barashgiri, Lahaul-Spiti dist., H.P.</td>
<td>Sheeted quartz-bearing veins in coarse-grained biotite-granite batholith (Ikhutung gneiss).</td>
<td>Sb, Pb, Zn, As, Au, Ag</td>
<td>Occurrence. Vein type Hydrothermal</td>
<td>Age uncertain</td>
</tr>
<tr>
<td></td>
<td>Zanskar Range, H.P.</td>
<td>The Volcanics and associated dykes (also in associated older sedimentary rocks)</td>
<td>Cu, (Fe)</td>
<td>Occurrence; Disseminated possibly magmatic/strata bound.</td>
<td>Permian</td>
</tr>
<tr>
<td></td>
<td>Genekha, Bhutan</td>
<td>Paro Group Carbonate rock</td>
<td>Pb, Zn (Cu, Ag, Sn, Cd)</td>
<td>Small deposit, sedimentary, strata bound.</td>
<td>Proterozoic</td>
</tr>
<tr>
<td>District</td>
<td>Formation</td>
<td>Mineralogy</td>
<td>Metallogeny</td>
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<tr>
<td>Sirhan Lst.</td>
<td>Quartz-cherty dolomitic limestone</td>
<td>Pb, Zn, Ba</td>
<td>Proterozoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dogs, Udhampur dist. J &amp; K.</td>
<td>Cherty dolomitic limestone</td>
<td>Cu</td>
<td>-do-</td>
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</tr>
<tr>
<td>Jitution-Gaitala, Udhampur dist. J &amp; K.</td>
<td>Great Lst. Dolomitic, Silicified Limestone</td>
<td>Zn, Cu</td>
<td>-do-</td>
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<tr>
<td>Sangam, Solon, Mahasu dist. H.P.</td>
<td>Quartz veins in schist/ Simla Slates</td>
<td>Cu</td>
<td>Occurrence</td>
<td></td>
<td></td>
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<tr>
<td>Matiana, Mahasu dist. H.P.</td>
<td>Chail Form. Calcareous talsco schist, phyllite</td>
<td>(Pyrus)</td>
<td>-do-</td>
<td></td>
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</tr>
<tr>
<td>Naraul-Danala, Kulu dt. (Garsali) valley, H.P.</td>
<td>Larji Form. Quartzite interbedded with slate-phyllite.</td>
<td>Cu, Ni, Co.</td>
<td>-do-</td>
<td></td>
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</tr>
<tr>
<td>Uchich, Kulu dt. (Parvatli valley), H.P.</td>
<td>Banjar Form. Manikaran quartzite</td>
<td>Pb, Ag, As (Pyrus)</td>
<td>-do-</td>
<td></td>
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</tr>
<tr>
<td>Kwanu &amp; Amlargar Mork, Dehradun dt. U.P. and Chauri Sirmur dist., H.P.</td>
<td>Contact zone between slates (Morar/Chakrata Fm and dolomitic limestone (Snall Fm. of Deuban Gp.)</td>
<td>Pb, Zn, Cu, Pyrite</td>
<td>Small deposit, Mineralisation controlled by shear/ fracture parallel/ subparallel to axial planes of folds. Both stratiiform &amp; vein type possibly hydrothermal.</td>
<td></td>
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<tr>
<td>Area/City</td>
<td>Description</td>
<td>Minerals</td>
<td>Deposits/Alteration</td>
<td>Age</td>
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<tr>
<td>Askot area, Pithoragarh dist, U.P.</td>
<td>Askot Crystallines, Sericite, Chlorite, Schist (Meta sedimentary volcanic)</td>
<td>Zn, Pb, Cu, (As, Sb, Sn, Ag, Au) Cu</td>
<td>Small deposit, strata bound, pronounced wall rock alteration (minor mineralization in quartz veins, possibly hydrothermal remobilized)</td>
<td>Proterozoic</td>
<td></td>
</tr>
<tr>
<td>Pokhri-Dhanpur area, Chamoli dist, U.P.</td>
<td>Garhwal Gp. Chlorite schist, quartzite, phyllite, etc., Dolomite, Quartz vein gneisses</td>
<td>Cu</td>
<td>Small pockets &amp; Lenses, Cu - Strata bound mainly, Sb - Vein type with quartzite, Vein in gneissic rocks, Age uncertain</td>
<td>Proterozoic</td>
<td></td>
</tr>
<tr>
<td>Dewalthal area, Pithoragarh dist, U.P.</td>
<td>Garhwal Gp. Dolomite</td>
<td>Cu</td>
<td>Occurrence</td>
<td>Proterozoic</td>
<td></td>
</tr>
<tr>
<td>Rain Agar, Bora Agar, Pithoragarh dist, U.P.</td>
<td>Garhwal Gp. Dolomite near contact of quartzites</td>
<td>Pb (Zn), Cu</td>
<td>Sporadic occurrence strata bound</td>
<td>Proterozoic</td>
<td></td>
</tr>
<tr>
<td>Chhanapani, Shishkhani area, Almora dist, U.P.</td>
<td>Garhwal Gp. Dolomite near contact with quartzite</td>
<td>Pb (Ag)</td>
<td>Sporadic occurrence strata bound</td>
<td>Proterozoic</td>
<td></td>
</tr>
<tr>
<td>Birgana area, Pauri dist, U.P.</td>
<td>Dudatoli Group Quartz veins traversing quartzite, associated with Malthana</td>
<td>Pb, Ag - (Pyrite)</td>
<td>Sporadic occurrence</td>
<td>Proterozoic</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Formation/Composition</td>
<td>Minerals</td>
<td>Type</td>
<td>Age</td>
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<tr>
<td>Galpakot-Kim-Khet-Khansyun area, Pithorgarh &amp; Nainital districts</td>
<td>Ramgarh-Shimtal Formm, Phyllite, Quartzite (quartz veins also)</td>
<td>Cu, Pb, Zn, Si</td>
<td>Sporadic occurrence Proterozoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dhotang-Rangpo Sikkim</td>
<td>Daling Group Chlorite Schist, Phyllite, Epidotortite</td>
<td>Pb, Cu, Zn (As, Co, Ni, Cd, Ag, Au, Mg)</td>
<td>Small deposit Strata-bound (Possibly volcanic/hydrothermal)</td>
<td>-do-</td>
<td></td>
</tr>
<tr>
<td>Dikhu, Sirbong, Pachikhami, Pakyong, Rohtak Valley, Sikkim</td>
<td>Phyllite &amp; Schist</td>
<td>Cu (Zn, Pb, Ni, Co, As, Bi, Sb, Ti)</td>
<td>-do-</td>
<td>-do-</td>
<td></td>
</tr>
<tr>
<td>Rishl, Sikkim</td>
<td>Duxa dolomite</td>
<td>Pb-Zn-Cu</td>
<td>Quartz vein in dolomite</td>
<td>-do-</td>
<td></td>
</tr>
<tr>
<td>Gorubathan area Darjeeling dist, West Bengal</td>
<td>Gorubathan Formm, Daling Gp. Quartz magnetite rock with bands of quartz-chlorite sericite schist, chlorite schist, cherty green quartzite &amp; epidotortite</td>
<td>Pb, Zn (Cu, Ag, Cd, Au, Hg) Magnetite</td>
<td>Small deposit Strata-bound</td>
<td>-do-</td>
<td></td>
</tr>
<tr>
<td>Mansong (Munsang), Darjeeling dist, West Bengal</td>
<td>Quartz veins in slate</td>
<td>W-Scheelite wolframite (Cu)</td>
<td>Occurrence Vein type</td>
<td>Age uncertain</td>
<td></td>
</tr>
<tr>
<td>Ranga Valley Subansiri dist, Arunachal Pradesh</td>
<td>Potin Formm, Garnet-qtz-chlorite-biotite schist, Sericite schist, Phyllite, Quartzite</td>
<td>Haematite &amp; Magnetite (Co, Ni, Cu, Ph, Zn, Sn, W)</td>
<td>Occurrence Proterozoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rupa Area, Menga Area, Arunachal Pradesh</td>
<td>Rupa Dolomite, Dolomite Chillpan Fm.</td>
<td>Pb-Zn</td>
<td>Occurrence</td>
<td>-do-</td>
<td></td>
</tr>
</tbody>
</table>
III FOOT HILL BELT

Foothills of Jammu, Himachal Pradesh, Uttar Pradesh.

(Sirmur dist, H.P.; Markanda & Chaggar rivers in Ambala dist, Haryana; Dehradun dist, Bijnor dist, Ramganga river and its tributary Sona nadi in Pauri-Garhwal dist, U.P.)

Siwalli Gr. Conglomerate, gravel of Middle and Upper Siwalik

Au Upper Tertiary Quaternary Detrital (Placer)

Sub-Recent Alluvium

Placer gold from sands of rivers draining through the Siwaliks

Arunachal Pradesh

Dikrang River near Doimukh (also in River Sand) and in Subansiri River.
HEAT FLOW REGIME IN HIMALAYA

By
Ravi Shanker
Geological Survey of India

ABSTRACT

Data base for establishing the heat flow regime in Himalaya is obtained from geothermal studies around some of the hot spring areas and well loggings of bore holes drilled for petroleum exploration in Foothill Tertiary Belt and the foredeep to its south. There are large number of hot springs in the Himalaya and their distribution is closely governed by tectonic framework and magmatic history. The heat flow values vary between 30 to 468 mW/m² (milli-Watt per square metre), and have been grouped into five zones viz., Heat Flow Zone (HFZ) I, II, III, IV and V, and they correspond to heat flow values of over 180 mW/m², 100-180 mW/m², 70-100 mW/m², 40-70 mW/m² and under 40 mW/m², respectively.

The thermal activity is strongest in the vicinity of the Indus Suture Zone and the Shyok Suture Zone. Puga-Chumathang hot spring areas in the Indus Valley and Nubra hot spring area in the Shyok Valley are the typical examples where in the temperature gradients in excess of 100°C/km and the heat flow in excess of 300 mW/m² have been recorded. The majority of the thermal springs in the Himalaya are located along a zone enclosing Main Central Thrust (MCT) and the Central Himalayan Axis. The hot springs of the Parbati, Sutlej and Alaknanda, Bhagirathi and Yamuna Valleys are the typical examples of such occurrences with 60 ± 20°C/km temperature gradient and 130 ± 30 mW/m² heat flow. The hot springs with low geochemically computed temperature generally occur along the margin of the Lesser Himalaya along the MBT and its equivalents. The foot hills of the Himalaya, where thick Tertiary sediments belonging to cycles IX & X are exposed, show low temperature gradient (17 ± 5°C/km) and low heat flow values (41 ± 10 mW/m²).

1 INTRODUCTION

Heat flow studies in India are in infancy and very few studies are available, which are exclusively devoted towards thermal regime in the Himalaya (Krishnaswamy, 1976; Gupta et al., 1976; Geol. Surv. Ind., Spl. Pub. No. 26
The basic data pertaining to subsurface temperatures, thermal gradients and heat flow is derived from geothermal exploration carried out in some hot spring areas by the Geological Survey of India and NGRI in the last two decades and during the course of well logging carried out by ONGC and Oil India Ltd., in connection with petroleum exploration in the Himalayan Foot Hills and the frontal alluvial tract. All the available data-base has been reviewed in this paper in the light of tectonic and magmatic history of the Himalayan region.

2 GEOTHERMAL MANIFESTATIONS IN THE HIMALAYA

Large number of thermal springs are known to occur in the Himalaya, many of which emerge at the boiling point temperature at the elevation of their occurrences. Almost every major valley in the Himalaya possesses several hot springs (Krishnaswamy and Ravi Shanker, 1982). There are 112 reported hot spring localities in the Northwestern Himalaya, 15 in the Northeastern Himalaya (Krishnaswamy & Ravi Shanker, 1982) and 12 (Bhattarai, 1986) have been recorded in Nepal. Keeping the tectonic setting of the Himalaya in view, these thermal springs can be broadly divided under four groups as under:

(a) Springs occurring to the south of MBT (Main Boundary Thrust = Krol Thrust = MBF1) in the Sub-Himalayas;
(b) Springs occurring between MBT and Main Central Thrust (MCT);
(c) Springs occurring between MCT and Indus Suture Zone;
(d) Springs occurring along and to the north of Indus Suture Zone.

Based on the available data on temperature gradient, thermal conductivity, magmatic history, and geochemistry collected during the course of various geoscientific investigation, heat flow has been computed (Table-1) (Panda, 1985; Ravi Shanker, 1988). The perusal of the table would indicate that the heat flow in various belts of the Himalaya vary between 30 to over 468 mW/m². These values have been grouped into five heat Flow Zones (HFZ), viz., I, II, III, IV and V. The distribution of various heat flow zones in the Himalaya is depicted in Plate-VII.

The perusal of Plate VII and Table 1 would indicate that the thermal activity is strongest in the vicinity of the Indus Suture Zone and the Shyok Suture Zone. Puga-Chumathang hot spring areas in the Indus Valley and Nubra hot spring area in the Shyok Valley.
are the typical examples of the thermal activity in these zones, where the temperature gradients in excess of 100° C/km and the heat flow in excess of 300 mW/m² has been recorded. The majority of the thermal springs in the Himalaya are located along Main Central Thrust and to its north upto the Central Himalayan Axis. The hot spring of the Parbati, Sutlej, Alaknanda, Bhagirathi and Yamuna Valleys are the typical examples of such occurrences with 60 ± 20° C/km temperature gradient and 130 ± 30 mW/m² heat flow values. The hot springs with low geothermically computed temperature generally occur along margin of the Lesser Himalaya along the MBT. The foot hills of the Himalaya, where thick Tertiary sediments belonging to cycles IX and X are exposed, show low temperature gradient (17 ± 5° C/km) and low heat flow values (41 ± 10 mW/m²).

**TABLE 1**

HEAT FLOW IN VARIOUS PARTS OF HIMALAYA AND ADJOINING REGIONS*

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Areas</th>
<th>Temp. gradient (in °C/km)</th>
<th>Measured Geochemically estimated Heat Flow (in mW/M²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Puga</td>
<td>234</td>
<td>468</td>
<td>216±23*</td>
</tr>
<tr>
<td>2</td>
<td>Chumathang</td>
<td>-</td>
<td>-</td>
<td>210±13</td>
</tr>
<tr>
<td>JAMMU HIMALAYA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Gul-Mahogala</td>
<td>-</td>
<td>-</td>
<td>96±23</td>
</tr>
<tr>
<td>4</td>
<td>Atholi area</td>
<td>-</td>
<td>-</td>
<td>111</td>
</tr>
</tbody>
</table>

Geol. Surv. Ind., Spl. Pub. No. 26
| 5. | Beas valley | 41.53±8.2 | 125±25 | 139±25 | Taking 3 wells in Bran near Kalath |
|    |            | (n=3)     |       |        |                               |
| 6. | Parbati valley | 66±13.5  | 165±32 | 140±62 | Using holes in Jan and Kasol only |
|    |            | (n=2)     |       |        |                               |
| 7. | Sutlej valley | -        | -     | 119±27 |                               |
|    | (a) Spiti area | -        | -     |        |                               |
|    | (b) Nathpa- | 92±28    | 164±56 | 128±57 |                               |
|    | Jhakri Rampur area | (n=2) | (n=7) |        |                               |
|    | Mean for HP | 63±21 | 148±20 | 133±45 |                               |
|    |            | (n=7)     | (n=14) |        |                               |
|    |            |           |        |        |                               |
|    |            |           |        |        |                               |
|    |            |           |        |        |                               |
| 8. | Tons valley | 42.47    | 89.2   | -     |                               |
| 9. | Yamuna valley | -        | -     | 133±43 |                               |
|    |            |           |        | (n=12) |                               |
| 10. | Bhagirathi valley | - | - | 128±32 |                               |
|    |            |           |        | (n=14) |                               |
| 11. | Bhilangana valley | - | - | 88 |                               |
| 12. | Alaknanda valley | -        | -     | 85 |                               |
|    | (a) Mandakini valley | - | - | 85 |                               |
|    | (b) Dhauli valley (Tapoban) | 64 | 160 | 128±40 | Using AGW/5 |
|    |            |           |        | (n=4) |                               |
|    | (c) Badrinath area | - | - | 157±42 |                               |
|    |            |           |        | (n=3) |                               |
| 13. | Gori Ganga valley | -        | -     | 91±37 |                               |
|    |            |           |        | (n=3) |                               |
|    | Mean of UP | 53±11 | 125±35 | 127±36 |                               |
|    |            | (n=38)   |        |        |                               |
|    | Mean of UP & HP | 61.0±20 | 142±26 | 129±38 |                               |
|    |            | (n=52)   |        |        |                               |

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Heat Flow Regime

<table>
<thead>
<tr>
<th>NEPAL HIMALAYAS</th>
<th>mean</th>
<th>114±31</th>
<th>(n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. (a) Areas south of Main Central Thrust (MCT)</td>
<td>-</td>
<td>-</td>
<td>97±25</td>
</tr>
<tr>
<td>(b) North of Main Central Thrust (MCT)</td>
<td>-</td>
<td>-</td>
<td>146±4.5</td>
</tr>
</tbody>
</table>

N.E. HIMALAYAS

15. Sikkim - - 128
16. Darjeeling - - 100
17. Assam Oil Basins 25.4±9.3 52±7.5 -
   drilled by ONGC/ (n=46)
   AOC/ BOC/ DPL
18. Kopli- Garampani - - 97.6±35
   hot spring belt (n=5)
19. Arunachal - - 107±26
   Pradesh between
   Lat. 28° 20' -
   28° 30' N and
   Long. 93° - 95°
   E
20. Guahati area and 23.15 72.4 -
    Shillong*

21. (a) Foot hill sedimentary basins drilled for oil by ONGC in NW Himalayas in J&K, H.P. and U.P.

   b. PLAINS OF PUNJAB-HARYANA

   Bore holes/ 17.0±4.81 41-51 -
   drilled in plains of Pun-
   jab, U.P., Bihar by ONGC (Sira, Adampur,

* For Shill-
long plateau value in 40 - 70 range is assumed

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Ujjhani, Badaun, Puranpur, Tilhar, Raxaul, Purnea etc.)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>22.</td>
<td>Tube wells in Hoshiarpur</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23.</td>
<td>Ambala</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24.</td>
<td>Gurgaon- Sohna area</td>
<td>41 ± 10</td>
<td>102 ± 25</td>
</tr>
<tr>
<td></td>
<td>(n=3)</td>
<td>(n=12)</td>
<td></td>
</tr>
<tr>
<td>25.</td>
<td>Nainital</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(n=2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26.</td>
<td>Etah</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>27.</td>
<td>Mainpuri</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(n=2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.</td>
<td>Allahabad</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(n=2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29.</td>
<td>Ghazipur</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mean for U.P. Plains</td>
<td>-</td>
<td>-</td>
<td>64.0 ± 21</td>
</tr>
<tr>
<td></td>
<td>(n=9)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PLAINS OF WEST BENGAL**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30.</td>
<td>Cooch Bihar</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>31.</td>
<td>Malda</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(n=4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32.</td>
<td>W. Dinajpur</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(n=4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33.</td>
<td>Nadia</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>34.</td>
<td>Calcutta</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(n=13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.</td>
<td>24 Parganas</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(n=6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36.</td>
<td>Hoogli</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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**3 MAGMATIC-TECTONIC HISTORY, HEAT FLOW ZONES AND ASSOCIATED GEOTHERMAL RESOURCES**

A perusal of the Plate VII would indicate that the Heat Flow Zone-I is confined along the convergent boundary of the Indian Plate with Asian and Burmese Plate in the north and east respectively. The existence of recent volcanoes with recorded history of eruptions at Barren, Narcodam and Coco-islands, and in western Burma beyond Indian boarder offer loci of active geothermal basin for high heat flow. Along the Indus-Tsangpo Suture Pliocene magmatism is reported south of Lhasa in the proximity of Yangbagan geothermal field, in Tibet and late-Quaternary volcanoes in Tenchong in western Yunnan (Ravi Shanker, 1988). A 3.5 million years old granite is recorded at Chumathang (Ravi Shanker, et al., 1976). The Chumathang granite is intruded by still younger (but undated) aplites, pegmatites and quartz veins. Fumarolic sulphur deposits are seen at Puga. All these telltale evidences indicate that the magmatic activity continued up to fairly late Quaternary times in this sector of the convergent plate boundary. These active geothermic sources are the main cause of high heat flow (300 ± 120 mW/m²) in Zone-I.

The areas belonging to HFZ-I are grade-I geothermal prospects. The chances of getting high temperature (200 ± 40 °C) geothermal resources suitable for power generation are fairly bright in this zone in the depth range of (2 ± 1.0 km).

The Heat Flow Zone-II occurs on the convex side of the HFZ-I all along the Himalayan region, then turning right and extending up to the Andaman-Nicobar group of islands beyond which it merges with the outer margin of Indonesian geothermal belt. Geologically, HFZ-II include the area enclosing Main Central Thrust (MCT) up to almost Indus-Suture Zone with dated Tertiary granitic and metamorphic events. Though no younger magmatic episodes are recorded the possibility that younger plutonism might be existing at the deeper levels cannot be ruled out. The average temperature gradient in this belt was measured to be of the order of 61 ± 20 °C/km in the northwestern Himalaya. This value is twice the glob-
al average. Even without this elevated thermal gradient recorded, the large elevation differences between Central Himalayan axis and deep river valleys (3-5 km) can itself generate adequate temperature to produce large quantities of hot/boiling waters to feed the known thermal springs.

The fact that many of the bore holes drilled to depths varying between 100 - 700 m in this belt have encountered reversals in temperature profiles with depth suggests the lateral inflow of hot water from underneath high hills into the deep cut river valleys to feed hot springs/boiling springs. It also means that the main reservoirs of high temperature resources may be located under the high mountains away from the valleys. The entire belt of HFZ-II in the Himalaya, has a very large potential for producing hot water of medium to low enthalpy (90-120 °C) fluids even within shallow depth range in almost all the river valleys. These resources can be put to use as a source of heat energy in numerous direct applications to support rural economy and the small scale industrial sector or for binary cycle electric power generation.

The HFZ-III (70-100 mW/m²) is seen all along the Himalaya to the south of HFZ-II upto structural unit known as Main Boundary Thrust (MBT). This zone can also be traced along the Indus Basin in Pakistan towards west, and in parts of Assam, Meghalaya, Tripura, Manipur and Nagaland in the east. The HFZ-III can be considered as a favourable locale for getting low-medium grade geothermal resources (90-120 °C) upto 3 km depth.

The Heat Flow Zones IV & V are the areas of normal and below sub-normal global heat flow respectively. These zones cover part of Lesser Himalaya south of Main Boundary Thrust where thick pile of Tertiary sediments are exposed and the area further south covering Punjab and Indo-Gangetic plains and Brahmaputra basin.

The presence of subnormal heat flow zone (HFZ-V) seen to be located along the foot hills of Himalaya right through Jammu, Himachal Pradesh and U.P. Hills (Panda, 1985); and possibly also through Nepal, inspite of recorded history of major earthquakes, active neotectonism and Upper Tertiary orogenesis is most unexpected and interesting. This zone exposes a very thick sequence of Tertiary sediments, which have been drilled upto 5-6 km at several locations. This has been attributed to the rapid lateral flushing of the vertical heat flow by the formation waters having their recharge zones located at higher hill ranges to the north, as a result of which the temperatures were not rising sufficiently in the vertical direction as recorded on the thermal logs of the deep bore holes (Shanker, 1988).
HFZ-V is not seen along the foothills in the North Eastern Himalaya where geological and tectonic set up is almost identical to the one seen in north western and central sectors of the Himalaya. The presence of mighty Brahmaputra river between the high Himalayan ranges and foothill petrolierous basins being explored in N.E. region appears to have made all the difference. It may be acting as a cut-off in the deep hydrological circulation pattern, thereby preventing substantially the lateral flushing of the upward flowing subterranean heat consequently the heat flow remains within the range of HFZ-V (Shanker, 1988), and the mean temperature gradients are higher than what is recorded in NW Himalayan foothill basins (Panda, 1985). So far as geothermal resources were concerned HFZ-IV and V are not of much interest. The only possibility of getting some low grade geothermal resources may arise if artesian hot water (60-100 °C) flows out from deep (5-6 km) but dry oil wells, as were reported from certain areas in Jammu. These resources could be used as source of direct heat applications.

Once the technology connected with binary cycle power generation and down hole heat exchangers become feasible and economically viable, the low to medium grade geothermal resources locked at shallower levels in HFZ I, II and those at deeper levels in HFZ III & IV would become attractive from the point of view of exploitation.

4 POSSIBLE MODELS FOR GEOTHERMAL SYSTEMS IN THE HIMALAYA

The model for a geothermal system has three basic components, viz. source of heat and mechanism of heat transfer and transmission upto the surface manifestations; reservoir of geothermal energy; and circulation pattern of hydrothermal system from possible absorption area of cold water through reservoir (where heat transfer takes place) upto surface emergence of hot springs through fracture zones and deep seated fault etc. Geohydrological and isotopic studies have established that geothermal fluids of Himalaya are predominantly meteoric in origin as observed in many other geothermal systems the world over.

As is well known the Himalaya had been a zone of active subduction of the Indian Plate underneath the Asian crustal plate during the Middle and Upper Cretaceous period followed by a period of continental collision leading to folding and mountain building activity throughout the Tertiary period. Several phases of granitic activities and the associated migmatisation/metamorphic events have been recognised in the different parts of the Himalaya, the youngest of which have been dated as 3.5 ± 1 Ma. It is, therefore, possible that some of these younger magmatic
episodes (though not yet identified in many areas) could be the source of anomalous geothermal regime in the Himalayan mountain system. A possible indication of such a regime is the presence of antimony and other sulphide crystals as hydrothermal deposits in reconsolidated valley fill, and fumarolic sulphur encrustations pointing to a magmatic source of heat for the thermal fluids.

In addition, recognition of 3.5 Ma granite phase in Chumathang indicates the magmatic heat as major source of heat for the geothermal system in the region.

Even where no evidence of late-Tertiary to Quaternary thermal events are known, following explanation for thermal anomalies has been advanced.

Thermal manifestations in the Himalayan terrain are either in the deep cut valley floors or on the slopes close to it. Due to large differences in altitude between the ridge tops and the valley floors (upto 5 or 6 km) it is possible for the water absorbed near the ridge tops to attain heat from the country rocks even with the normal geothermal gradient during its movement downwards along a circuitous route (McNitt, 1981). This process also can heat the water up to near boiling points.

The Manikaran Geothermal system in the Parbati Valley (H.P.) represents one such system. According to this model, the absorption area is in the higher reaches of Brahmaganga catchment where from the cold waters descend through the gneisses, schists and other associated rocks to depths of 4-5 km and attain the normal geothermal gradient (130°C/km). These heated waters migrate upwards along the thrust contact and enter into the Manikaran quartzite through the joints/fractures. The planes of intersection of the thrust and steep joints/fractures act as the main channels of upflow for the deep thermal waters. During upward migration deep thermal water losses some amount of heat firstly because of boiling and secondly due to mixing with cold shallow groundwater prior to emergence as hot springs. The phenomenon of beverial hot temperature with depth observed in the test bore drill holes at Manikaran below the depth of 150 metres suggests that the thermal waters flow especially into the valley floor from the northern side and not vertically. This seems to indicate that the lower portions have been hot for a long period of time and have been heated by the geothermal regime in the upper crust. However, it should be noted that some of these lower portions may not
Another model visualises contribution of heat to the thermal fluids from two sources, viz. the prevailing geothermal gradient and from cooling acid magmatic intrusives at depths. The Tapoban Geothermal System (U.P.) represents such a system. Under such a situation the reversal of temperatures with depth is not visualised as evidenced upto a depth of 500 m probed so far in Tapoban area. Middle to Upper Tertiary granites/thermal events are known to occur in the vicinity and therefore the possibility of still younger phases of acid magmatism, not yet exposed by erosion, cannot be ruled out. Such younger acid magmatic bodies may be contributing heat by conduction to the geothermal system.

5 CONCLUDING REMARKS

The Heat Flow Map of Himalaya represented here must be taken only as a first step towards understanding its thermal regime. This need to be refined and periodically updated as additional data become available. However, it gives fairly good idea about the operating geothermal regime underneath the Himalaya and the close relationship between magmatic history and the major geotectonic features and various heat flow zones is evident.

6 ACKNOWLEDGEMENTS

The author wishes to express his gratitude to the Director General, Geological Survey of India, for providing this opportunity to prepare this base paper for the consideration of the geoscientific community.

7 REFERENCES


