# ROCK GLACIERS IN INFERRING ENVIRONMENTAL CHANGES IN LAHUL HIMALAYA, HIMACHAL PRADESH

Dissertation submitted in partial fulfillment of the requirement for the award of the degree of

**MASTER OF PHILOSOPHY**

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## CERTIFICATE

I, **Vivek Kumar**, certify that the dissertation entitled **"ROCK GLACIERS IN INFERRING ENVIRONMENTAL CHANGES IN LAHUL HIMALAYA, HIMACHAL PRADESH"** for the degree of **MASTER OF PHILOSOPHY** is my bonafide work and may be placed before the examiners for evaluation.

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Dedicated to........................

My parents

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*Vivek Kumar*

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Chapter One

# INTRODUCTION

## 1.1 DEFINING ROCK GLACIER

Although rock glaciers are indomitable landform expressions in the high latitudes and altitudes, reflecting many unexplained characteristics, yet it has not been easy to coin a definition of rock glacier. The theoretical development of the concept is still in its initial stages, thus the various contradictory opinions make it rather more difficult to clinch a conclusive definition. A provisional definition may be coined on the basis of field observation and available scientific literature for any further elaboration and analysis:

*"Rock glacier is a sediment transportation system under glacial and periglacial conditions, with peculiar landform expressions."*

The term 'rock glacier' is restricted to that accumulation of rock debris, which has movement, due to the deformation of 'interstitial' or clear 'ice-core', found within the debris. The movement extends sediments outward and downward from talus cones, snout of glaciers or from the terminal moraines. Rock glacier is known for slow movement, which generally ranges from 0.1m -2m per year, nevertheless, it is a major transporting mechanism of detritus from the base of talus and cirques in high latitudes and altitudes. Although, its role in erosion is not significant by itself, yet it assists the process by keeping the cirque walls free of talus.

The importance of rock glacier in the domain of scientific study has steadily increased in the recent years on two counts. First, as an important mass transportation system at high altitudes, it affects landforms and in some cases becomes natural hazards to anthropogenic features (e.g. road, settlement etc.). Secondly, the palaeo-climatic reconstruction and modelling has started putting considerable focus on the information input from its nature and behaviour.

## 1.2 SURVEY OF LITERATURE

In order to have an appraisal of the development made on this front, survey of literature has been necessitated. As much of the research on the topic was carried out either in the Western Cordillera of USA and Canada or in the Alps of Europe, this study borrows much of the information from the existing literature on these regions. This information, thus collected, has helped to initiate a debate and discussion, on the nature and internal mechanism of rock glacier. The views and opinions of many scholars have been accommodated under the following categories –

Rock Glacier

- Evolution of the Idea
- Classification of Rock Glacier
- Identification of Rock Glacier
- Causes of Origin Of Rock Glacier
- Rock Glacier and the Reconstruction of Palaeoenvironment

Environmental Change

- Reconstruction of the Past

- Global Climate Change
- Relationship between Cenozoic Uplift and Ice Age
- Effect of Ice Ages on Monsoon
- Ice Ages in Lahul Himalaya

## 1.2.1 ROCK GLACIER

### 1.2.1.1. EVOLUTION OF THE IDEA

The knowledge base of rock glacier is increasing steadily but even today it is still in the nascent phase of development in the global context. The first reference to rock glacier was made by Steenstrup in 1883. Howe (1905) was the first person to use the term `rock glacier' (as cited by Giardino et al, 1988). Initially there was much confusion over the meaning of it and its connotation varied markedly. While Spencer (1900) described it as a peculiar form of talus, Rohn (1900) took it as a talus slope that flows (as cited by Vitec et al, 1887). Various terminologies were coined in different languages to serve as its supplement (Giardino and Shroder 1978).

The contribution of Capps (1910) on the surface morphology of rock glacier ushered a new interest into the process (es) of its formation. The subsequent researches on this front suggested two theories of genesis, leading to the recognition of two types (i.e. ice cored and ice cemented) of rock glaciers (White 1971, Potter 1972). The term 'rock glacier' is made up of two words- rock and glacier. The older view on origin suggest that this feature is nothing but a transformed glacier which contain more sediment than a glacier normally has and its core is made up of the 'remnant ice' of receding glaciers. As the research proceeded further, the scholars started questioning the validity of 'ice-core' concept of genesis. Field investigations suggest that while there may be only few rock glaciers, which have ice core, the most of them lack it. The interstitial ice that holds the debris together, imparts peculiar characteristics to the feature. Quite a few researchers completely reject the possibility of ice core in rock glacier. Amid the debate between the two streams of thought, a question has been raised on the propriety of the term 'rock glacier' as it suggests an inevitable genetic link between rock glacier and glaciers. They are in favour of a suitable alternative term to describe the feature (Johnson, 1983).

There is another debate regarding the causes and processes of its movement. Howe 1909 held high velocity rock-fall avalanches might be responsible for the movement (as cited by Giardino et al, 1887). But other scholars are of different view. Gorbunov (1983) and Johnson (1984) proposed that catastrophic mass movement events might be the mechanism for the formation of rock bases for the formation of rock glacier. Chaix, 1919 underlined the importance of slow movement of landslip, because of the presence of mud in them causing freeze thaw activity (as cited by Vitec et al, 1887). Ives (1914) suggested that cold climate favours its formation by causing rapid production and instability of detritus and lubrication of slip plains by water, mud, ice and algae. But in the Himalayan environment algae may have no relevance.

Wahrhaftig and Cox' work (1959) is considered the foundation of modern research on rock glacier. The other important contributions came from Schweizer, 1968, White, 1976 and Corte, 1976 (as cited by Vitek et al, 1987). Hollerman (1983) formulated association between rock glacier's distribution on the one hand and location characteristics, macro climatic and micro topographic, on the other hand. The research has gained momentum in the last few decades but the theoretical foundations are still not on a strong footing.

Rock glaciers do not occur in large numbers; nonetheless they are common and perhaps the largest landform of unconsolidated debris in Alpine environment (Giardino, 1979, 1983). It could well be regarded as a debris transport system, which is viewed as a subsystem within the Alpine environment (Giardino, 1979).

### 1.2.1.2. CLASSIFICATION OF ROCK GLACIER

There may be various bases for the classification of rock glaciers but their origin and shape are the most important among all. The survey of literature highlights the divergence of opinion on different issues, as the knowledge base is still not vast and the concepts are yet to concretise.

#### 1.2.1.2.(I). SHAPE BASED CLASSIFICATION

Tamorodzki, 1951 is credited to have established two fold classification of rock glaciers- tongue shaped and lobate (as cited by Vitek et al, 1987). Wahrhaftig and Cox (1959) added a third class called spatulate. These were to be distinguished on the basis of following characteristics: lobate, in which length is less than width; tongue shaped, with length greater than breadth; and spatulate which is tongue shaped but broader at the front. While the lobate rock glaciers, which lines cliff and cirque walls, probably represent an initial stage in the development towards maturity of rock glaciers; the other two develop later and move down valley-axis. These probably represent more mature stages (Wahrhaftig and Cox 1959).

Richmond (1962) coined the term "protalus lobe", referring to the incipient form of a lobate rock glacier and distinguished it from protalus ramparts, which do not show any evidence of past or present mobility on its surface. But many scholars view that it should not be put into a separate category.

Wahrhaftig and Cox (1959) discussed about theoretical distinction between spatulate and tongue shaped rock glaciers but, the difficulty of distinguishing them in field lead Parson (1987) suggest two more classes-'transitional' and 'complex'(as cited by Giardino et al, 1987). These classes include all those that can't be accommodated in the above-mentioned two classes. The scheme of classification, thus evolved contains five categories: lobate, tongue shaped, spatulate, transitional and complex.

#### 1.2.1.2.(II) ORIGIN BASED CLASSIFICATION

There are two schools of thought subscribing to different views on the origin of rock glaciers-'glacial' and 'periglacial'. On the basis of the study conducted in Galena Creek (situated in the northern Absaroka Mountains), Potter (1972) proposed a model of 'ice- cored' rock glacier i.e., a glacier ice core mantled by 1 to 1.5 metres of debris. In other words, it is a debris-covered glacier, whereas its counterpart, the ice-cemented rock glacier, forms a rock glacier of true periglacial origin. It lacks the so-called 'core of ice'. This division has been accepted in a number of important papers (Wahrhaftig and Cox 1959, White 1976). It is thought that the internal structure of both types has a specific expression by which they could be differentiated (White 1976).

Few scholars are of the opinion that only the 'ice cemented rock glaciers' could be considered as 'normal' rock glacier whereas some of them even suggest the abolition of the model of the so-called ice cored rock glacier, which don't exhibit 'genuine' rock glacier properties (Brown 1925 and Barsch, 1987). It should be noted here that large bodies of glacier ice have not yet been encountered in any 'true' rock glaciers (Barsch 1987). The scholars on the other side of divide argue that internal structure (core) of an active glacier is close to that of a glacier (Wahrhaftig and Cox 1959; Barsch 1977; Haeberli 1985). But the objection raised over the genetic connection of rock glaciers with glaciers can't be simply discarded. With the debate progressing, the balance seems to be tilting towards the proponents of 'periglacial' concept.

The survey of literature suggests that the rock glaciers could be classified into four genetic groups-glaciogenic, avalanche debris rock glaciers, gelifluction debris rock glaciers and unusual (or various) rock glaciers (Corte 1987).

1.2.1.2.(IIa).*Glaciogenic Rock Glacier*: This is a category of perennially frozen debris bodies with an ice core and it is ~~in~~ not associated with any particular morphology (Corte 1987). The basic criterion of this group is the glacial origin and cirque location. The scholars have used the following nomenclature to denote the rock glaciers of this type (Corte 1987):

- Debris covered glaciers.

- Ice cored moraines.
- Rock glaciers below moraines.
- Ice cored rock glaciers.
- Ablation complexes.
- Tongue shaped rock glaciers.
- Glacial ice cored rock glacier.
- Near glacier rock glacier.

Broadly, glaciogenic category could be further divided into two – 'debris covered' type and 'moraine material flow' type. Though they exhibit different features, they are generically related to glaciers (Corte, 1987).

1.2.1.2.(IIb). *Avalanche-Debris Rock Glacier*: The avalanche of snow, debris and cryogenic action, needed for the formation of ice lenses, are responsible for its formation (Giardino 1979, 1983). Avalanche tracks are normally present above the rock glacier bodies. Very elaborate surface characteristics of transverse and longitudinal ridges are found in the advanced stage of its development. The following are the examples that fall in this category (Corte, 1987):

- Peculiar form of talus.
- Valley wall type.
- Talus and slope type.
- The primary type.
- Lobate rock glacier.

- None glacial ice cemented rock glacier.
- Ice cemented with ice lenses rock glacier.
- Near slope rock glacier.
- Rock fall talus (colluvial) rock stream.

1.2.1.2.(IIc).*Gelifluction Debris Rock Glacier:* Frozen debris dominates in this type of rock glacier. Avalanche chutes are absent on the slope above it and this category is found in low precipitation areas. Its association to cryogenic features and small aerial extent are important properties (Corte1987).

1.2.1.2.(IId). *Miscellaneous And Transitional Rock Glacier*: These are those rock glaciers, which do not fall in any of the above categories due to some peculiar features and genetic properties.

Although the problem of classification of rock glaciers into distinct classes have been well appreciated by many scholars (the forceful pleading of Giardino et al. 1988 is the most noticeable) yet they have no choice. Any genuine scientific study has to be based on classification. Some of the recent studies have preferred to use the classification of rock glaciers into protalus and morainic types (Owen et al., 1998, Mitchell et al., 2001).

### 1.2.1.3 IDENTIFICATION OF ROCK GLACIER

What induced Capps (1910) to coin a term "rock glacier" to represent a distinctive landform was the pattern of 'ridges and furrows' on its surface. But later this feature was not considered an inevitable indicator. There are many rock glaciers, which completely lack it. Especially the smaller ones have fewer ridges and furrows. Hence, the identification of rock glacier is not always easy. Parson (1980) suggested the following four criteria to rock glacier identification on satellite imagery and aerial photos:

- The surfaces are formed by coarse talus.
- Talus slopes terminating on rock glaciers.
- The talus slopes, the upper surface of the landform and the front of the landform have three distinct slopes.
- The front of the landform contrast sharply with the upper surface in terms of both tone and texture. The front is lighter in tone and smoother in texture indicating less oxidized, more finely textured materials at the front. This criterion defines small rock glaciers. Additionally, larger one exhibits patterns reminiscent of porridge-poured on a gently sloping surface.

We can sum up by saying that the rock glaciers are lobate or tongue shaped landforms composed of coarse angular boulder debris with steep lateral flanks and frontal ramps (Mitchell and Taylor 2001). A distinctive surface morphology of arcuate ridges and furrows is interpreted as reflecting slow rates of internal deformation and flow that is associated with buried ice (Martin and Whalley 1987; Vitek and Giardino 1987; Whalley and Azizi 1994; Hamilton and Whalley 1995; Barsch 1996).

### 1.2.1.4 CAUSES OF ROCK GLACIER'S ORIGIN

Howe (1909) suggested that the morphological extension at the base of talus slope movement, which is triggered by instability, causes the formation of this feature (as cited by Vitec et al., 1987). The unloading and release of stress during deglaciation accentuate the structural weakness of rock resulting in the genesis of rock glaciers. Giardino (1983) emphasised the role of hydrostatic pressure as a contributory factor. A major contributor to the development of hydrostatic pressure in the over burdened material is the groundwater regime. The geological structure and geology either direct the water towards or away from the contact with the overburdened material. Water channelled towards the contact can either contribute to the water in the overburdened material or affect the contact to promote slope failure (Johnson 1987). The hydrostatic pressure in unconsolidated burden does the same work but due to its seasonal availability, its effect is confined to a particular period of year. The amount of water is important as well. The instability increases with increasing amount of water (Johnson 1987).

Among other factors, the undercutting of streams in narrow valleys and some catastrophic events such as earthquakes are important. The ice deformation, which is affected by gravity, has been a major attraction to many theories on the origin of rock glacier (Wahrhaftig and Cox 1959). Although, reservations have been expressed on the efficacy of the movement of 'ice rock mixtures' (Whalley 1974), it is still accepted as the primary cause of rock glacier's genesis (White 1981). Mention must be made of the role of incorporated ice, which melts to create instability, conducive for rock glacier genesis. This factor is generally associated with moraines and debris above the former ice margin (Johnson 1987).

Parson (1980) proposed an important model, for looking in to rock glacier genesis (as cited by Vitec et al., 1987). He appreciated the role of multitudes of interrelated controlling factors (explained earlier) and attempted to incorporate the known relationship among them. The model tries to explain the spatial distribution as well as the variation in the size and morphology of it. It is based upon the site characteristics and was developed during a study on the Blanca Massif, Colorado, U.S.A. It works on the following principles:

- Those sites where talus accumulation provides insulation to snow accumulation, causing positive perennial snow budget, are favourable.
- The blocky nature of talus favours sufficient snow accumulation in the interstices. The additional insulation caused by talus accumulation has been considered a must in the genesis and development.
- The talus accumulation as well as the snow accumulation should be sufficient for providing enough insulation.
- The preceding conditions of rock glacial genesis are effective only when the site of development is nearly level or slopes slightly away from the talus source, as it provides suitable circumstances for heavy accumulation of talus.
- The orientation of source is important as well. If the talus source faces north to east, then there is always a chance of effective mass wasting.

- Snow accumulation sites are based in leeward trending valleys with cols at the head.
- The special condition of high walls facing each other is suitable as it focuses the falling debris on a common site.
- Valley head ending in a horn will produce more talus than the one ending in col.

Summarily, it could be said that the proposed model is based on the observed facts that the enhanced accumulation of debris and ice, with retarded ablation, is conducive for the formation and maintenance of rock glaciers.

As the proposed model is not quantitative in nature, which engenders subjectivity, makes it less applicable for practical purposes, even though it may be theoretically very sound.

### 1.2.1.5 ROCK GLACIER AND RECONSTRUCTION OF PALAEOCLIMATE

There has been keen interest among earth scientists to find out the nature and character of past climate as they seek to understand the events of past with the help of various climate sensitive indicators present today. Though the effort to use rock glacier as an indicator for this purpose has not been fruitful to that extent, nevertheless it could well be used as a proxy along with some other indicators, such as changes in the behaviour of rock glaciers in response to changing climatic regime.

A very important observation on 'climate- rock glacier relationship' was made by Harris (1981), who stated that the active rock glaciers are limited to permafrost locations. This proposition made the morphological study of rock glaciers very important. Hollerman, 1983 demonstrated in his study that rock glaciers, possess certain microclimatic and topoclimatic conditions (as cited by Vitec et al., 1987). Any change in the behaviour of it may unravel the character of climate change (Kerschner 1983, Humlum 1984 and Haeberli 1985). Because of the debris that comprises rock glaciers, is capable of protecting the internal characteristics of rock glacier (especially ice), evidences of past environments are supposed to be preserved in it. But the problem lies with the complex relationship among the controlling factors of rock glacier, which hasn't been understood properly (Giardino et al 1987).

Whalley (1979) mentioned the utility of this method for palaeoclimatic inferences. But the problem of subjectivity continuously haunts scholars on this front. The same case may evoke different interpretations (Humlum 1982). This shows the immaturity of the technique developed so far which grants space for subjectivity. Many scholars have tried to explain the inherent subjectivity in terms of locational factors- latitude, altitude, aspect, relief of the bedrock, cliffs-which collectively determine the energy input into rock glacier system (Giardino and Vitek 1987). This makes generalization practically impossible at this stage. If the internal thermal characteristics of rock glaciers and changes observed in it over time could be related with the present weather phenomenon then we can use the result in making palaeotemperature maps (Hassinger and Myaewski 1983). Understanding the dynamics of rock-glacier core, as well, could generate the palaeomoisture trends (Giardino and Vitek 1987).

Recently, there has been some interesting development. The basis of this development is the periglacial model, which says that the rock glaciers could be taken as the lower limit of mountain permafrost (Haeberli 1985, Barsch 1996). If this statement happens to be true, the construction of climate might be carried out on the basis of the empirical fact that the mountain permafrost indicates a mean annual average temperature (MAAT) of less than minus twenty degrees centigrade and the mean annual precipitation as 250 cms (Barsch 1996). Another suggestion lowers the precipitation figure to 100 Cms (Humlum 1998). The comparison of climatic control on glacier and rock glacier could be done by the study of RGILA (Rock Glacier Initiation Line Altitude) and ELA (Equilibrium Line Altitude) (Humlum 1998).

## 1.2.2 ENVIRONMENTAL CHANGE

### 1.2.2.1 RECONSTRUCTION OF THE PAST

Climate is variable over geological time and now we have many evidences to indicate that it has never been uniform over fairly long period. Although, the nature and causes of changes have been widely debated, yet there is no controversy over the proposition of change. For the geomorphologists, there is a reason to be involved into this speculation, as climate inevitably affects the type and intensity of geomorphic processes, therefore landforms. We extend our investigation into the geological past through the proper understanding of present. A saying goes, 'present is the key to the past'

After making the assertion that we do look in to the past through the tools of presenc~~e~~t, we must say that this visualisation has its own limitations. Looking back into the past we realise that the distant vision is not that clear. The farther we look, the more indistinct it becomes. It is therefore more difficult to speculate about Palaeozoic and Mesozoic than Cenozoic. Therefore the most of the information, that we have, are of Cenozoic Era (Bradley, 1990).

### 1.2.2.2 GLOBAL CLIMATE CHANGE

Milankovitch (1941) ascribed many reasons to the recurring cold phases of climate (as cited by Bradley, 1990). These cold phases are known as ` ice ages'. Among various reasons, scientists consider the slow wobbling of the earth's axis, and the uncommon orbit around the sun, as the most important factor. These factors collectively affect the total amount of energy that the planet receives from the sun and its geographical distribution. The global temperatures fell by 5 degree centigrade in these phases causing tremendous accumulation of snow and ice. The northern part of Europe was completely covered under ice sheets and larger icecaps developed on the tropical mountains. There are evidences to show that there were several short glacial period or ice ages separated by longer period of warm temperature or inter-glacial phases. In the history of earth, the Pleistocene glaciation is the most recent and known, which extensively affected the evolution of landforms.

Two seemingly synchronous activities, (i.e., the cooling of earth, which subsequently resulted into the advent of the Pleistocene glaciation and the collision between Austro-Indian Plate and Eurasian Plate, which caused the genesis of Tibet and Himalayas) have puzzled the scholars since long (Coleman and Hodge, 1995).

Whether ~~there~~ it was a mere coincidence in the timing of these two events or critical causal relationship needs proper exploration.

### 1.2.2.3. RELATIONSHIP BETWEEN CENOZOIC UPLIFT AND ICE AGES

Most of the scholars believe that the tectonic uplift had considerable effect on the global climate, that led to the initiation of the ice ages (Raymo et al., 1992) but some scholars contradict it by suggesting that it was not necessarily the tectonic upliftment of mountain which subsequently led to the ice ages but it could be the other way round. There is a possibility that the ice ages, which could have initiated due to some unknown reasons, 'polluted' the 'evidences' upon which the proposition on the relationship between Cenozoic orogeny and climate changes is based (England et al.1990).

#### 1.2.2.3.(I) ARGUMENTS IN FAVOUR OF THE NOTION THAT THE TECTONIC UPLIFTMENT RESULTED INTO PLEISTOCENE GLACIATION

Danna, 1856, proposed a link between the continental glaciation and Cenozoic rise of mountain ranges, which was later supported by many other scholars viz. Lyell, 1875; Conte, 1886; Ramsay, 1924; Umgrove, 1947; Holmes, 1965; Hamilton, 1968; (cited by Molnar et al 1990). The temporal correlation of mountain building with the onset of glaciation was the main logical link for the hypothesis. The supporters of this proposition (Birchfield, 1983, Kutzbach et al., 1989, Raymo, et al., 1988) have held three physical machinations accountable for global cooling (cited by England et al., 1990). First, increased elevation could extend the duration of winter in temperate latitudes and with increased duration of snow cover, the albedo should increase.

Second, increased elevation could disturb the global circulation of atmosphere. The experiments with the general circulation model suggest that the presence of high terrain in Central Asia and Western North America would lead to lower global temperatures than if these areas were low. Third, chemical weathering, enhanced the increased exposure of minerals eroded rapidly from cold high latitudes and transported to warmer moister low elevations, would absorb more carbon dioxide from the atmosphere, thus decreasing the annual green house effect.

### 1.2.2.3.(II).ARGUMENT AGAINST THE NOTION THAT THE TECTONIC UPLIFTMENT RESULTED INTO PLEISTOCENE GLACIATION

England et al., (1990) have argued that the widespread orogenesis of Cenozoic era could not be held responsible for Pleistocene glaciation. They have suggested that the most of the evidences used to infer late Cenozoic uplift could, in a large part, be a consequence of the very climate changes, which the supposed tectonics is thought to have caused. In simple words it could be said that some areas may virtually appear to be higher, in comparison to their actual height as the geological effects of late Cenozoic climate change could have the same changes on the landscape and fossil records as regional uplift would have had. The explanation of glacial phases in terms of tectonic upliftment was very popular till glaciations were not considered to be recurring in nature. When people realised that the glaciation did not occur only at the time of the Cenozoic uplift, this proposition lost its attraction. It gave way to a new theory of Hays and Shackleton (1976), which proposed that the Pleistocene glaciation was a consequence of variations in the earth's orbit superimposed upon long term global cooling throughout the Cenozoic era (cited by England et al., 1990).

### 1.2.2.4 EFFECTS OF THE ICE AGES ON MONSOON

The evidences indicate that the ice ages were accompanied by attenuated southwest monsoon and stronger northeast monsoon. This could have resulted in less precipitation over Indian subcontinent, much of the Himalayas, Tibet, and Bangladesh (Dupplessy 1982). This aberration has been explained in terms of the speculated change in the prevailing environmental conditions. All of us know that the central and southeastern Tibetan plateau, which remains free of snow throughout the year, seems to accelerate the onset of Asian monsoon and increases its ultimate intensity, due to its rapid heating during spring and summer in the northern hemisphere (MONEX 1976). In the last ice age these mountains were covered with glaciers, which could have prevented any marked summer warming of the Asian continent. Thus the pressure gradient between the continent and Indian Ocean would have been weaker during the summer but the opposite could have been true for the winter season because of the stronger northeast monsoon and weaker southwest monsoon, resulting into probably more precipitation in the form of snowfall (Dupplessy 1982).

### 1.2.2.5 ICE AGES IN LAHUL HIMALAYAS

Two reasons could be cited, to explain the increasing interest of people, in the investigation of the glacial history of the Himalayas. One of them is the interesting debate, over the role of Cenozoic uplift in lowering global temperature, which subsequently resulted in various 'ice ages'. Another cause of growing interest is the fact that the mountains of the Western and Central Himalayas and the Karakoram, have the greatest concentration of glaciers, outside of the Polar Regions (Owen et al., 1995). It makes, the study on the Himalayan environment-its present and past, especially valuable for global climate modelling.

Despite the importance of Lahul Himalayas (due to its location at the junction between the monsoon influenced southern flank of the Pir Panjal and the Great Himalayas) which makes it sensitive to the fluctuations in the south Asian monsoon through time; and also because it provides the best preservation of the evidences of glaciations within the western Himalayas, there has been little work on the chronology of glacial phases and the nature and thickness of glaciers (Owen et al. 1996).

The lead, in establishing glacier chronology in Lahul, was taken by Krenek (1945). Later Owen et al., (1996) came out with a scientific chronology for the region. Their formulation of three major glacial phases (Chandra, Batal and Kulti) and two minor advances (Sonapani I and Sonapani II) has become an important insight into the climatic history of Lahul. The names of glacial stages have been given after the sites where evidences of these phases are found in abundance. It is also a widely held hypothesis that each subsequent glaciation was less extensive than the earlier one (Shroder et al 1993, Owen et al., 1995, 96, 97, 98, 2001). There are geological evidences to show that the later glaciations were confined within constricted valleys (Derbyshire et al 1984, Owen et al 1996) whereas the earlier glaciations occupied fairly broad valleys. Two reasons could be assigned for this. First, the glaciers, had to occupy the already deepened valleys, in later phases of glaciation, and thus got confined into them (Shroder et al 1993; Owen et al 1996). Second, the upliftment of Pir Panjal Mountain, which took place at the time of Pleistocene glaciation, could have partially obstructed the entry of monsoonal wind into the region (Owen et al., 1997) resulting into less amount of precipitation and depletion of glacial mass. Thus, the history of ice ages in Lahul is a reflection on increasing aridity in subsequent glacial phases.

## 1.3 SELECTION OF THE STUDY AREA

The Lahul Himalaya is a repository of palaeoglacial evidences in India. This region receives very low amount of rainfall which enfeebles the erosional activity (which might have posed a threat to glacial landforms) of one of the most important gradational forces i.e. stream. Moreover, anthropogenic modifications of the landforms have been minimal, compared to any other region. Thus, the marks of glacial phases are almost unaltered, making it suitable for the study of land evolution through the past glacial activities.

The study area falls within the administrative boundary of Lahul and Spiti district of Himachal Pradesh. It is comprised of three-river basins- the Chandra basin, the Bhaga basin and the upper Yunam basin. There is a close association between the Chandra and the Bhaga and their basins are sometimes taken together and collectively called as the Chandra –Bhaga basin. The Chandra-Bhaga basin is a part of Lahul Himalaya. It is situated between the Middle Himalaya and Inner Himalaya. But the Upper Yunam basin is located to the north of this mountain range. Technically speaking, this forms a part of Trans-Himalayan zone (between Great Himalaya and Zanskar ranges). The inclusion of Upper Yunam basin, along with Chandra-Bhaga basin, is based on the observation that the glacial phases of both these regions were identical. Besides, landforms and climatic similarity and continuity of rock glaciers, into the Upper Yunam basin, have promoted its inclusion. The other justifications are as follows:

- This area has not been properly studied, despite its potential to reveal a lot more clues to earth scientists. This area needs more serious attention of researchers than it has been getting.
- The geomorphologic variations, which are many, make it a very fascinating and challenging puzzle.
- Earlier visits of the author, to this area, during post-graduation field surveys, triggered his interest for this investigation.
- The availability of toposheet, satellite imagery, and sufficient literature.

## 1.4. OBJECTIVES

The objectives of the study are as follows:

- To look into the evolution of surface irregularities, by examining the glaciofluvial features and sediment deposits.
- To study the distribution and typology of rock glaciers.

- To understand the origin of rock glaciers in the context of its relationship with environment and sediment supply.
- Morphometric study of the Chandra, Bhaga and Upper Yunam basins, in order to appreciate the fluvial and areal characteristics.

## 1.5. DATA BASE

The database could be divided into two classes - primary and secondary.

### 1.5.1 PRIMARY

The photographs, observation of glaciofluvial features, sediment deposits, rock glaciers, and rock type were obtained from various field surveys undertaken by the author.

### 1.5.2 SECONDARY:

The study is based on the following secondary data:

- Toposheet (1:250,000), named PALAMPUR, prepared by U.S. army.
- Toposheets on large scale (1: 50,000). (SOI)
- Geological and vegetational maps of the region.
- Digital satellite imagery, NRSA.

- Weather data from SASE, Chandigarh
- Thematic map of Lahul and Spiti, published by NATMO.

## 1.6 METHODOLOGY

Field observation forms a very important part of this study. The time spent in field was devoted to the recording of the following features:

- The structural, sedimentological, lithological and moranic evidences of glaciations were identified and the prevalent rock types were noticed. For relative dating of moraines, lichenometric study was conducted at few places. As the relative size of some lichens depends on the age of exposure of the rock surface, some inferences are drawn regarding the age of rock deposition. This technique is more helpful in determining, whether neighbouring moraines belong to the same glacial age or not. Although this is a crude way of age determination, but the lack of organic material in the region and necessary infrastructure for other methods of dating, this was the one, which was ultimately resorted to.
- The recording of location was done with the help of GPS (Global Positioning System).
- In order to have a better understanding of some of the important morphological and relief records, large-scale toposheets (1:50,000) were used.
- The data from toposheet and secondary sources were analysed with the help of few GIS softwares. The geo-referencing of the maps, after scanning, was done in IRDAS 8.4. This software was helpful in sub-setting of map and image. All

of the digitisation work was done in ARC- VIEW 3.2a. Demarcation of watershed was done after the digitization of contour had been completed. The same process also helped in the creation of digital elevation model, based on the attributes of contour.

- In order to incorporate information from relevant maps of the region, georeferencing was done. This enabled superimposition of the boundary of the study area, various geo-referenced map of the region.

## 1.7 CHAPTERISATION SCHEME

The scheme of chapterisation is as follows:

- The first chapter deals with the general framework of the study. It includes an appraisal of researches carried out by various scholars on issues like rock glacier, climate change and Himalayan environment. The emphasis has been put to include quality research papers, on rock glaciers. As, research on rock glacier, is still in its nascent phase, in India; the most of the papers, included in the literature survey, are based on the observations made in the Alps or the Western Cordillera of North America. In addition to literature survey, this chapter includes the information regarding the source of data, methodology, and chapterisation scheme.

- This chapter provides the introductory information, regarding the area, along with morphomertic analysis, in terms of aerial and fluvial features. In order to visually show the variation in elevation, throughout the region, 'digital elevation model' has been used.

- The evolution of landforms through various glacial phases forms the focus of the third chapter. It deals with the proposed sequence of glaciation and evidences, collected in the field. The authenticity of the model of three major glacial phases, i.e. Chandra, Batal, Kulti, and two minor glacial advances, in the form of Sonapani-1, and Sonapani-2, has been collaborated with some field observations and photographs.
- The fourth chapter is devoted to the distribution and type of rock glacier, found in the region. The crux of the chapter lies in the discussion over the origin of rock glaciers. The environmental conditions, surrounding rock glaciers, in this region, provide some sort of challenge, to a well-established theory, which links its origin to environmental conditions. The role of structure, which affects sediment supply in a considerable way, seems to be playing an important role here.
- This is the last chapter of the dissertation that includes summary and conclusion of the study.

## 1.8 LIMITATIONS OF THE STUDY

- The area of study is located in an inaccessible region. That's why the accessibility to a large part of the region is limited. This has resulted in less accuracy in the eastern part of the toposheet. The inaccuracy, inherent to the toposheet, could be well highlighted by the fact that the largest glacier of the region i.e., Bara Shigri is not shown on it. Moreover, the information from various sources are not exactly compatible.

- The satellite imagery is not available for the area located to the north of Bralacha Pass. Because of this the upper Yunam basin as well as the northern part of Janakar Nala could not be studied in detail. Besides this, the study lacks multi-date satellite imagery.
- The data available from SASE can be used for inference only. There are some discrepancies in it and some of the entries are missing. Thus the quantitative representation of spatial climatic variation is not possible. Besides, the data is available for a very short span on time. Hence it could not be analysed to show the climatic characteristics of the region.
- This study is based on various secondary sources. The reliability of it is thus definitely linked with their authenticity.

Chapter Two

# INTRODUCTION OF THE STUDY AREA

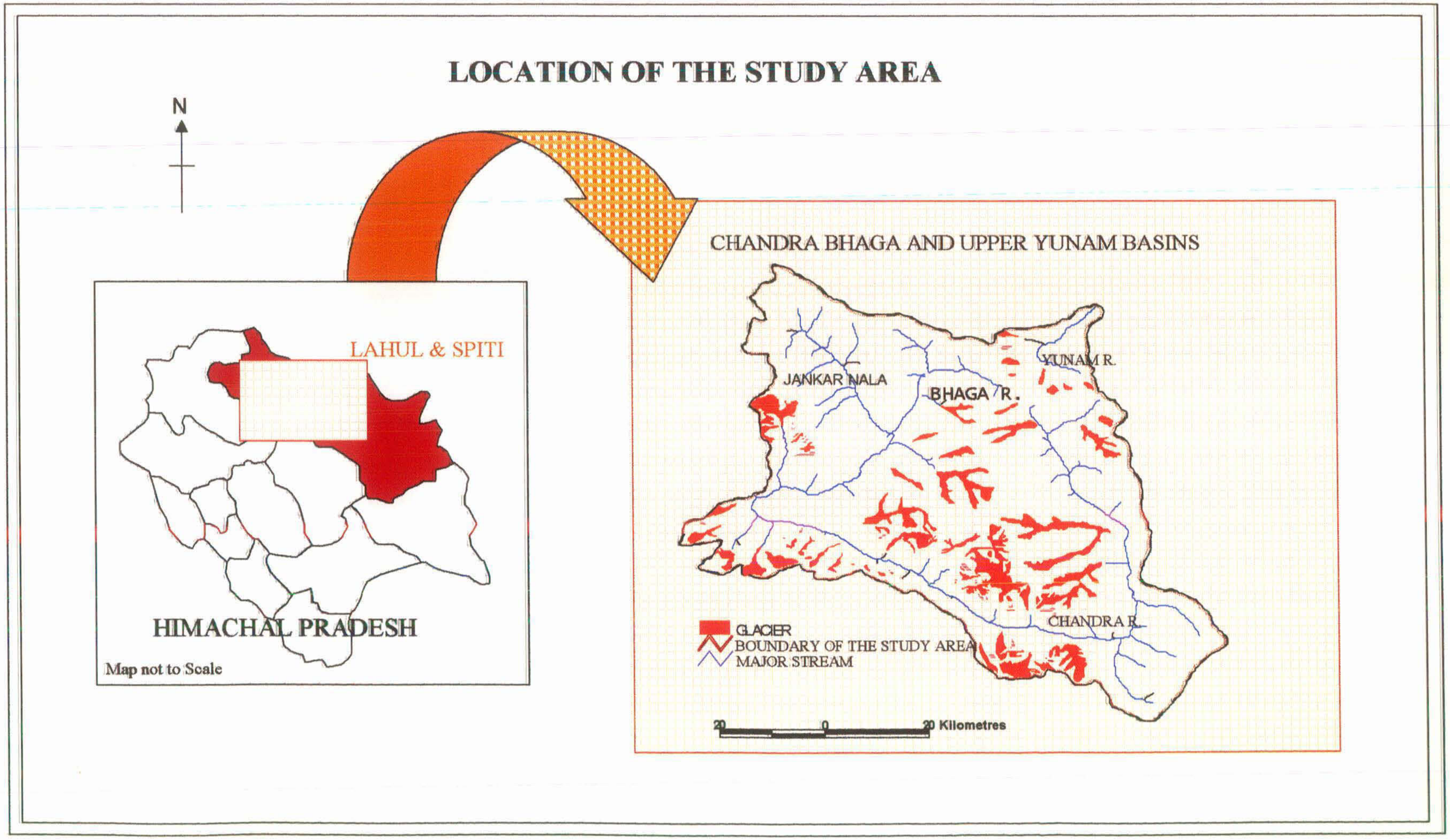
## 2.1 LOCATION

The study area is a part of Lahul and Spiti district of Himachal Pradesh. It stretches from 31° 07' N to 33° N and from 76° 50' E to 77° 47' E (*see figure 1*). The people enter this rather inaccessible region through mountain-passes and the most important among them is the Rohtang Pass (3978 metres), located to the north of Manali. The other relatively less important passes are Baralacha (4892 metres), Sara Umga and Kunjum (4420 metres).

This area is made up of three-river basins- Chandra, Bhaga, and upper Yunam. The basins of the Chandra and the Bhaga are sandwiched between Pir Panjal, which is in the Middle Himalayas, and Zanskar ranges (Inner Himalayas). The Upper Yunam basin is situated to the north of the Himalayan Mountains.

All the three rivers emanate from a common source region, Baralacha. The Chandra and Bhaga, which initially start in opposite directions, finally confluence at Tandi, to form Chandrabhaga, which is later known as Chenab. The Chandra and Bhaga basins are interrelated in many senses, so their basins are sometimes collectively called as the Chandra-Bhaga basin. The third stream, Yunam, which initially flows away from these two streams, in the northerly direction, ultimately serves as a tributary to the Indus. This study is concerned with the upper basin of this river. The northern limit of the study has been identified with the confluence of Sarchu River with Yunam.

*Figure: 1*


LOCATION OF THE STUDY AREA
N
LAHUL & SPITI
HIMACHAL PRADESH
Map not to Scale
CHANDRA BHAGA AND UPPER YUNAM BASINS
JANKAR NALA
BHAGA R.
YUNAM R.
CHANDRA R.
GLACIER
BOUNDARY OF THE STUDY AREA
MAJOR STREAM
20
0
20 Kilometres

The Chandra and Bhaga Rivers encircle a triangular mass. Some scholars prefer to call it 'median mass'. Many big glaciers, such as Sonapani, Dhaka, Batal, Kulti, Mulkila and Kao Rong are situated here. They continuous melt to feed numerous streams, which ultimately empty into either the Chandra or the Bhaga (*See figure 2*).

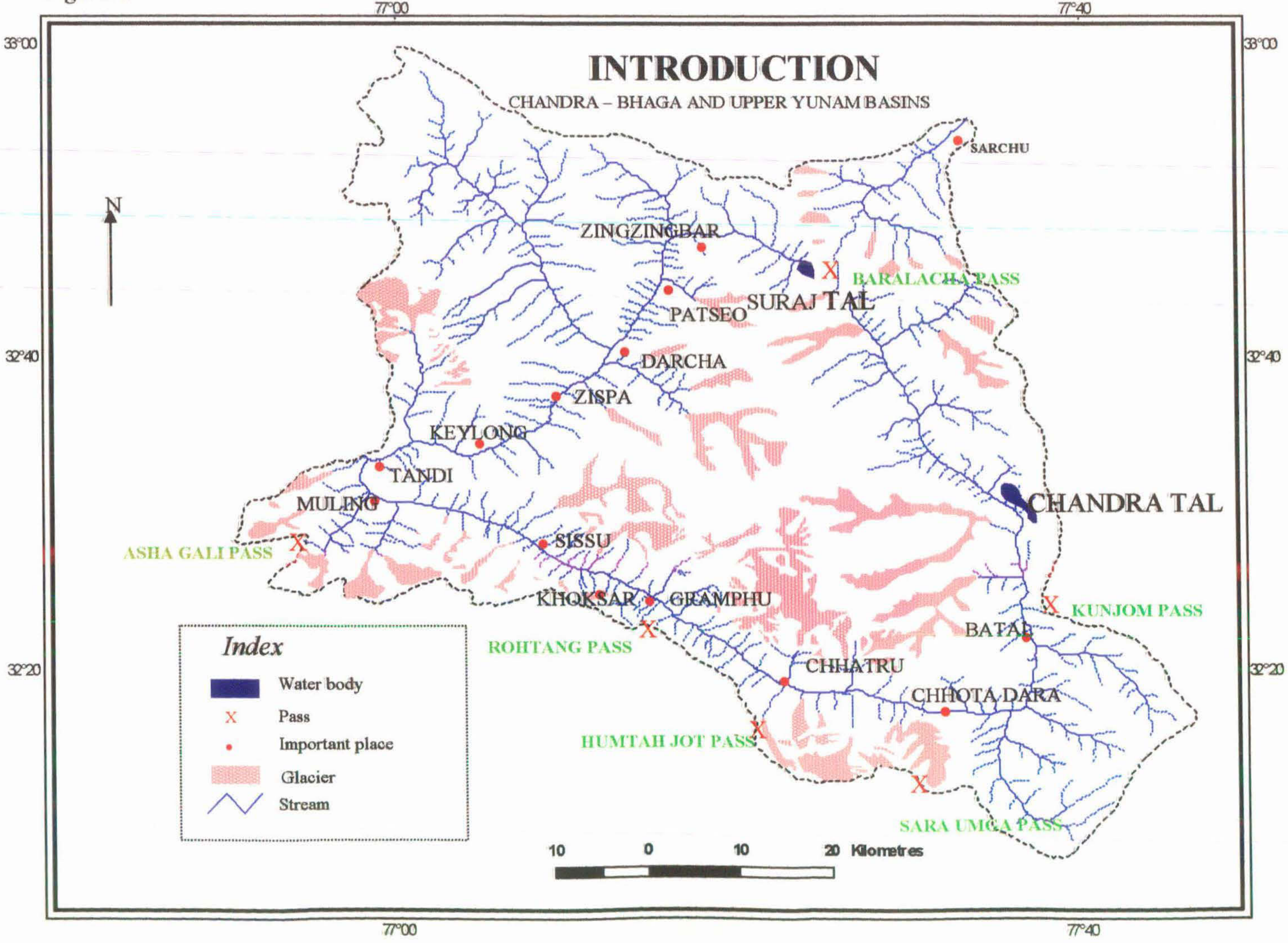
The rivers valleys are flanked with rugged mountain slopes, which are fairly steep and unstable due to the incessant glacial and periglacial activities. These are covered with thick sediment everywhere. One can easily witness the evidences of glacial phases on these slopes. These include glacial trim-line, palaeo-cirque, moraine and hanging valley. Many mountainous streams, flowing down-slope, have deposited small alluvial fans. But most of the fans, found the slopes are sedimentary in nature. Their origin is related with the weathering and slope movement processes (*Plate 1*).

The amount of rainfall is very low, and whatever precipitation occurs, it is in the form of snowfall. The rhythm of season is marked with severe winter and mild summer. Though, the air temperature never goes very high, the days of summer witness scorching sunrays. The southwest monsoon as well as westerly disturbances is responsible for precipitation. The high-pressure gradient makes the climate very windy throughout the year.

## 2.2 PHYSIOGRAPHIC SETTING

The region is separated from other neighboring areas by the arêtes of snow-clad mountain ranges. It encloses an area of 5028 sq kilometres, and has the circumference of 356 kilometres. Its maximum length and breath are about 79 kilometres and 76 kilometres, respectively.

*Figure: 2*

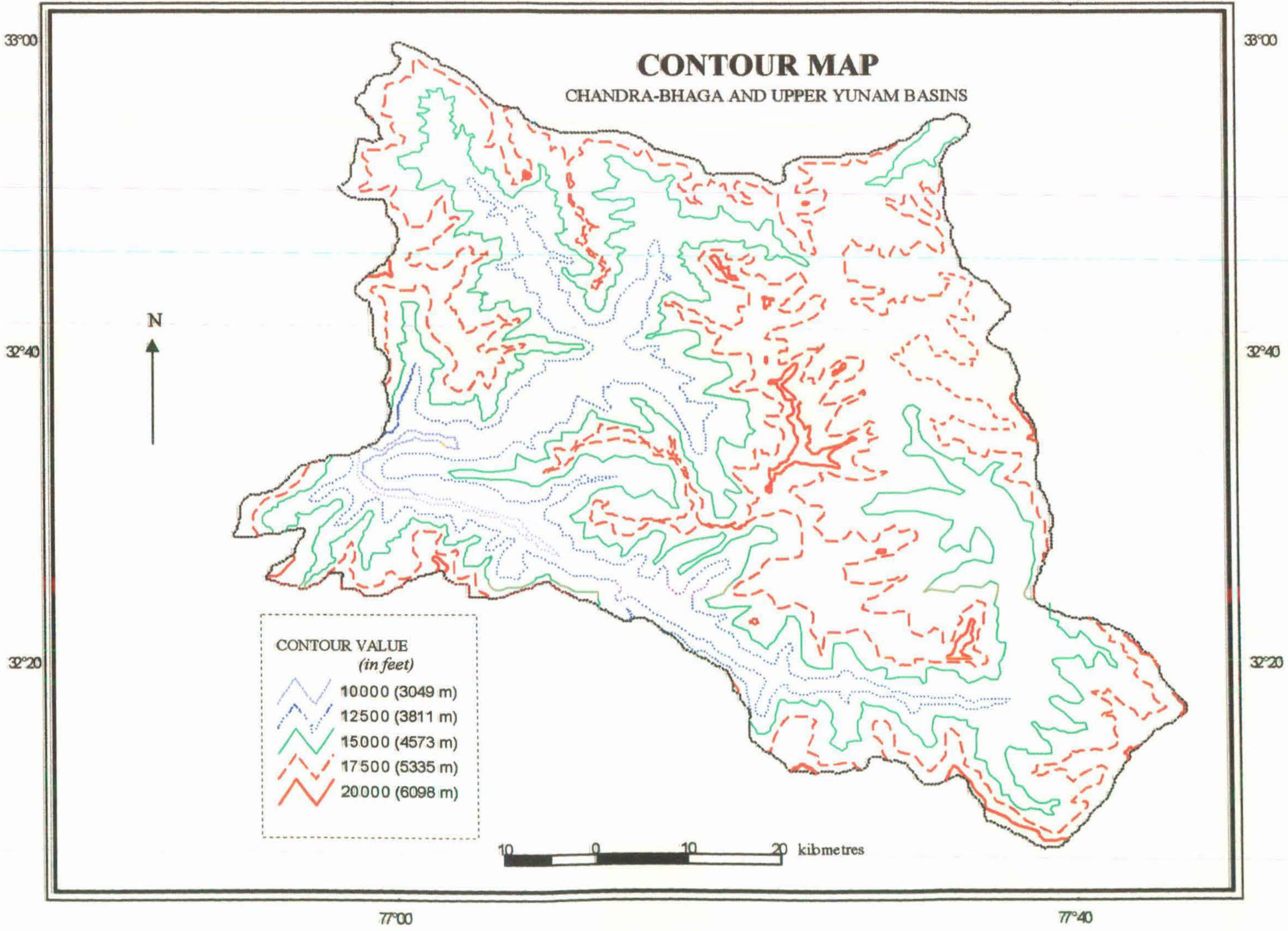

INTRODUCTION
CHANDRA - BHAGA AND UPPER YUNAM BASINS
77°00
77°40
33°00
32°40
32°20
N
SARCHU
ZINGZINGBAR
BARALACHA PASS
SURAJ TAL
PATSEO
DARCHA
ZISPA
KEYLONG
TANDI
MULING
CHANDRA TAL
ASHA GALI PASS
SISSU
KHOKSAR
GRAMPHU
KUNJOM PASS
BATAL
ROHTANG PASS
CHHATRU
CHHOTA DARA
HUMTAH JOT PASS
SARA UMGA PASS
Index
Water body
Pass
Important place
Glacier
Stream
10 0 10 20 Kilometres

The neighbouring regions are Kullu valley to the southeast, Kangra in the south, Laddakh in the north, and Spiti in the east. The lower part of the Lahul administrative division continues to the west of it. Some important passes that lead to the region are Rohtang (3978 meter), and Kunjum (4420 metres). While the former provides entry from Kullu, the latter does the same from Spiti (*see figure 2*). In addition to these, there are some other important passes, like Baralacha (4892 metres), within the region. The Baralacha Pass connects it with Laddakh, and is thus very important, both strategically and otherwise.

The Lahul is peculiar in many senses. The lavishly green landscapes of Kullu, disappears as one crosses the Rohtang (3978). Unlike the densely vegetated mountain slopes of south, one encounters stunted trees and clumps of grasses. The mountain slopes are clean and bare. The vegetation cover becomes thinner and thinner as one moves away from the pass. Much of the region is scrub dominated, with few natural and planted trees along river valleys .The upper portions of both Chandra and Bhaga are completely devoid of trees. Similar is the case with the Yunam basin.

The area has more topographical diversity than Kullu. Highly rugged mountain ranges and narrow river valleys dominate the landscape (S*ee figure 3*). Continuous glacial activity has made the mountainsides look sharp. The peaks are highly pinnacled and thus look very elegant. There is no part of the area that is less than 2890 metres in elevation. The highest part is about 6707 metres high. Much of the area lies between 4878 metres to 6097 metres. Even the source region of all the three streams is located at the height of about 5940 metres.

*Figure: 3*



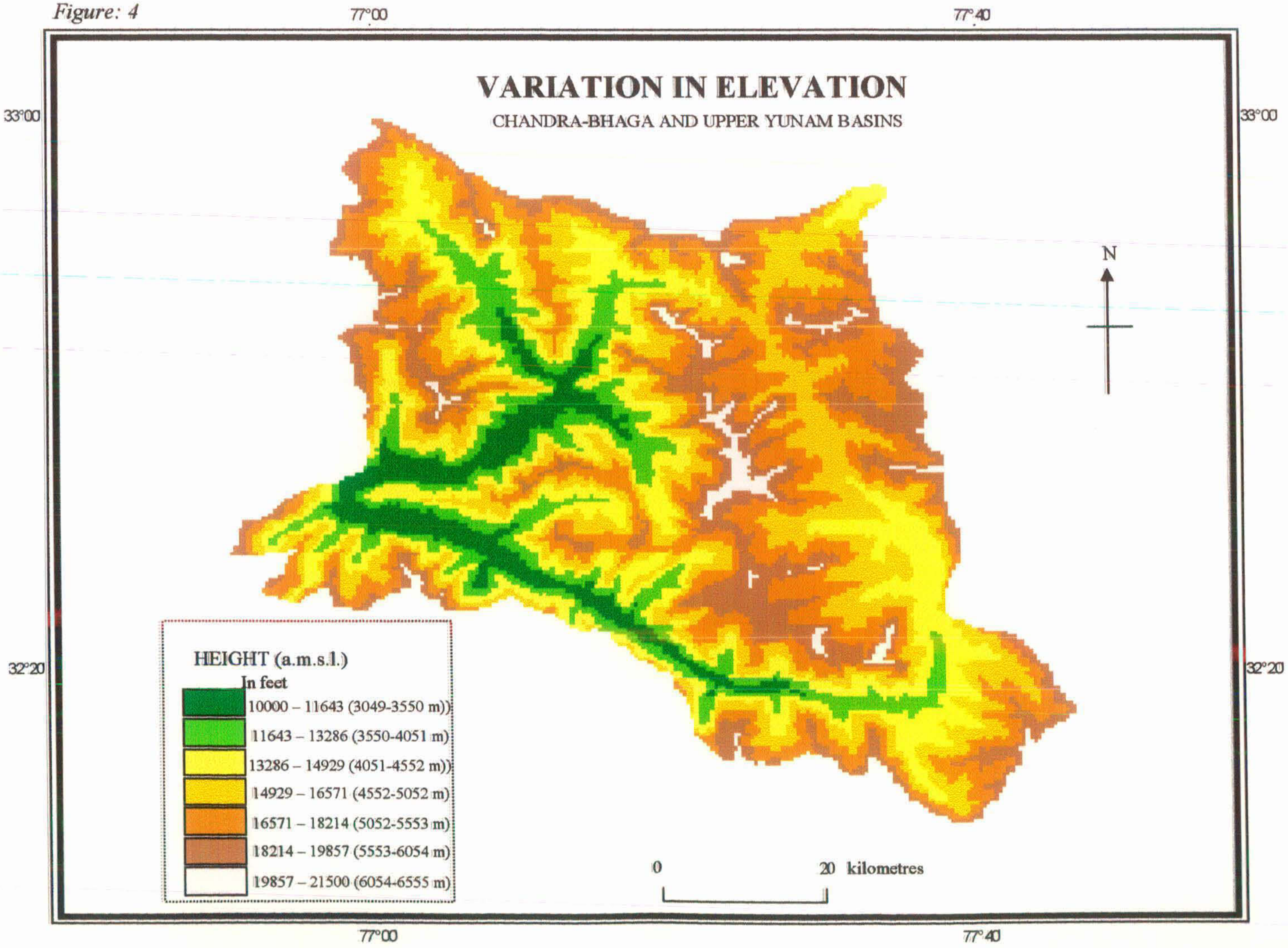
CONTOUR MAP
CHANDRA-BHAGA AND UPPER YUNAM BASINS
77°00
77°40
33°00
32°40
32°20
N
CONTOUR VALUE
(in feet)
10000 (3049 m)
12500 (3811 m)
15000 (4573 m)
17500 (5335 m)
20000 (6098 m)
10
0
10
20
kilometres

The precipitous slope and glaciers provide play a host for processes and landforms. The process of mass wasting is very common natural hazard of this region. The evidences of present and past glaciations are present all over. The landscape is a product of the interaction between different geomorphic processes and varying structural strength of the ground surface. Although the intra-regional physiographic variations are quite large, we could group them into three major divisions (*see figure 4*):

- The River Valleys
- The mountain Ranges.
- Middle slopes

The river valleys of Chandra (136 kilometer), Bhaga (64 kilometer) and upper Yunam (27 kilometres) are the most conspicuous among valleys, along with Jankar Nala (42 kilometer), which although a tributary of Bhaga, is very important. The most of the valleys of the region are still in the early stages of evolution. Their length varies between 5 to 7 kilometres. The tributaries of the Chandra and Bhaga Rivers have carved these small valleys. Their sources lie near the snout of glaciers. The valleys are invariably very narrow. Due to decreasing aridity, they progressively become narrower towards north (*see figure 2*). As these rivers collect water from glaciers, their nature is broadly determined by the behaviour of glacial melt-water. The discharge of melt-water comes from the melting of glacial ice. This melting is in turn determined by temperature that varies considerably, both diurnally and seasonally. Thus one finds wide seasonal and diurnal fluctuation in the discharge of these rivers.

*Figure: 4*


77°00
77°40
33°00
33°00
VARIATION IN ELEVATION
CHANDRA-BHAGA AND UPPER YUNAM BASINS
N
32°20
32°20
HEIGHT (a.m.s.l.)
In feet
10000 – 11643 (3049-3550 m)
11643 – 13286 (3550-4051 m)
13286 – 14929 (4051-4552 m)
14929 – 16571 (4552-5052 m)
16571 – 18214 (5052-5553 m)
18214 – 19857 (5553-6054 m)
19857 – 21500 (6054-6555 m)
0
20 kilometres
77°00
77°40

Likewise the loads of streams are mainly composed of glacial debris (sediment and gravel), which they pick at glacial snouts. As glaciers drops a lot of loose material at their snouts, these streams are heavily loaded and as and when discharge drops (diurnally or seasonally), they starts depositing material mid-way in their courses, resulting into heavy braiding at many places viz. Darcha, Batal etc (*Plate 4*).

A very large part of the area falls within the Great and Middle Himalayan Ranges. These ranges are not a single continuous chain or range of mountains, but a series of more or less parallel or converging ridges intersected by numerous valleys. The axes of most of the ranges, of both the Middle (or Lesser) as well as the Inner (or Greater) Himalayas, are from northwest to southeast. The Pir Panjal, a range of the Middle Himalayas, forms the southern boundary of the study area. The Zanskar, which is a major range of the Inner or Greater Himalayas, is located in the northeastern part, and marks the northern boundary of the Himalayas.

The average height of the Pir Panjal Range varies between 3500-5000 metres; however some of its peaks exceed the mark of 6000 metres. The considerable height of this range has made it a practical barrier, not only to the monsoonal winds, coming from the south, but to the people as well, who seek to enter Lahul from Kullu. Thus, this range could be justifiably held responsible for the relative seclusion of the region from the outer world. The geological study of the region shows that the Pir Panjal, like many other mountain ranges of the Middle Himalayas, is made up of highly compressed and altered rocks of various geological ages. (Sharma, 1986)

The Zanskar range marks the boundary between the Chandra-Bhaga and Yunam basins. It merges with the Pir Panjal Ranges in the east at Kunjum and its average height is 5000 metres. This part of the Himalayas is made up of exceedingly crystalline and volcanic rocks. Because of locational and altitudinal factors, a large number of glaciers with varied dimensions are found here. The Zanskar range is also known for some peculiar land features and processes like 'rock glaciers'. Roche moutonnees_and drumlins are_well preserved in the valleys. The arid environment and altitude of the region is responsible for the lack of trees and thus slopes are covered with sediment cones, of significant depth, but the soil formation process is retarded. There are many evidences of intense periglacial activities in the form of land features such as lobes, patterned ground, aprons etc.

## 2.2.1 PHYSIOGRAPHIC DIVISION

On the basis of intra regional variations, the study area could be divided into six physiographic units. These are quite distinct from adjoining areas. Their names are given as follows:

- The Central Triangular Mass (or Median Mass)
- The Mountain Ranges
- The Chandra Valley
- The Bhaga valley
- The Jankar Valley
- The Yunam Valley

### 2.2.1.1 THE CENTRAL TRIANGULAR MASS

It is an interesting physiographic unit, enclosed by the Chandra and Bhaga from all sides. It comprises about one-fourth of the total study area and plays a very significant role in the origin of many streams of glacial origin. Many glaciers are found here which are the perennial sources of water, and that's why, even small streams of the region do not go dry at peak summers. The noticeable among all glaciers is the 'Samudri', which is located on the right bank of the Chandra River, opposite to the Chandra Tal. There are two branches of the glacier. Although both of its branches are almost of equal length (almost 17 kilometres each), yet the northern one is slightly bigger than the southern one. There are other important glaciers and most of them feed Chandra, as mentioned earlier.

The major axis of the Central Mass is from southeast to northwest. The length of this axis is almost 60 kilometres. From north to south, the maximum length is 44 kilometres, likewise the maximum breadth; from west to east is about 50 kilometres.

### 2.2.1.2 THE MOUNTAIN RANGES

The description of mountain ranges has already been dealt with earlier. These ranges confine the river valleys and thus look like rampart from terraces. The spurs of these mountains are truncated at various places. An important expression of these ranges is in the form of passes, which are locally known as 'la'.

The Rohtang Pass (3978 metres), as mentioned earlier, connects Kullu with Lahul. Its economic as well as climatic significance is well noted. It connects in fact two completely different environmental regimes. Everything, visible over the surface, changes across the pass.

The Kunjum Pass (4420 metres) connects Lahul with Spiti. It is the only important connection between these two regions. Near the pass the Pir Panjal merges with the Greater Himalaya.

The Baralacha Pass (4892 metres) lies within the study area. Its location is in the far north-northeast of the Lahul district. This pass is a host of glacial landforms and source of all the three important streams i.e. Chandra, Bhaga and Yunam. A fantastic, as well as extensive (250 sq kilometres) plain area, known as Lingti Maidan (*Plate 13*) is located here. River Yunam has incised its previous banks to give rise to a spectacular canyon (abut 100m × 100m). Despite the natural beauty of the plain area, it could not have intensive use, as the inhospitable climate discourages settlement and agriculture. The plain is used as a grazing land, by Gaddi (a native tribe involved in the occupation of nomadic herding).

### 2.2.1.4 THE CHANDRA VALLEY

The Chandra River is the largest river (136 kilometres) of the region. After its origin at the Baralacha (4892 metres), it flows towards southeast, till it reaches Batal. There it starts turning westward, and by the time it reaches Chhota Dara, its direction gets completely changed towards west-northwest. Thereafter no major change in its flow-direction is observed as it flows along the weaker geological line between the Pir Panjal and Great Himalaya. The initial course of the stream is antecedent on the mountain grains.

The Central Triangular Mass, located to the west of the river, has many large glaciers that feed the river. Some important among them are Samudri, Bara Shigri, Dhaka etc.

The glacial melt water reaches the stream through small channels, which are numerous on its right bank.

A long stretch of the Chandra valley, from its source (at Baralacha, 4892 metres) to Gramphu, is completely uninhabited. The extreme altitude, aridity and lack of vegetation, discourages settlement growth. The length of this stretch of the Chandra valley is about 95 kilometres. This forms more than two third of the river-valley which is devoid of permanent settlement. Below Gramphu, the climate becomes more conducive and thus favours settlement growth. The lower part of the Chandra valley is greener than the upper stretch, which is devoid of soil, vegetation. The most of the settlements along the valley has developed on fluvial and glacio-fluvial terraces. The right bank of the river is generally wider where the majority of settlements and cultivable land are found.

A very beautiful lake (Chandra Tal) is located on the left bank of the river, near Batal. It is about a kilometer long and half a kilometer wide. The lake is situated in between a low ridge (to its right) and the Kunjum range (to its left). The rock bars and roche moutonnees have been responsible for its evolution. Its elevation is more than 4400 metres.

### 2.2.1.4 THE BHAGA VALLEY

The Bhaga River also originates at Baralacha, at an altitude of about 4800 metres. Initially its course is towards northwest, but later it swiftly turns towards southwest, near Zinzingbar. The upper course of the valley is barren like that of the Chandra. It is narrow as well bounded by talus fans, cones, scree cones. The valley opens at Darcha-

Sumdo, a village where Jankar Nala meets Bhaga where Jankar Nala and Yoche Nala confluence with the Bhaga. This place is important in many senses. It is where the aridity of the upper Bhaga valley gives way to fairly lush vegetation of blue pine, Juniper and birch. The inhabited area, with planted tree species of Willow and Poplar, begins here and continues down-valley. The right bank of the valley is more conducive for the growth of settlement as it is broader and flatter than the left bank.

The total length of the Bhaga valley, from its source at Baralacha, (4892) to the point of its confluence with Chandra is about 64 kilometres. The streams, emanating from the glaciers of the Central Triangular Mass, feed the river. These streams are found mostly on the west bank of the river. The important right bank tributaries include Jankar and Biling Lumpa. The later has its source in Gangstang glacier.

### 2.2.1.5 THE JANKAR NALA

This is an important tributary of Bhaga. The immensity of its basin size is the basis for identifying it as a separate physiographic unit. It originates in the northwestern extremity of the study area and flows towards southeast. It has many tributaries that meet it from both the sides. The length of the valley is 42 kilometer. It is almost uninhabited except for two villages; namely Rarik and Chhika.

### 2.2.1.6 THE YUNAM VALLEY

This valley originates from Baralacha and extends northward, until it meets Tsharap Chu (a tributary of Indus). It travels through Trans-Himalayan zone that is known for its geomorphic complexities. Numerous moraines and large planes are found here.

This study covers only the upper part of the basin. A place, called Sarchu, marks the northern limit of the study area. Extremely arid conditions and very high elevation are noticeable throughout the valley (*see figure 3*). Various geomorphic complexities of landforms have made it a geomorphic puzzle with canyons, moraines, erratics and mis-fit rivers.

## 2.3 GEOLOGY

Although, geology is never the main focus of any geographical study, its knowledge is essential for better appraisal of landform evolution and soil genesis. The knowledge of geology provides us with the information of the type of 'structure', which, to a large extent, decides the nature of landforms evolution and effectiveness of geomorphic processes. It is one important controlling factor of landform evolution.

The geology of the area is not very dissimilar to other Himalayan regions. The stratigraphic set-up of the region, which was provided by Sharma (1986) on the basis of various publications of G.S.I (Geological Survey of India), is given below:

TABLE: 1

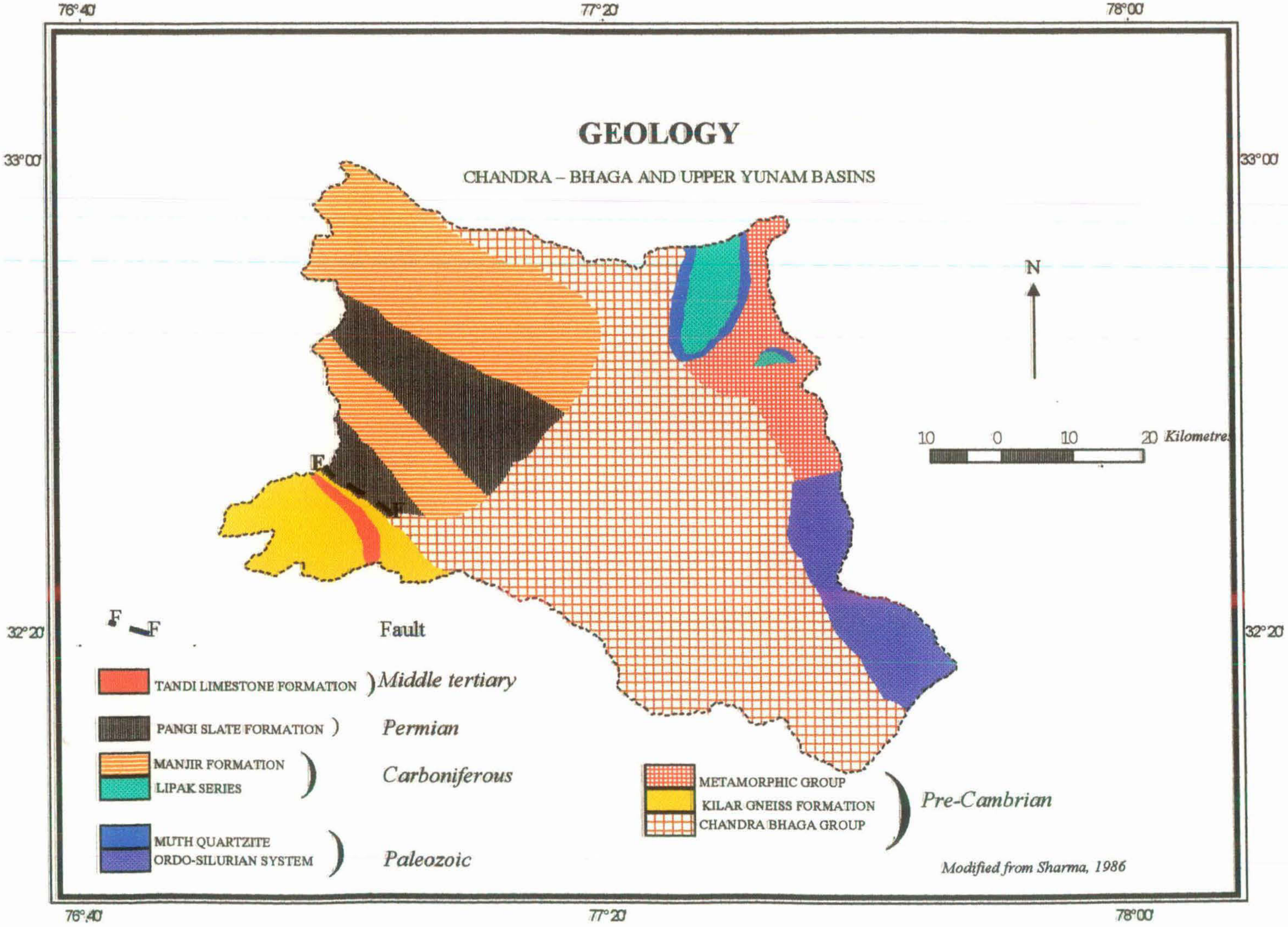
| *System* | *Rocks* | *Geo.Time* |
|---|---|---|
| Recent Formation | Soils, scree, valley fills | Holocene |
| Pleistocene Formation | Moraine, glacial till, lacustrine deposit, U-shaped valley etc. | Pleistocene |

| | | |
|---|---|---|
| Tandi Limestone Formation | Grayish white and cherty white limestone intercalated with phyllite, slate, quartzite and calclutites | Mid Triassic |
| Pangi Slate Formation | Gushal member: Greyish green slates and phyllites with occasional quartzite bands<br>Kugti member: Grayish green micacious quartzites with grit bands and lazutite bearing granite veins | Permian |
| Manjir Formation<br>&<br>Lipak Series | Pebbles, boulders bearing slates and quartzite with locally intrusive biotite, granite veins, dolomite<br>Muth Quartzite, shale siltstones bedded crystalline limestone | Carboniferous |
| Ordo-Silurian<br>&<br>Muth Quartzite System | Sericitic quartzite, porphyritic granite, amphibi~~otite,~~ olite silt, biotite, whitish quartz, silica and recrystallised carbonate limestone bands | Paleozoic |

| *System* | *Rocks* | *Geo. Time* |
|---|---|---|
| Metamorphic Group | Ch~~o~~lo~~a~~rite, biotite garnet, staurolite and kyanite bearing schist, c~~h~~alc~~e~~silicate bands, and lenses, biotite and tourmaline bearing granite, amphibolites and grabbo | Pre-Cambrian |
| Killer Gneiss Formation | Augen, granite and gneiss with roof pendents of the older metamorphics, and xenolites of ~~pf~~ older formation | |
| Chandra Bhaga Group | Metamorphosed arenaceous sediments sericite quartzite, slate, phyllite, schist, crystalline limestone, dolomite quartz, schist, migmatites and gneiss | |

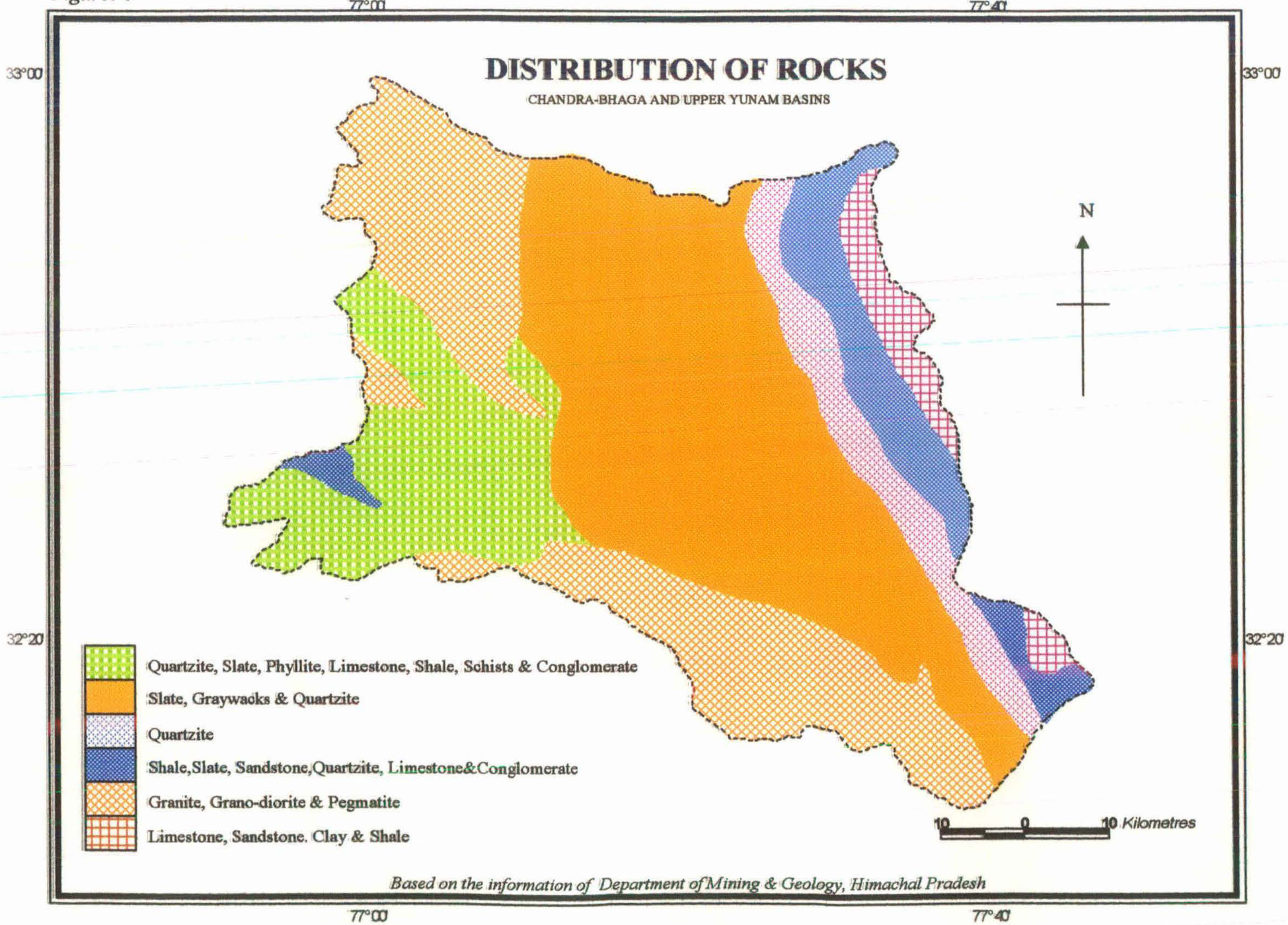
(*See figure 5 & 6*)

*Figure: 5*



Modified from Sharma, 1986

*Figure: 6*



*Based on the information of Department of Mining & Geology, Himachal Pradesh*

## 2.4 CLIMATE

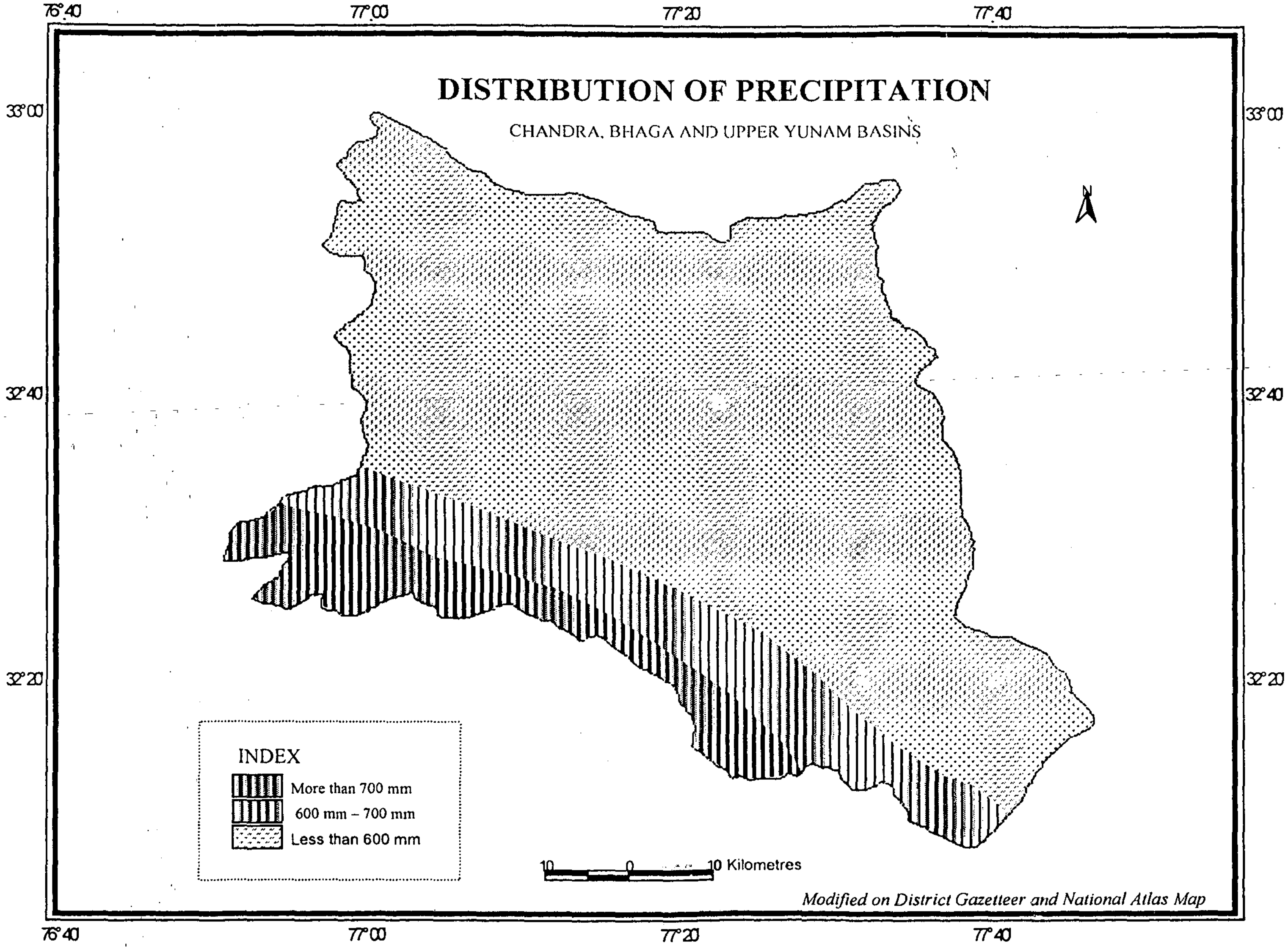
Aridity, along with the wide range of fluctuations of temperature is common in, Lahul. The climate is dominated by a long winter season from mid November to March, with a spring season that lasts until the end of May. Summer extends to the end of September, with October and early November being a short autumn season. The most of precipitation falls as snow in winter with little during the monsoon months from June to September (Sharma, 1986). Its climate could be explained by mainly two factors – the arrangement of the mountain ranges and high elevation of the region as a whole (*See figure 7*).

The Pir Panjal Range, as the southern boundary of the region, blocks the path of southwest monsoon, resulting into heavy rainfall on the southern slope of it. The entry of S-W monsoon wind into the region is restricted through some selected openings (e.g. Rohtang Pass) in the mountainous rampart of the Pir Panjal. As the wind has to rise to a considerable height, in order to pass through these passes, the adiabatic cooling robs it of much of its moisture. Thus the area located to the north of it experiences very small amount of monsoon rain. The wind coming from Mediterranean Sea, in the form of western-disturbances, is responsible for maximum precipitation (in the form of snowfall) in winter season.

### 2.4.1 PRECIPITATION

The official figures on the climate of the area are available for Keylong, which is located near the confluence of Chandra and Bhaga. But this data could not be generalized, due to high topographical variations of the region.

*Figure: 7*


76°40
77°00
77°20
77°40
33°00
32°40
32°20
DISTRIBUTION OF PRECIPITATION
CHANDRA, BHAGA AND UPPER YUNAM BASINS
N
INDEX
More than 700 mm
600 mm – 700 mm
Less than 600 mm
10 0 10 Kilometres
Modified on District Gazetteer and National Atlas Map

The District Gazetteers of Lahul and Spiti, gives the mean monthly precipitation figure for Keylong weather station:

Average Annual: 55.46 mm (millimeter)

TABLE: 2- Monthly Breakup of Precipitation (in mm) ?

| | | | | | |
|---|---|---|---|---|---|
| *January* | *February* | *March* | *April* | *May* | *June* |
| 58.7 | 61.7 | 101.9 | 78.7 | 55.9 | 22.9 |
| *July* | *August* | *September* | *October* | *November* | *December* |
| 33.3 | 33.0 | 32.1 | 20.8 | 7.4 | 26.2 |

The amount of precipitation shows that the climate is semi-arid. While March has the largest share in the monthly distribution, the month of November is the driest month. The table shows that the monsoon months from June to September do not have any important contribution in the total amount of annual precipitation. The notable contribution comes at the time of late winter and spring, under the influence of western disturbances. On an average, there are 50 rainy days (i.e. the days with rainfall of 2.5 mm or more) in a year at Keylong.

## 2.4.2 TEMPERATURE

The eastern part of Lahul is known for severe winter and mild summer. There are mainly two factors, high elevation of the area and presence of many huge glaciers, which are responsible for low temperature, throughout the year. Though there is no official record of temperature for the distant past of the region, yet one can get some inferences of climate from the available historical records (Sharma, 1986).The District

Gazetteers of Lahul and Spiti, displays the following temperature table, for Keylong, showing mean monthly temperature (in °C)

Annual Average Temperature: 6.2

TABLE: 4-Monthly Breakup of Temperature: 2

| *January* | *February* | *March* | *April* | *May* | *June* |
|---|---|---|---|---|---|
| - 4.9 | - 5.85 | -2.0 | 3.7 | 10.6 | 14.4 |
| *July* | *August* | *September* | *October* | *November* | *December* |
| 16.05 | 16.7 | 13.45 | 8.86 | 4.3 | -1.0 |

The record of the table shows that the months of July and August experience the maximum temperature. The months, from May to September have pleasantly high temperature. The temperature goes below the freezing point in the months of December, January, February, and March. The life comes to a standstill in these months. The months of October and November falls in the period of transition, from summer to winter.

On the basis of varied climatic conditions, Sharma (1986) has divided the region into four broad groups- sub-tropical warm temperate zone (below 2500 metres), sub-tropical cool temperate zone (2500-3500 metres), cold zone (3500-4500 metres), and glaciated zone (above 4500 metres).

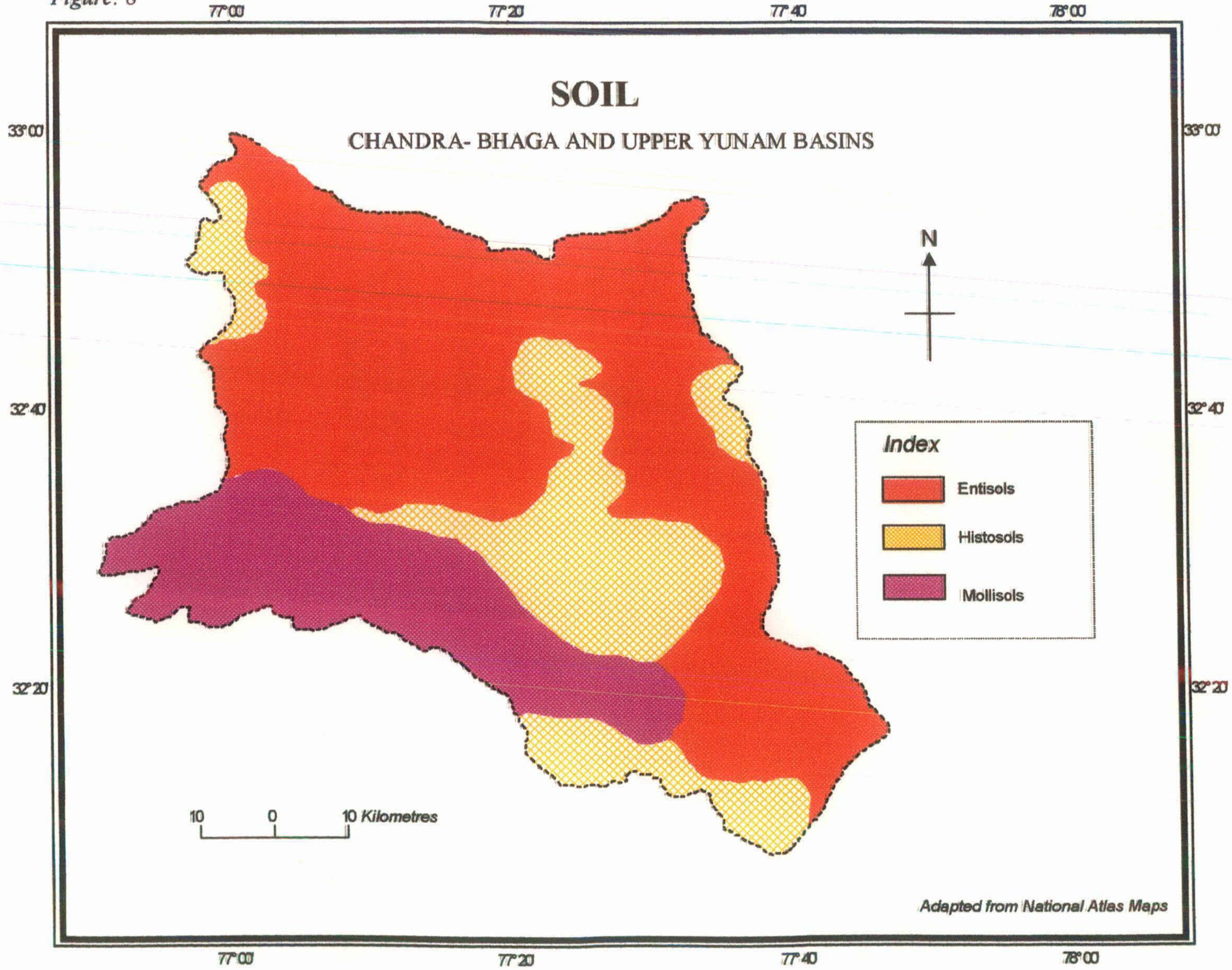
## 2.5 SOIL

The soils of the region are rather known for their, infertility and shallowness, than productivity. Like any other mountainous area, the soils are gravelly and immature. It can be broadly divided into three groups: Mollisols, Histosols, and Entisols (*See figure 8*).

The Mollisols is a 'mountain-meadow' kind of soil. Its share in the total area of the region is about one fifth. This soil is found in the southwest, along the Chandra River. The other important soil type is Histosols. Although, it constitutes about one fourth of the total area, it is literally good for nothing. This kind of the soil is found near glaciers. But the most extensive soil is Entisols. It covers a little more than half of the total area. The northern part, not covered with glacier ice, has this type of soil.

The soils are gravelly loamy sands to loam, usually neutral in soil reaction. The availability of phosphorous and potassium (derived from muscovite of schist) is average to high. The abundance of mica and schist rocks has produced siliceous and aluminous soils, which are generally characterized by stiff red clay. The soils lack some important elements, e.g. lime, magnesia, phosphorous and nitrogen. The area of shale, phyllite and slate are covered with thick mantle of soil, as these rocks are soft and thus prone to decay and disintegration rather easily. These areas are conducive for vegetation growth (Statistical Outline of Himachal Pradesh, 1981).

*Figure: 8*



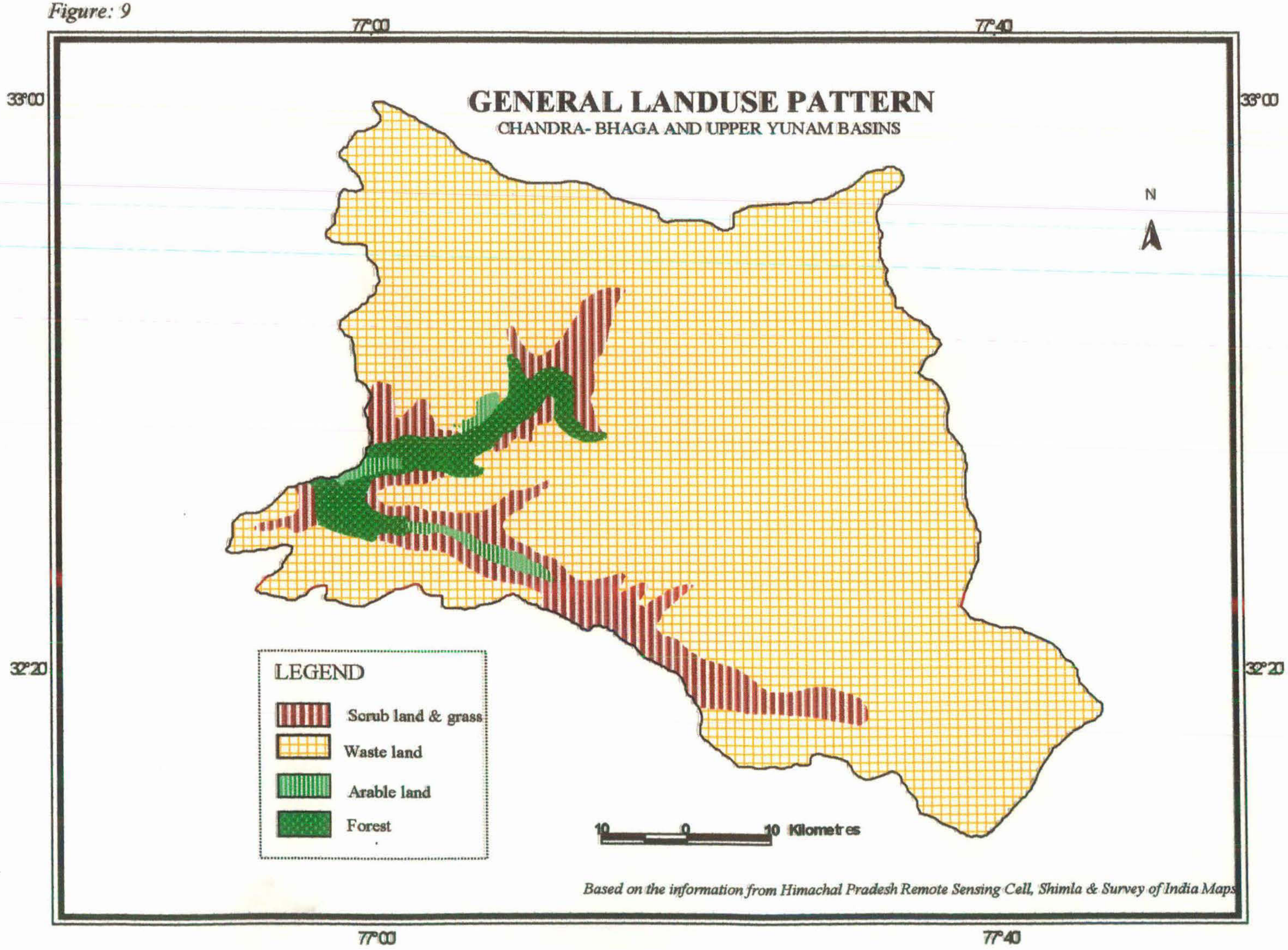
*Adapted from National Atlas Maps*

## 2.6 VEGETATION

If we go by the Koppenian wisdom that the vegetation is nothing, but a manifestation of the climatic conditions of a place, we could easily guess the types and conditions of plants and trees in the region. On an average, vegetation is thin, and that too, is confined to a few locations (*See figure 9*). The physiographic conditions do matter in the determination of vegetation as it affects the amount of precipitation received at a place, in a year. Besides, it determines the temperature regime of the place. The other less important factors controlling vegetation are soil and slope. Only four percent of the area is under tree cover. This figure is very low by any standard. Even that cover is confined to the south and west only. The remaining parts have shrubs and lichen growth in the name of vegetation. The mountain slopes, generally devoid of vegetation, are very vulnerable to mass wasting. Even the artificial planting of trees on these slopes is not feasible. The severity of climate seems to be well determined to frustrate any drive of this kind.

The growth of tree is very poor and slow and the flora is of dry temperate to dry alpine type. It is of the Central Asiatic Siberian character. Sharma (1986) has divided vegetation types into three altitudinal zones; the first extending from 2450 metres to 3550 metres contains mixed vegetation. The trees found here are juniper, blue pine, birch, willow, poplar, spruce, walnut etc. From 3550metres to 4850metres, the zone of alpine vegetation is found. This zone lacks fully-grown up trees. Some of the trees (viz. juniper, birch, and rhododendron) are found in the form of shrubs and that too up to the height of 4250metres. The beautiful flowering plants and large tracts of open grasslands are the peculiarities of this zone.

*Figure: 9*



*Based on the information from Himachal Pradesh Remote Sensing Cell, Shimla & Survey of India Maps*

The upper most vegetation zone (above 4850 metres) in this scheme of division is almost non-existent. Only some micro plants and lichens are found here.

## 2.7 RELIEF

The incessant work of indogenetic and exogenetic forces, continuously fashion (and refashion) the surface configuration. But, equally important factor, in this respect, is the local 'structure' of a place. The interaction between them gives rise to various landforms, at any particular point of time. The irregularities of the surface vary spatially as well as temporarily, depending upon the nature and relative strength of the affecting factors, mentioned above.

The concern here is to describe and analyze the earth's surface of the study area, as objectively as possible. The morphometric analysis, used by Sharma (1986) for the study of Lahul, has been resorted to, for present purpose. This is based on the uniformed grid method.

### 2.7.1 ABSOLUTE RELIEF

In simple words, it is the vertical elevation of a region from the mean sea level. It's dominating role in determining the vegetation, climate, and many other attribute of the area has been discussed earlier.

The elevation of the area is fairly high everywhere (*See figure 3 & 4*). The river valleys are relatively low than the other parts. Despite this, the valleys are higher than 1000 feet (3049 metres) at most of the places, except in the extreme west. These valleys belong to the Chandra and Bhaga. The share of the area, which is lower than 1000 feet (3049 metres) for the entire region in the total area, is less than 1%.

The elevation range of 10,000 (3049 metres) feet to 15,000 feet (4573 metres) has a considerable share i.e. 32%, in the total area. This is also confined to the valleys of the rivers. All the major rivers (Bhaga, Chandra, Jankar, and Yunam) of the region have their valleys in this range. The lower portion of the Yunam valley, almost the whole of the Bhaga and the Jankar valleys, and much of the Chandra valley (except its upper part) fall in this range.

The most extensive elevation range is 15000 feet (4573 metres) to 20,000 feet (6098 metres). Its share in the total area is almost 62%. The margin of the study area and the Central Triangular Mass (a part of the Zanskar Range) are included in it. The most of the mountain passes are found in this range. The area towards the upper limit of it is snow-clad and has glacier cover.

Some parts of the study-area are more than 20,000 feet (6098 metres) high. But its share in the total area is merely 2%. Location wise, it is either located along the watershed boundary of the streams or in the Central Triangular Mass.

The mean height of contours is 17693 feet (5394 metres). Its minimum and maximum values are 10000 feet (3049 metres) and 21500 feet (6555 metres) respectively. The maximum elevation is found in the northeastern part of the region, near Mulkila glacier. This is a clear evidence of very high absolute relief of the study-area.

## 2.7.2 RELATIVE RELIEF

While the absolute relief shows the variation in elevation of a surface from the mean sea level, the relative relief is concerned with local variations in elevation. It is defined as the difference in elevation, of the highest and the lowest point, in a given area. It is a more significant aspect of an area, than the absolute relief.

There are many factors (e.g. absolute relief, climate, geomorphic processes, lithology, slope etc.) that affect the relative relief of the area. Here the analysis of relative relief should be done in the context of the Himalayan orogeny. As the study area is largely a part the Himalayan Mountains, which is young and imposing, accordingly the relative relief is very high. This study is based on uniform grid (one square inch) calculation. The values thus obtained, has been divided into five classes, for description and analysis purpose (*See figure 10*).

Unlike absolute relief, it is more prominent in the western part of the region, where the Chandra and Bhaga have considerably dissected the landscape. All those pockets, which have been little disturbed by the gradational forces, have very low relative relief. This observation is compatible with the contention of W.M. Davis, which states that the relative relief increases as an area approaches the stage of 'maturity'.

The lowest relative relief i.e. below 3000 feet (915 metres) is found in two different parts and covers about 5% of the area. The first one is located to the southeast of the Baralacha Pass (4892 metres), and forms the eastern side of the Central Triangular Mass. Lack of powerful stream, aridity and rigid structure help stop considerable erosion. This is the area where the source of Chandra is located and the river does not look mighty. The other part is situated in the northwestern extremities of the study area. The Jankar Naia, the most important tributary of the Bhaga, has its origin here.

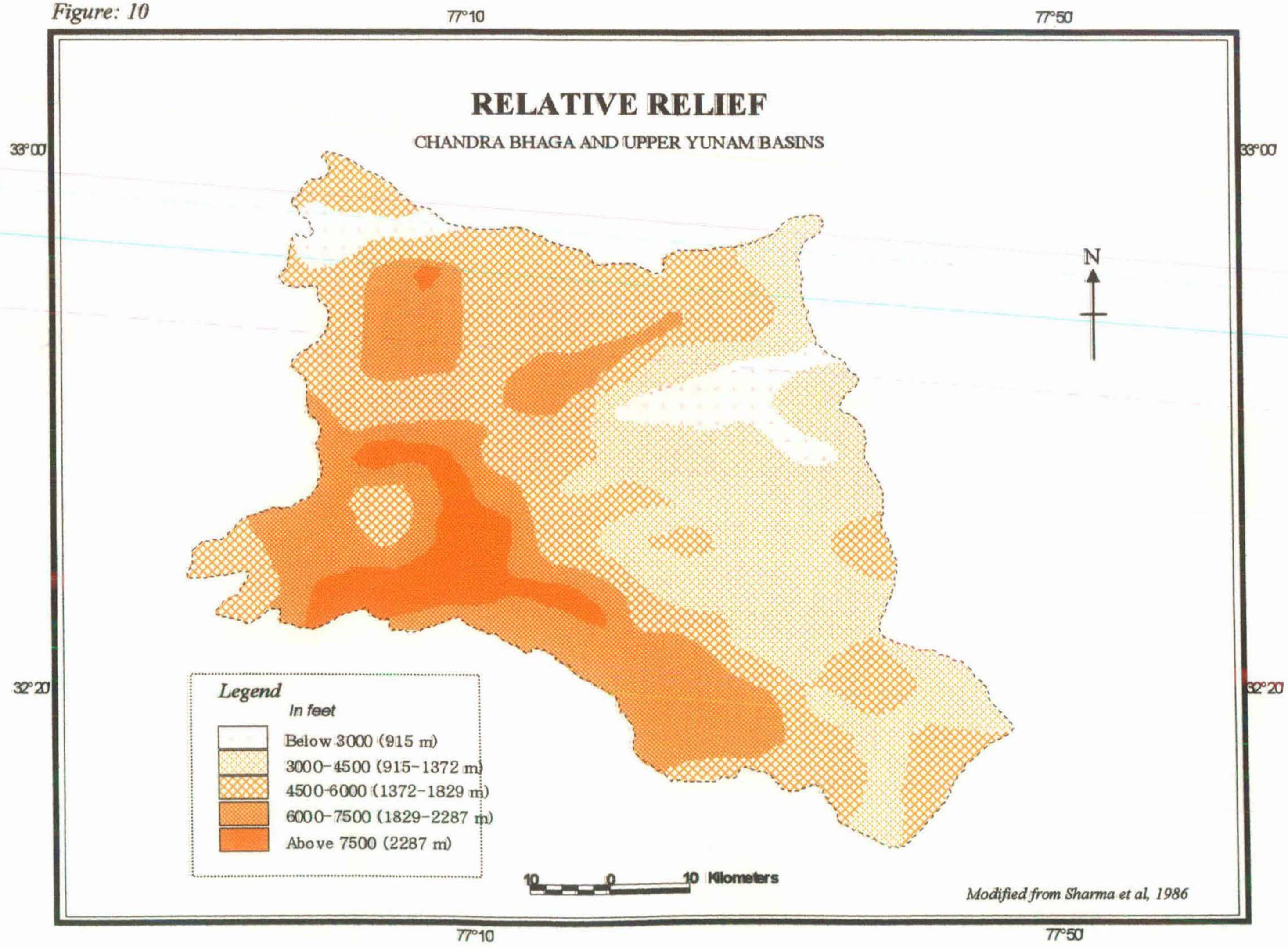
The second lowest class i.e. 3000 feet-4500 feet (915 metres - 1372 metres) of relative relief covers 27% of the total area. It encompasses about three-fourth of the Central Triangular Mass (mainly the eastern part). The lower valley of the upper Yunam is also included in this range. Rocky surface and the presence of glaciers are the reasons for less dissection of these parts, with little relative relief per unit area.

The range of 4500 feet-6000 feet (1372 metres- 1829 metres) has the largest share of 39% in the area. The western and southern fringe of the Central Triangular Mass and much of the upper Bhaga and Jankar valleys fall into this category. It represents minor dissection of surface by streams.

Another important category of relative relief is 6000 feet - 7500 feet (1372 metres – 2287 metres) and it has a share of 22% in the total area. It is almost continuous along the Chandra valley, from a little west of Chhota Dara to its confluence with the Bhaga at Tandi. A less extensive area, which falls in this category, is located in the lower half of the Bhaga. A large area of this category is found along the Chandra. Middle Jankar valley is the other area under this category.

The maximum relative relief of more than 7500 feet (2287 metres) is found in the lower valleys of the Chandra and Bhaga, but not along their channels. About 7% of the area comes under it. One can observe that the highest relative relief occurs in the region of minimum absolute relief.

Figure: 10



*Modified from Sharma et al, 1986*

## 2.8 AVERAGE SLOPE

Slope is defined as an inclined surface. It has two components, the angle of inclination (or gradient) and length. The gradient of slope is its angle of inclination from a horizontal surface and the distance from its crest to its foot is called its length.

The analysis of slope could be done through many techniques, but the method devised by Wentworth (1930) is the most commonly used. The analysis of slope, in this study, is based on his method, using the following formula:

$$Tan\ Ø = (N \times CI)\ 3361$$

Where,

N = number of contour crossings in a grid of one square unit

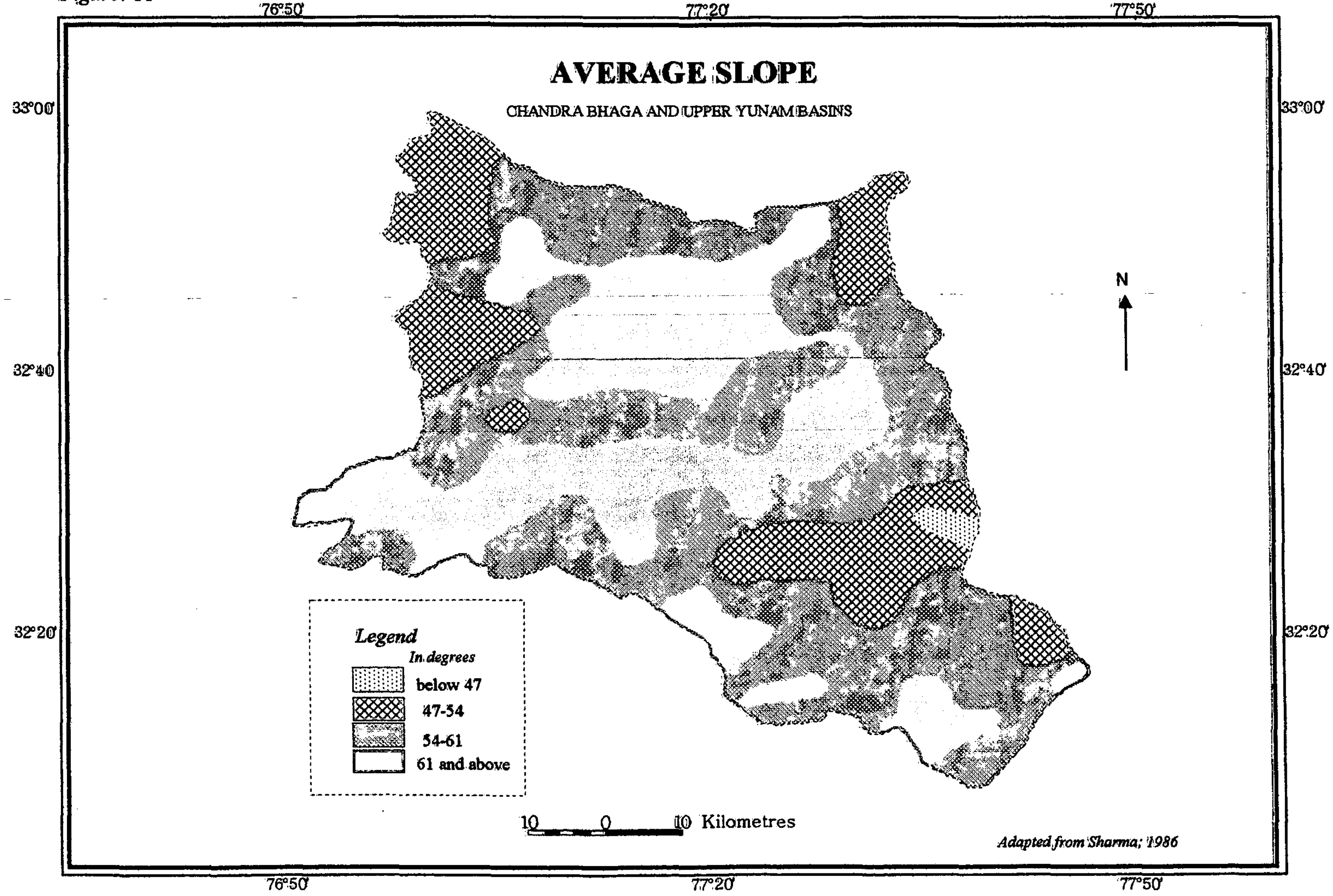
C.I. = contour interval

3361 = constant

The slope values have been then classified into four groups for convenience in analysis. The variation in slope is about 14°. The lowest average slope, i.e. below 47°, is found in a very small area, located to the north of Batal and Kunjum Pass. It contributes about 0.6% in the total area (*See figure 11*).

The second class, which ranges from 47°-54°, has a fair share of 16% in the total area.

*Figure: 11*



*Adapted from Sharma; 1986*

It is found in the western and northwestern parts of the study area, as well as, in its southeast (near Batal). A small patch is located in the lower valley of Yunam. In all the cases, it is found near the boundary of the region.

The two higher-value classes (54°-61°, and more than 61°) cover 57% and 26% of the total area. Collectively, they control a little more than four fifth of the total. This is an evidence of very high degree of slope.

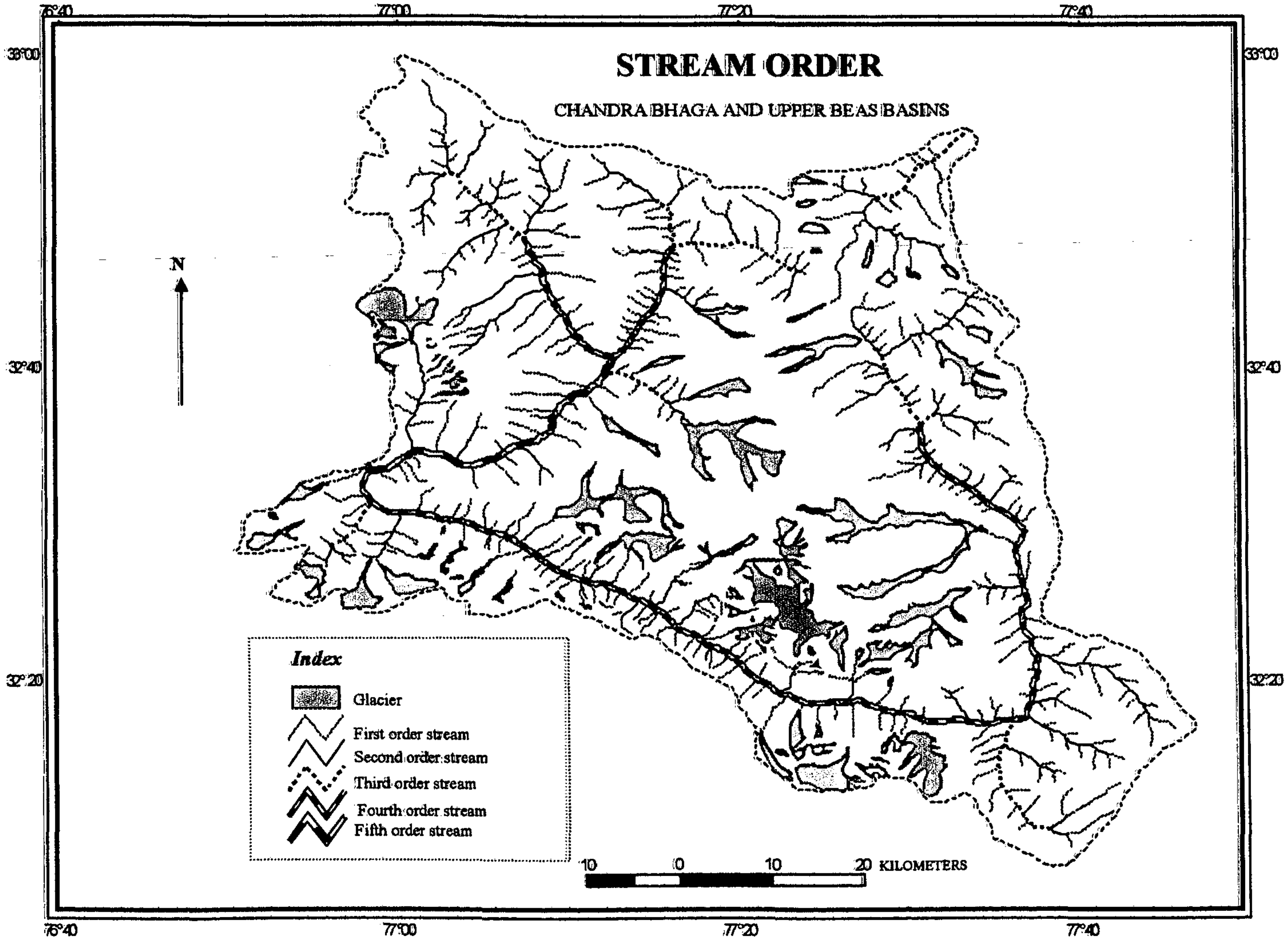
After studying the various relief parameters as above one can say that their values are very high. In most of the cases, higher values of different parameters are found in same areas. We could safely arrive at the conclusion that the evolution of this region is in the early stage of evolution, and the landforms are still very young.

## 2.9 DRAINAGE ANALYSIS

The importance of river lies in the fact that it is the most important land-sculpturing agent of gradation. Although a large part of the study area is covered with glaciers and its climate is semi-arid as well, yet streams have made their presence felt as a natural agent of gradation. The fluvial process considerably affects the southwestern part of the area. The valleys of Chandra, Bhaga, Jankar, and Yunam seem to be the axes of erosion (*See figure 12*).

The longest and the most important river of the region is the Chandra. Much has already been described about the river. Although there are more than 150 tributaries of Chandra yet, only few among them are 'not small' e.g. Topoyogma, Topokoma, and Karcha Nullah etc.

*Figure: 12*



STREAM ORDER
CHANDRA BHAGA AND UPPER BEAS BASINS
N
76°40
77°00
77°20
77°40
33°00
32°40
32°20
Index
Glacier
First order stream
Second order stream
Third order stream
Fourth order stream
Fifth order stream
10
0
10
20 KILOMETERS

The average fall of Chandra is 12.5 metres per kilometer (Sharma, 1986). There are many glaciers that feed the river, with their melt-water. Among the major glaciers on its right bank are Samudri, Dakka, and Sonapani. The glaciers on its left bank are Bara Shigri, Chota Shigri, Hamta, and Chandra Ketu.

A beautiful lake, named Suraj Tal, is the source of the Bhaga River. It is located near Baralacha Pass (4892 metres). Its major tributaries are Jankar Nala, Yoche Nala and Milang Nala. Another important tributary, which meets it ~~meets it~~ near Keylong is Biling Lumpa. The Bhaga has an average fall of about 28 metres per kilometer (Sharma 1986) and its tributaries are more than 60 in number.

That part of the region, which is located to the north of the Baralacha Pass (4892 metres), is drained by Yunam River. It drains an important area called Lingti Maidan-an extensive plain that is a well-known pastureland in the otherwise barren topography. After confluence with Lingti Chu (not included in this study), it's known as Tsarap Chu, a tributary of the Zanskar River, which in turn is a tributary of the Indus.

## 2.9.1 DRAINAGE PATTERN

Drainage pattern refers to the particular plan or design, which the individual stream courses collectively form (Thornbury, 1954). The spatial relationship of stream courses, give an indication of the climate, structure and topography of the area. The drainage pattern here hasn't developed well, as the region is still in the first stage of evolution and the semi-arid climate does not favour stream development (*See figure 12*).

The streams are parallel to sub-parallel at many places. But the pattern looks more like dendritic than trellis. One thing is for sure that the whole design of the stream courses of this region could not be described by any single pattern. The sharp bends in both the major streams, the Chandra and Bhaga, indicate that the control of structure on the course of streams may be substantial at some places. At most of the places the courses of streams do not bend around spurs. In fact the spurs were truncated in order to make valleys straighter during the phases of glaciations. The drainage pattern will gradually develop to become more elaborate as the region progresses towards maturity.

### 2.9.2 STREAM FREQUENCY

Stream frequency is the number of stream segments per unit of area. This is thus an indicator of the spacing of steam courses. The Horton's method (1945) has been adopted for this study, which uses the following formula for its calculation:

$$\textit{Stream Frequency} = N/A$$

Where,

N = Number of stream segments in an area

A = Area of calculation

The values of stream frequency could be explained by the amount of rainfall, structure, vegetation, and the stage of evolution of the area.

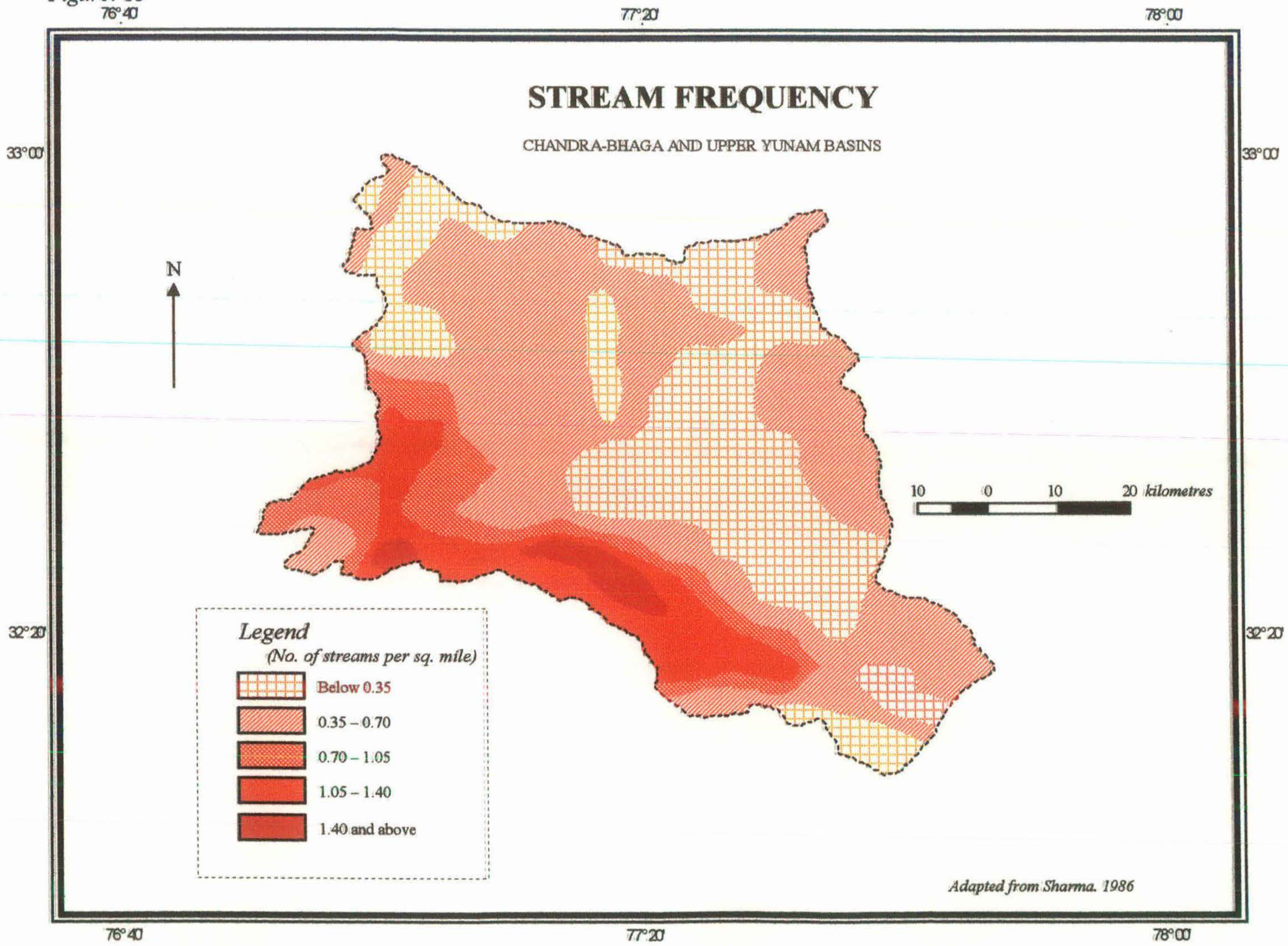
The values, obtained from the aforesaid calculation, have been divided into five classes. The lowest frequency class (0-0.35) covers about 29% of the region. The eastern part of the Triangular Mass has the most extensive area of low frequency.. Glaciers dominate the landscape. It continues to the Kunjum Pass (4420 metres) in the east and Baralacha Pass (4892 metres) in the west. The other important patch of low stream frequency is in the upper reaches of Shigri Glaciers. The northwestern part of the region is also a low stream frequency area probably due to large ice cover.

The next class is from 0.35-0.70. It covers the rest of the glaciated terrain and upper river basins of Chandra and Bhaga. This is the most extensive class, in terms of area covered (about 47% of the area). We find that the two lowest classes of stream frequency completely cover the northern and the eastern parts of the area.

The remaining classes of 0.7-1.05, 1.05-1.40, and above 1.40, have their respective share as 10%, 12%, and 2%. They all are confined to the southwest and south of the region. A narrow strip of relatively high stream frequency runs from Chhota Dara in the east, to the boundary of the study area in the west. The highest stream frequency is found between Chhatru and Khoksar. Its nearness to Rohtang Pass (the well known 'opening' through which monsoon enters the region) and long slopes with hanging glaciers probably results in higher value of stream frequency.

In nutshell, one can say that a large part of the region shows dismally low values, which is an indication of the widespread aridity and incomplete growth of river system. The climate (i.e. semi-arid), and the early evolutionary stage, provides the context for explanation (*See figure 13*).

Figure: 13



Adapted from Sharma. 1986

### 2.9.3 DRAINAGE DENSITY

The ratio between the total channel length and area of either a river basin or a part thereof is called drainage density. It is considered to be an important indicator of the surface and climatic characteristics. Less permeability, high denudation, and huge runoff are favourable for high value of drainage density. The stage of evolution of a landform is important as well. The maximum drainage density is found when an area approaches the stage of maturity.

The following formula has been used for the calculation of drainage density

$$Dd = \Sigma L / A$$

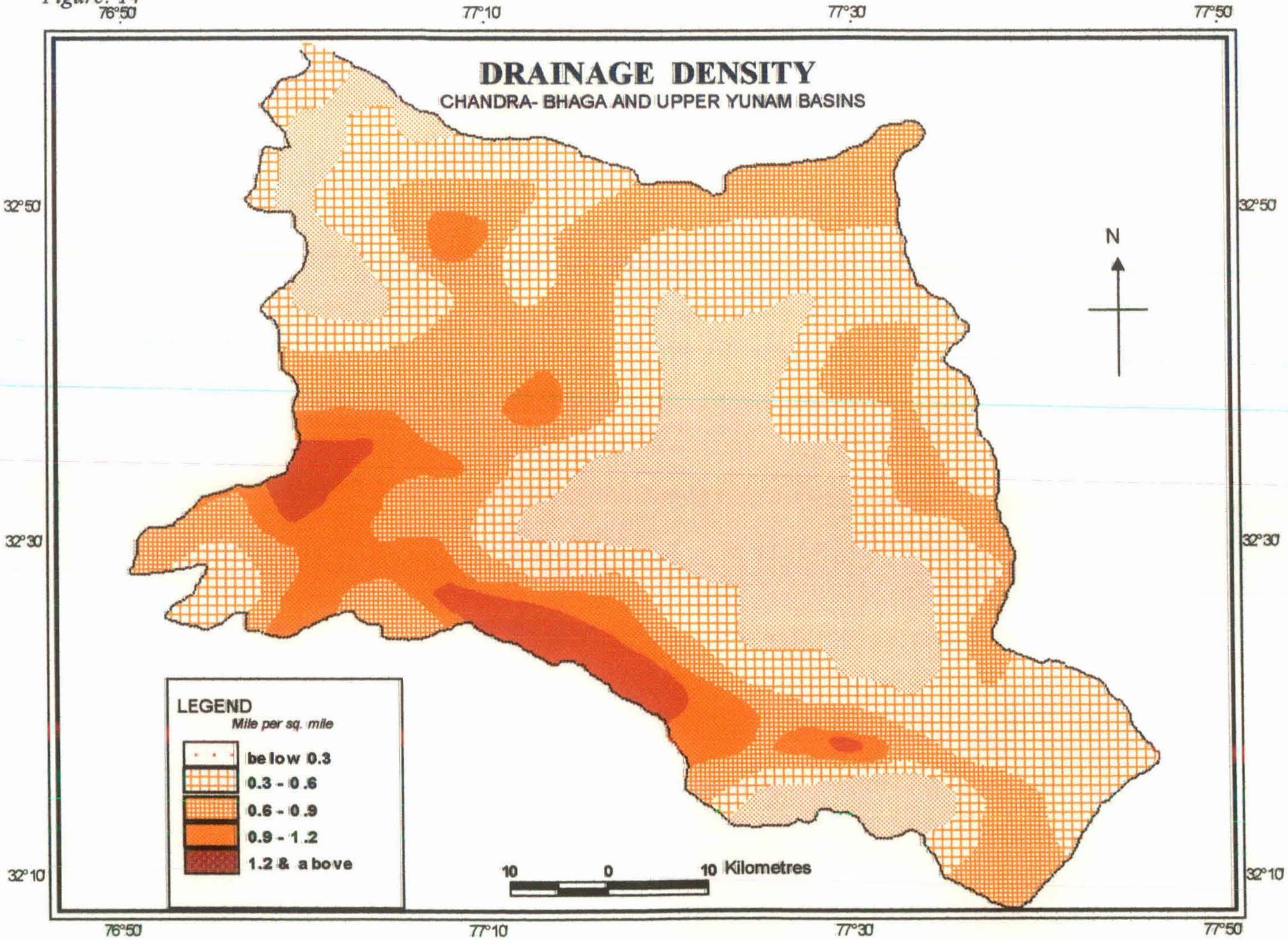
Where,

$\Sigma L$ = The total length of all the segments of stream in a region

A. = The area of the region

The lowest class of drainage density (i.e. 0-0.3) has a share of 21% in the total area. It covers the glaciated highlands of the Central Triangular Mass. The explanation could be found in the less susceptibility of the Pre-Cambrian formation (mainly the rocks of Chandrabhaga group and metamorphic group) to erosion and sub-zero temperature. The other areas of less importance are located near Bara Shigri and in the upper basin of the Jankar Nala. In later case the low value of drainage density is found in a strip shape (*See figure 14*).

Figure: 14


76°50
77°10
77°30
77°50
32°50
32°30
32°10
DRAINAGE DENSITY
CHANDRA- BHAGA AND UPPER YUNAM BASINS
N
LEGEND
Mile per sq. mile
below 0.3
0.3 - 0.6
0.6 - 0.9
0.9 - 1.2
1.2 & above
10
0
10 Kilometres

The maximum share (36%) in the area is that of the second lowest class of drainage density i.e. 0.3-0.6. It encloses the regions, which belong to the least value class of drainage density. In a way it shows a transition from very low to fairly low density.

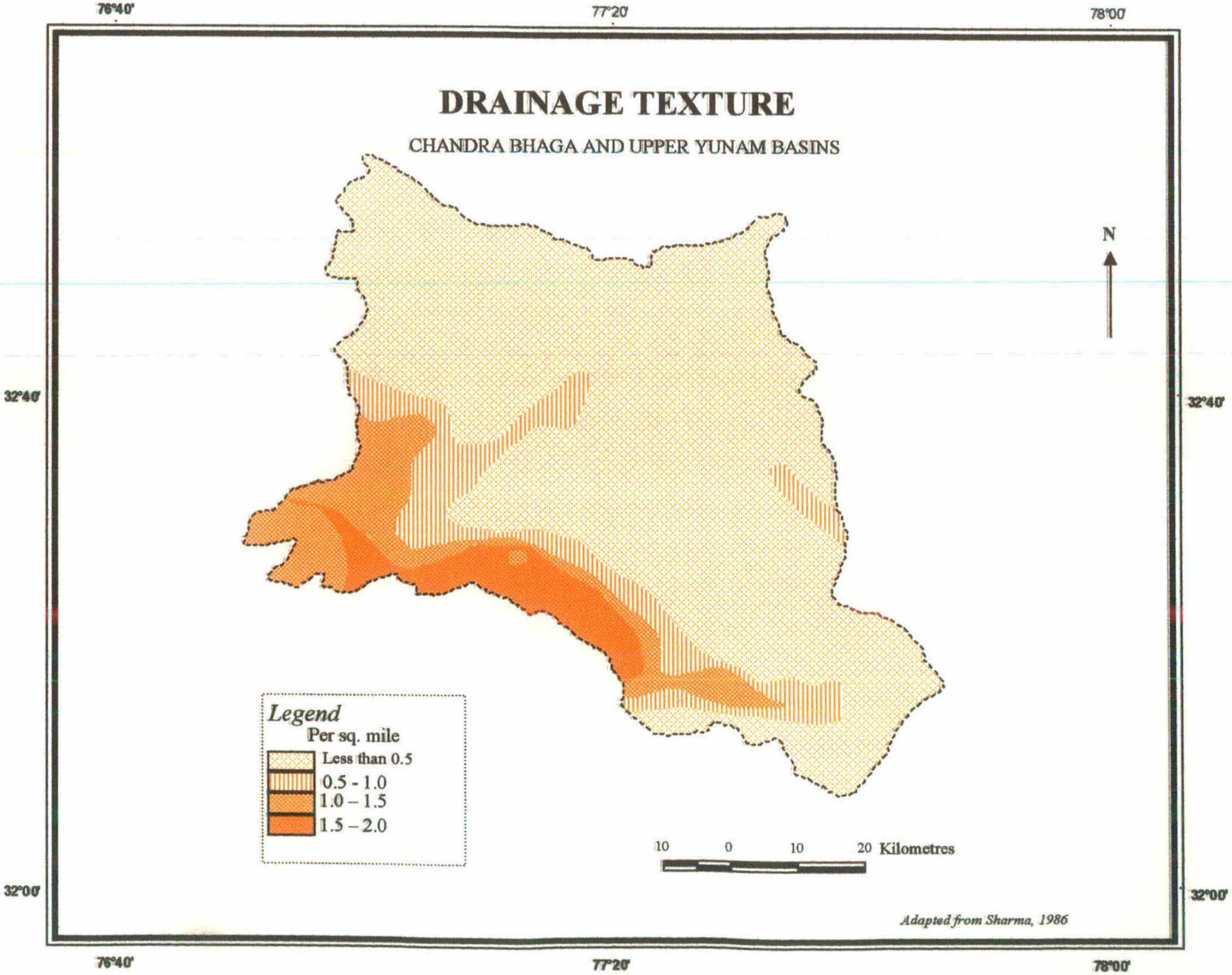
The fourth size-class ranges from 0.6 to 0.9. It is found in the form of broad belts along the major streams of the region. Its share in the area is 30%. The belt, which starts from Sarchu (on Yunam River), continues all along Bhaga. The width of this belt varies from les than 15 kilometres in the upper Bhaga basin, to more than 25 kilometres, to the south of Darcha. The same belt continues along Chandra as well, till Chhota Dara. Another belt is found along Chandra River, from its source to Batal.

The larger entries have been clubbed into two groups. The lesser group ranges from 0.9 to 1.20 and the higher category is an open-ended class, which includes any value from 1.20 and above. They cover respective 9% and 4% of the total area of the region. Both of them are mainly confined to the south and southwest parts. The valley of the Chandra, near Rohtang Pass (3978 metres) is especially noticeable in this regard. The amount of precipitation probably holds the key, in this regard. The site of confluence of the Chandra and Bhaga (*Plate 3*) is another area of very high drainage density. The presence of slate, which is favourable for valley development, may be accounted for the high value.

### 2.9.4 DRAINAGE TEXTURE

It is an important geomorphic concept by which the relative spacing of drainage lines is determined. Drainage texture includes both drainage density and stream frequency (*See figure 15*).

*Figure: 15*



*Adapted from Sharma, 1986*

It does not refer to such factors as steepness of slope, amount of relief, or stage in the geomorphic cycle (Thornbury, 1954). The calculation of drainage texture is based on the values of drainage density and stream frequency. When their values for a unit area are multiplied, one gets the value of drainage texture.

The values of drainage texture for the region have been grouped into five classes. The lowest class (below 0.5) covers more than four-fifth of the total area. The northern and southeastern parts of the study area are completely covered by this class, which represents very coarse texture.

The second class (0.5-1.0) displays a transition towards finer texture. It is confined to the lower valley of Bhaga and the eastern flank of the lower valley of Chandra.

All the three classes of relatively finer drainage texture are confined to the southern flank. The value progressively increases towards south. While the second and the third highest classes are found in strips the highest class, representing the finest texture, is found in a very small but circular patch.

## SUMMARY

The study area is a part of Lahul and Spiti district of Himachal Pradesh. Some important passes connect it with neighbouring regions. The important among them are as follows- the Rohtang (3978 metres), Baralacha (4892 metres), Sara Umga and Kunjum (4420 metres).

The rhythm of season is marked with severe winter and mild summer. Though, the air temperature never goes very high, the days of summer witness scorching sunrays.

The southwest monsoon as well as westerly disturbances is responsible for precipitation, which is relatively low and it mainly takes place in the form of snowfall.

The morphometric analysis of the region suggests that this is a high-activity region. The geomorphic processes are active at high pace and the surface contains sharp landforms having various origin- glacial, paraglacial, fluvial and glaciao-fluvial. The overall topography looks young and refreshing. The region shows high relief.

The landforms of the region show the evidences of Pleistocene glaciation through the assemblage of palaeo-cirque, U-shaped valley, arête, hanging valley etc.

Although there are numerous rivers, only few of them are of fairly considerable length. The important among them are the Chandra, Bhaga, Jankar and Yunam. They occupy are narrow but deep valleys. But their tributaries are usually small and carry glacial melt water. The most of the rivers carry very high amount of load and have fluctuating discharge. This has resulted in river braiding at many places. The overall river system is not well developed.

Chapter Three

# QUATERNARY GLACIAL HISTORY OF THE REGION

## 3.1 INTRODUCTION

The palaeo-environmental study of the Himalaya is very important in order to understand the behaviour of overall global climate. The various critical links between the climate changes in these mountains, and that of the globe as a whole, are still to be deciphered completely. But many scholars are recognizing the importance of these links, of late.

The study area is a part of the Lahul Himalaya, a local name given to the Western Himalaya in the Lahul and Spiti district of Himachal Pradesh. As the mountain ranges of the region are an important part of the central Asian mountains, their supposed role in affecting climate change in Pleistocene need to be explored (England et al, 1990; Raymo et al, 1992). Besides, there are some additional advantages of the region that makes it more important for serious research, which could be summed up as follows:

1. The possible link between the Cenozoic uplift of the Central Asian mountains and the global climate change leading to Pleistocene ice age could be explored here.
2. The presence of many large mountain glaciers in Lahul Himalaya make it more suitable for palaeoclimatic study. The behaviour of glaciers is largely determined by climatic regime of the day. Any change in its parameters results in noticeable glacial advances or retreats.

3. The region experiences very low amount of precipitation resulting into low humidity and underdevelopment of streams. Thus the wear and tear of palaeoglacial evidences, due to weathering and fluvial erosion, is minimal.

The likely role of late Cenozoic uplift (during late Quaternary and Tertiary times) of the central Asian mountains in affecting regional and global climate change is a matter of debate (discussed in the first chapter). The discussions are over the forcing mechanisms, the timing of uplift, and the nature of environmental change (England et al, 1990; Raymo et al, 1992; Taylor et al., 2000). It is equally important to appreciate the fact that the mountains of the western and central Himalaya and the Karakoram mountains comprise the greatest concentration of glaciers outside of the polar regions (Owen et al. 1996). There is a possibility that the study of glaciers, located in the Himalayan ranges and Tibetan Plateau, could provide us with a better insight in to the recurring climate changes, possibly all over the globe.

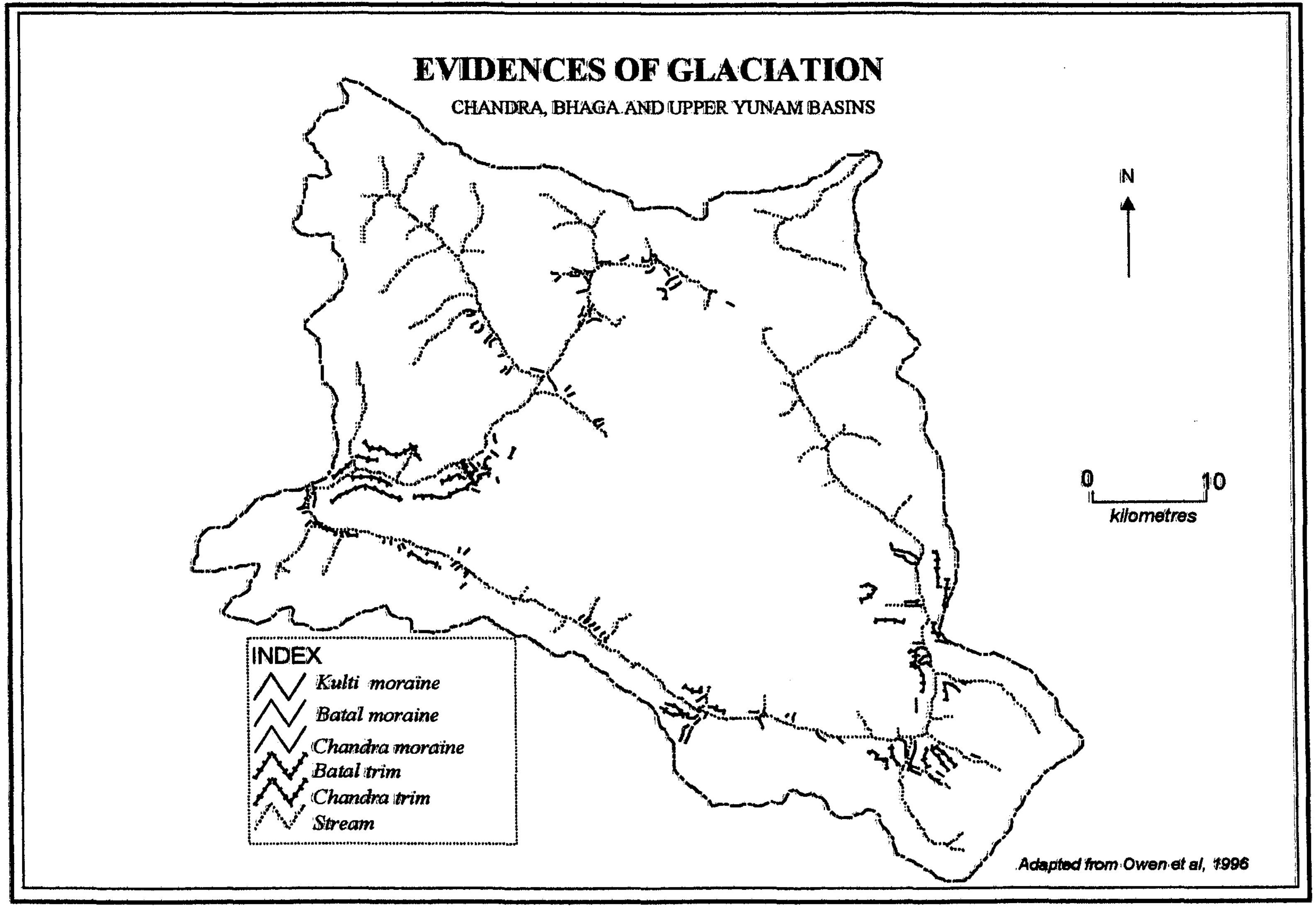
The glaciers are mass transportation systems, governed by the amount of precipitation and the nature of temperature regime. They are well known for their sensitivity to the controlling factors. Any slight change in them, considerably affects their extent and nature. Although it is applicable in all kinds of glacier, yet the mountain glaciers, owing to their small size, are better suited for the study of these fluctuations. The glaciers leave behind the evidences of their extent in the form of glacial deposits. As the size of glaciers is controlled by the climatic factors, these deposits could be taken as palaeoclimatic evidences to show the palaeoclimatic conditions. Clapperton, (1990) and Gillespie et al., (1995) have underlined the importance of glacial evidences by highlighting the fact that these are found at high-altitudes, where biostratigraphic evidences are either fragmentary or absent (cited by Owen et al., 1997).

## 3.2 THE IMPORTANCE OF CHANDRA AND BHAGA BASINS IN PALAEOCLIMATIC RECONSTRUCTION

The Chandra and Bhaga basins are strategically located in between the Middle Himalaya and the Greater Himalaya. The Pir Panjal Range, which belongs to the Middle Himalaya, is the southern boundary of the Chandra basin. The range trends in NW-SE direction. The Zanskar Range of the Greater Himalaya marks the northern boundary of the region. The axis of this range is also from NW-SE. But the two ranges are not essentially parallel to each other. They rather merge with each other in the southeastern part near the Karcha Nala at Kunjum Pass (4420 metres).

The Pir Panjal Range is very important as an orographic barrier to the region. It separates the monsoon affected south from the semi-arid north. Much of the precipitation, to the north of the Pir Panjal Range, is supplied by the mid latitude westerlies. However during strong monsoon years, such as that of 1996, heavy rainfall can occur could occur throughout the Chandra valley, at the southern end of the Lahul Himalaya, and even to elevated regions as far north as Chandra Tal and the Bhaga valley (Owen et al., 2001). This aspect has already been dealt with in the second chapter. Thus we could see that the Chandra and Bhaga basins witness two competing weather systems i.e., monsoon and westerly. There may be some link between the varying strength of these weather systems and the episodic advance and the retreat of glaciers (*See figure 16*).

*Figure: 16*



Adapted from Owen et al, 1996

Of late, researchers have started looking for geological and geomorphological evidence for climatic fluctuations at the northern limit of the south Asian monsoon, in the past. The information thus collected, could be linked up with the local and global climate change, in the future.

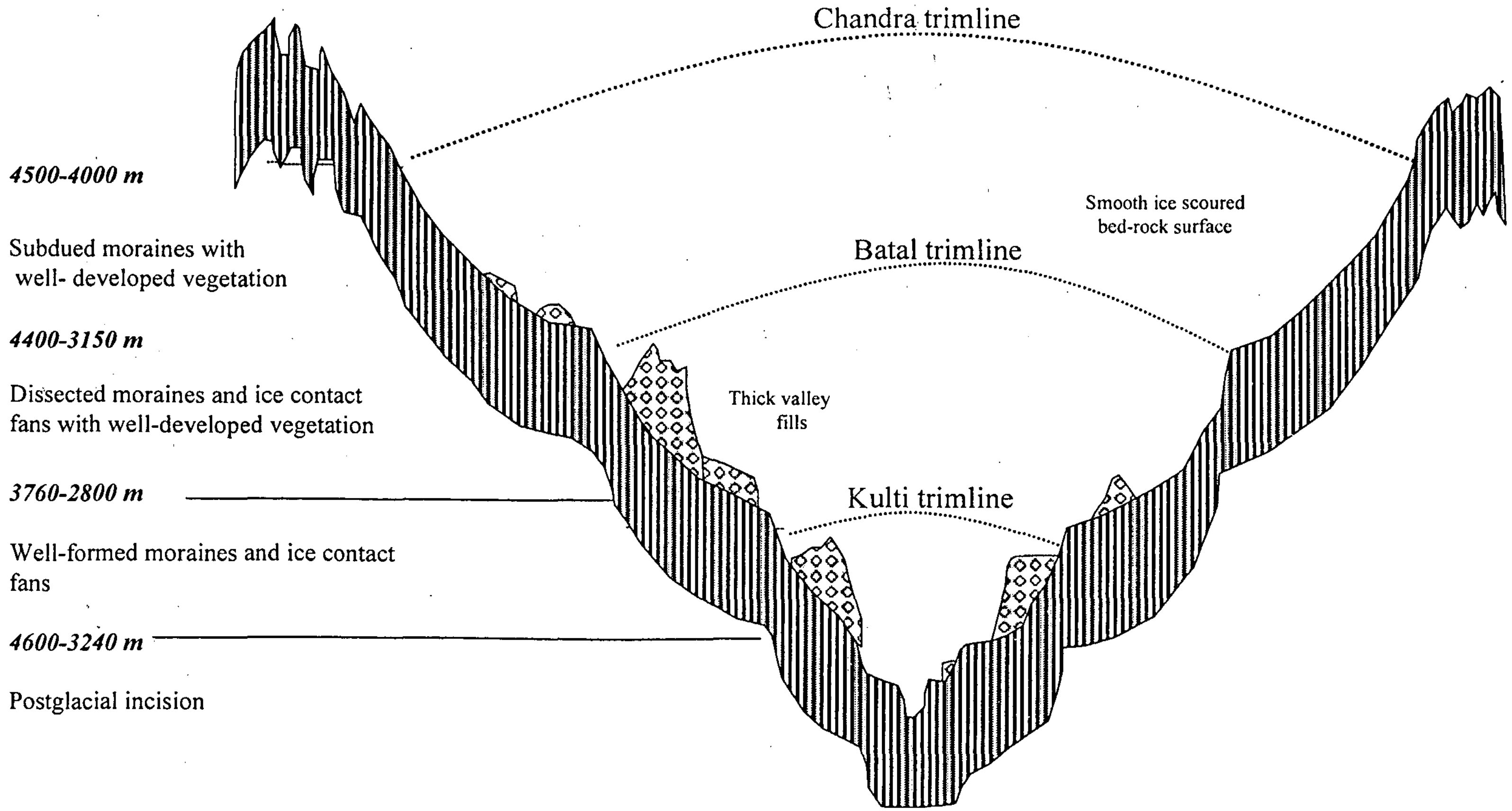
The other important characteristic of the region is its semi-arid climate. The lack of precipitation helps preserve the palaeoclimatic evidences from the wear and tear of river work and weathering processes. The contrast becomes very much felt, when one compares the glacial landforms of the region with those located to the south of the Pir Panjal. The area provides the best preservation of evidence of glaciation within the western Himalaya (Owen et al., 1997). The region thus is the repository of the glacial evidences (*See figure 17*).

## 3.3 DIFFICULTIES IN RECONSTRUCTION OF THE CLIMATIC HISTORY OF THE REGION

Owen et al. (1996) report that despite the critical importance of the region in deciphering the nature and timing of global climate change, only a few research have been undertaken. Krenek (1945) carried out an important study on the glaciation of the region though it was not the earliest one (Sharma, M.C., 1986). The other noticeable contributions came from Egerton (1864) on Bara Shigari glacier and Walker et al. (1907) on the Sonapani glacier (as cited by Owen, 1997). But it was Owen et al, who took their contributions further by developing a systematic chronology on the glacial history of Lahul in 1996.

*Figure: 17*

SCHEMATIC SECTION SHOWING THE ALTITUDINAL ZONATION OF LANDFORMS ASSOCIATED WITH THE MAIN VALLEY OF LAHUL



*Adapted from Owen et al 1997*

The long neglect of the region by scholars could be well explained by the various factors, which dishearten serious researcher work. These have been listed below:

1. The inaccessibility of the region is the major hurdle in any serious research. This is due to the stupendous height of the region.
2. The lack of settlement and weak transportation infrastructure discourage researchers.
3. The Govt. of India, due to strategic reasons, does not make the accurate base map available.
4. Lack of weather stations result in the poor quality of the climatic data.
5. Accurate dating is not possible due to the lack of datable organic material.

## 3.4 THE NATURE OF GLACIATION

The present day ELA of the major glaciers is about 5280 metres but it was much lower in Pleistocene. This kept fluctuating with advances and retreat of glaciers at various point of time. The nature and extent of glaciations in Lahul is intricately related with the glacial history of the other parts of the western Himalaya. The entire area remained neglected till the late eighties and early nineties; later, some scholars realized its importance in deciphering the climatic puzzle of the Pleistocene glaciation. Some of the serious and systematic researches were taken up in 1990's. Although, a lot of study were carried out for Karakoram Range (Derbyshire et al., 1984; Shroder et al., 1993), Swat Kohistan (Porter, 1970; Owen et al., 1992), Lahul (Owen et al., 1995, 1996, 1997, 2001), Garhwal (Sharma and Owen, 1996) and Zanskar Range (Osmoston, 1994) the lack of absolute dating control in these areas made temporal and spatial correlation of the glaciations difficult (Owen et al., 1997). The higher location, coupled with semi-arid climate, discourages the growth of vegetation, which subsequently results in the lack of organic material for absolute dating. Even the sediments appropriate for palaeomagnetic dating is not found here (Owen et al., 1996). Thus many researches are based on the relative dating techniques. Of late scholars have started using OSL and isotope dating, which are very accurate dating techniques.

The glacial chronology of Lahul Himalaya has not concretized as yet. The relative chronology of the area has been established using morphostatigraphy, lichenometry, stage of soil development, thickness of rock varnish, stage of vegetation development the effect of weathering processes, OSL and isotope dating. The study of sediments and landforms assist considerably in the assessment of former ice positions.

The first tentative chronology, which was proposed by Owen et al (1996), envisaged a polyglacial evolution of the region. This proposal is still uncontested. The authors suggested three major glacial phases, and two minor advances. The names of these phases have been given after those localities (site specific), where the evidences of particular glacial phases are found in abundance. The sequence of major glacial phases has been identified, as Chandra, Batal, and Kulti. The other two minor advances have been named as Sonapani I, and Sonapani II. This tripartite pattern of glaciation is a common feature of the glacial history of the western Himalaya and Karakoram mountains. The glacial extent, in the successive glacial phases got progressively narrower, in both of these mountain systems.

Geological evidences have shown that the earlier glaciers were associated with broad valleys, whereas, the later glacial advances were more topographically constrained (*See figure 17*), within the present valley system (Derbyshire et al., 1984; Owen et al., 1996). The could be explained as follows

1. There is a chance that the continuous valley erosion, in the successive glacial and inter-glacial phases probably made the existing valleys narrower, and thus pre-decided the extent of the successive glaciations, which was obviously more constrained than the previous one.
2. The other possibility is that the region underwent drier climatic condition with the passage of time. This could have happened due to the uplift of central Asian mountains to a considerable height. Had it been so, it would have provided orographic shielding to the area from the Asian summer monsoon. The weakened monsoon results in lesser amount of rainfall.

Generally, mountain glaciers leave behind fragmentary evidences, as there is always a chance that the later glaciations would wipe out the evidences of the earlier phases. But, here in the western Himalaya, the evidences are fairly intact. The rapid rate of uplift of the central Mountain system (Pir Panjal Range in the case of Lahul) left the evidences stranded on the high benches. The rapid erosion of river valleys, induced by upliftment, restricted the extent of later glaciation in them and thus the evidences of the earlier glaciations located on the margin of the valleys or benches, were little disturbed (*See figure 18*).

## 3.5 THE GLACIAL PHASES

The proposition of three major glaciations (Chandra, Bhaga, and Kulti) and two minor advances (Sonapani I, and Sonapani II) has already been mentioned above. The major evidences, left behind by glaciers in different glacial phases, are found in the form of moraines, sediments, and trim lines (*See figure 18*). The younger glacial landforms and sediments are inset into the older landscape, generally at lower altitudes. It seems that the more favourable combination of precipitation and temperature, earlier rather than later, resulted in the diminishing size of glaciers in successive phases. It may be elaborated as follows.

### 3.5.1 CHANDRA STAGE

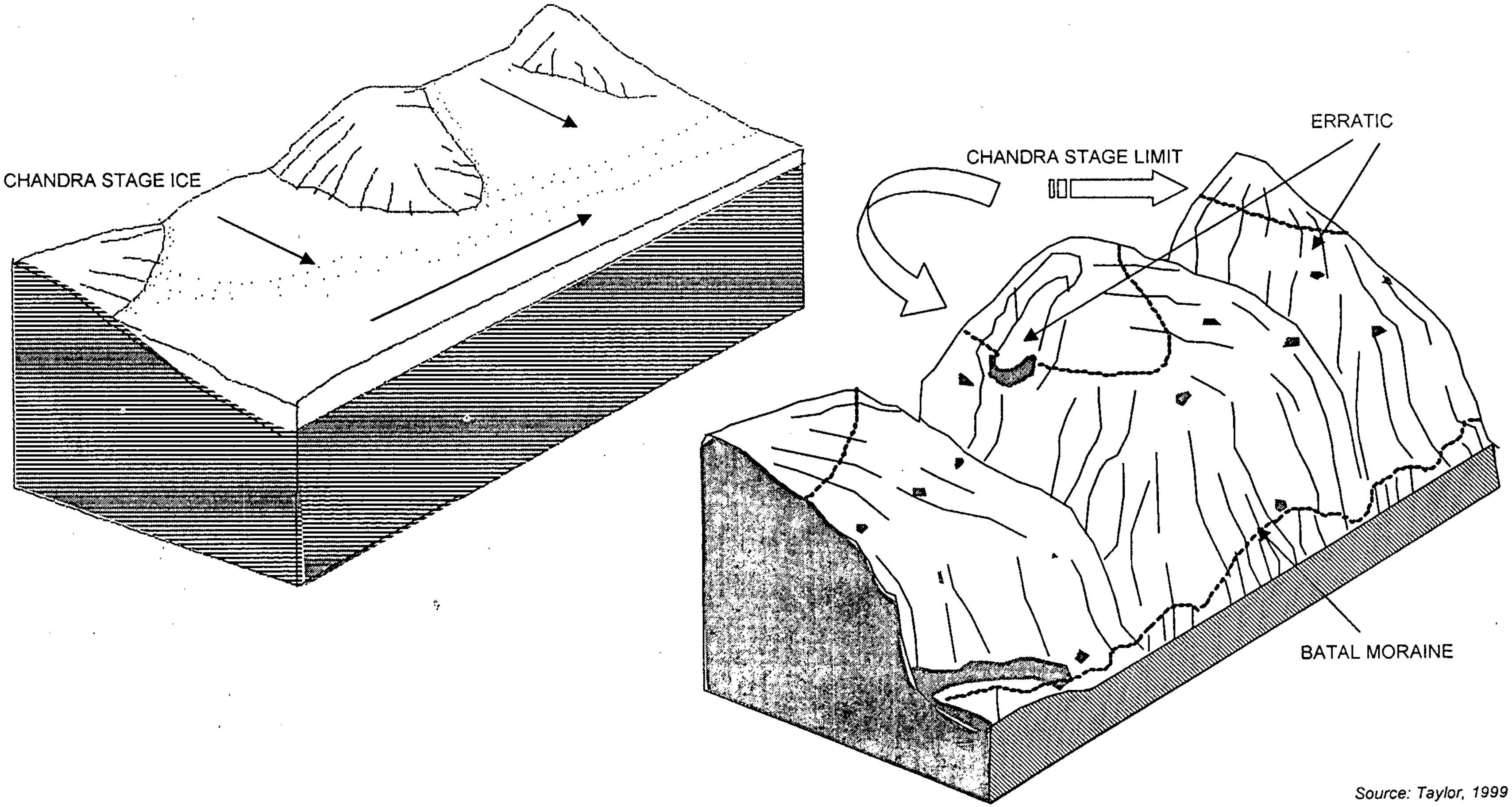
This is the oldest and the most extensive stage of glaciation in the Lahul Himalaya, generally characterized as broad valley type (Owen et.al.1996, 1997; Taylor et al., 2000). It took place in late Pleistocene. The evidences of this glaciation are found along the Chandra and the Bhaga valleys. For later, it is rather the lower part of the valley, which is important. The trim line of this phase is found continuously along the left bank of the river, from a little south of Zispa village to a place called Tandi. It is best developed near Keylong, where one can notice it on both the sides of the valley. These landforms have been brought under various cultural activities.

The upper Chandra valley, near Chandra Tal and North Dakka glacier are quite noticeable for the Chandra stage evidence.

*Figure: 18*

# SCHEMATIC DIAGRAM SHOWING EVOLUTION OF LANSCAPE AFTER GLACIATION

CHANDRA BHAGA AND UPPER YUNAM BASINS



*Source: Taylor, 1999*

The major landforms are whalebacks, roche moutonnee, glacially eroded rock benches (with abundant striations), drumlins (*See figure 31*), and thickly vegetated moraines (found in fragments). The associated rocks and outcrops are covered with deep varnishes. These features are mostly found at the elevation between 3800-4500 meters. But, at few places their height exceeds 4600 meters (e.g. near Kunjum la). The presence of glacially affected features at such height is an indication of the nature of snow cover in this glacial phase. The chances of blanket like snow cover, which completely covered the local topography, with a few exceptions of nunataks, cannot be ruled out. The evidences of ice caps are still present around Baralacha.

Near Kunzum La, the flow direction, as indicated by striations on rock outcrop, is oblique to the present trend of the Chandra valley. Owen et al., (1997) hypothesizes that the ice of this stage could not be contained within the existing valley or that the glaciation predates the valley. But they highlight another important fact, which questions the hypothesis of orographic (Pir Panjal) uplift for explaining increasing aridity in the subsequent glacial phases. What they point out is the presence of striation marks to the west of Bara Shigari glacier. These indicate the northward flow of ice from the area where the Pir Panjal Range is located. If this is correct, then one can say that the mountain was sufficiently high to generate glacier, even in the first glacial phase. In that case, the attempt to seek mountain upliftment, as a cause for the weakening of monsoon and diminishing precipitation leading to decreasing size of glacier in subsequent phases, looks untenable.

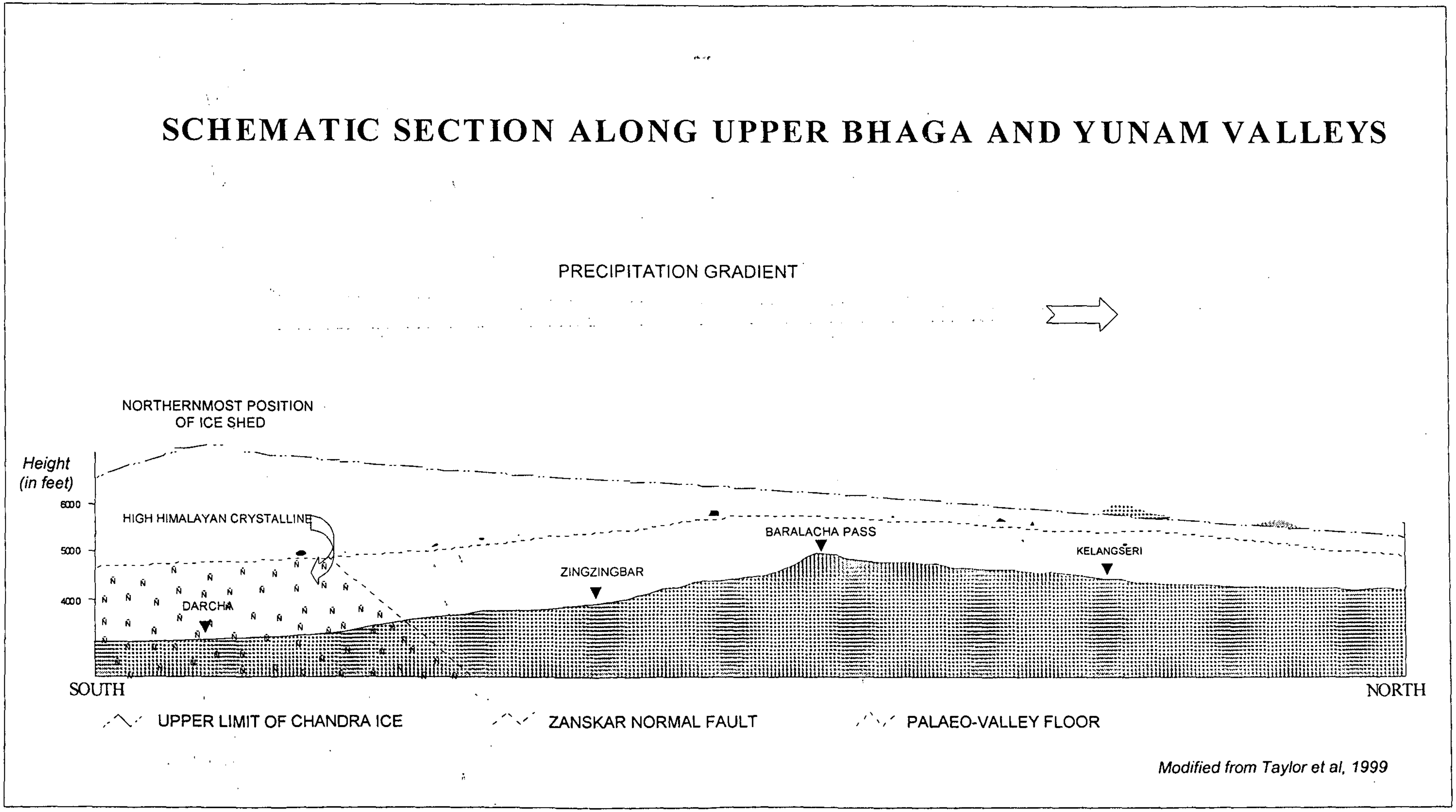
The evidences are also found at Baralacha Pass, in the form of tillite and striations. The glacier valleys at this time were broad with gentle sides (*See figure 17*). The locations of erratics, in some problematic positions, suggest that the glaciation was possibly in the form of ice cap..

The striations are directed towards south, as well as towards north. This shows that the present watershed was not the ice-shed at that time. The glaciers had entered the Yunam valley through this pass, and dropped some large gneiss erratic blocks (*See figure19*). Many of them seem to be carried away from the Zanskar Range Normal Fault, which is located somewhere in between Darcha and Zingzingbar (Taylor et al., 2000). It suggests that the ice-shed was to the south of the fault. This contradicts the hypothesis of Owen et al (1997), which states that the ice-shed was not away from the Baralacha Pass. In the light of the available evidences, this is simply an untenable assumption.

### 3.5.2 BATAL STAGE

The second stage of glaciation is known as Batal stage. This was an extensive valley glaciation (Owen et al., 1996, 1997). Optically stimulated luminescence (OSL) dating indicates that glaciers probably started to retreat between 43,400 ± 10,300 and 36,900 ± 8,400 years ago during the Batal stage (Owen et al., 1997). This stage could be divided into two sub-types on the basis of the altitudinal position of landforms. But the radiocarbon dating by Owen et al. in 2001 came to a contradictory result. It gave a new date of Batal deglaciarion (~17,000-13,000 years) that is much younger that what was estimated earlier. Its type-site is located to the south of the Chandra Tal (*See figure20*).

*Figure: 19*

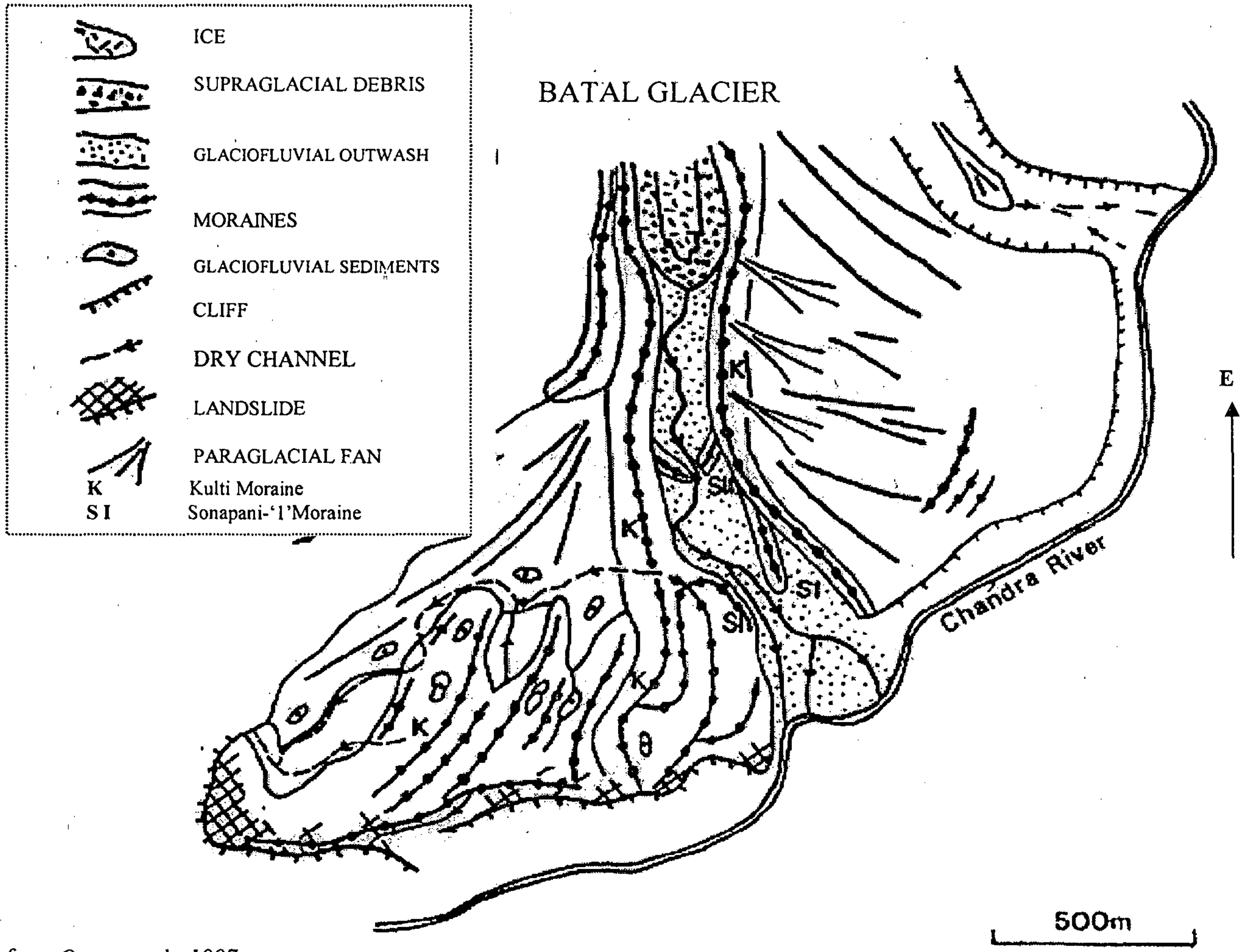


SCHEMATIC SECTION ALONG UPPER BHAGA AND YUNAM VALLEYS

*Modified from Taylor et al, 1999*

*Figure: 20*

**THE EVIDENCES OF GLACIATION AT BATAL**



*Modified from Owen et al , 1997*

The peculiar characteristics of this glaciation, which was marked by an oscillating regression or a re-advance, created two sets of landforms, superimposed at some places. These two parts or sub-stages of the Batal glaciation are called as Batal I, and Batal II. Their division becomes very much clear when one observes the superimposed drumlins in the area around Chandra Tal (Owen et al., 1997). Here, the earlier sub-stage, Batal I, had formed approximately 50m long drumlins. The second sub-stage i.e. Batal II, created another set of much smaller drumlins upon the already existing drumlins of the first sub-stage (*See figure21*).

Highly weathered and dissected moraines with fairly good vegetation represent Batal phase of glaciation (*See figure 22*). At some of the places, their thickness exceeds over 100 meters (Owen et al., 1996). But irrespective of their thickness, they look subdued (Taylor et al., 2000). The maximum advance of the Batal glaciation is difficult to determine because the moraines are rather fragmented and discontinuous. They are best preserved near Batal along the east side of the Chandra valley, between Kulti and Khoksar valleys and in the lower Milang valley. Owen et al., (1996) have estimated that the ice probably extended all the way down the Chandra and Bhaga valleys to at least their confluence at Tandi. But it may have extended further down the Chandrabhaga valley, beyond Tandi, but it is not proved till date because of lack of evidence.

The study of the Yunam valley by Taylor and Mitchell (2000) highlights the characteristics of Batal landforms. The broad U-shaped valleys of Chandra origin are quite distinct from the narrow valleys of Batal origin. The moraines are subdued and dissected.

*Figure: 21*

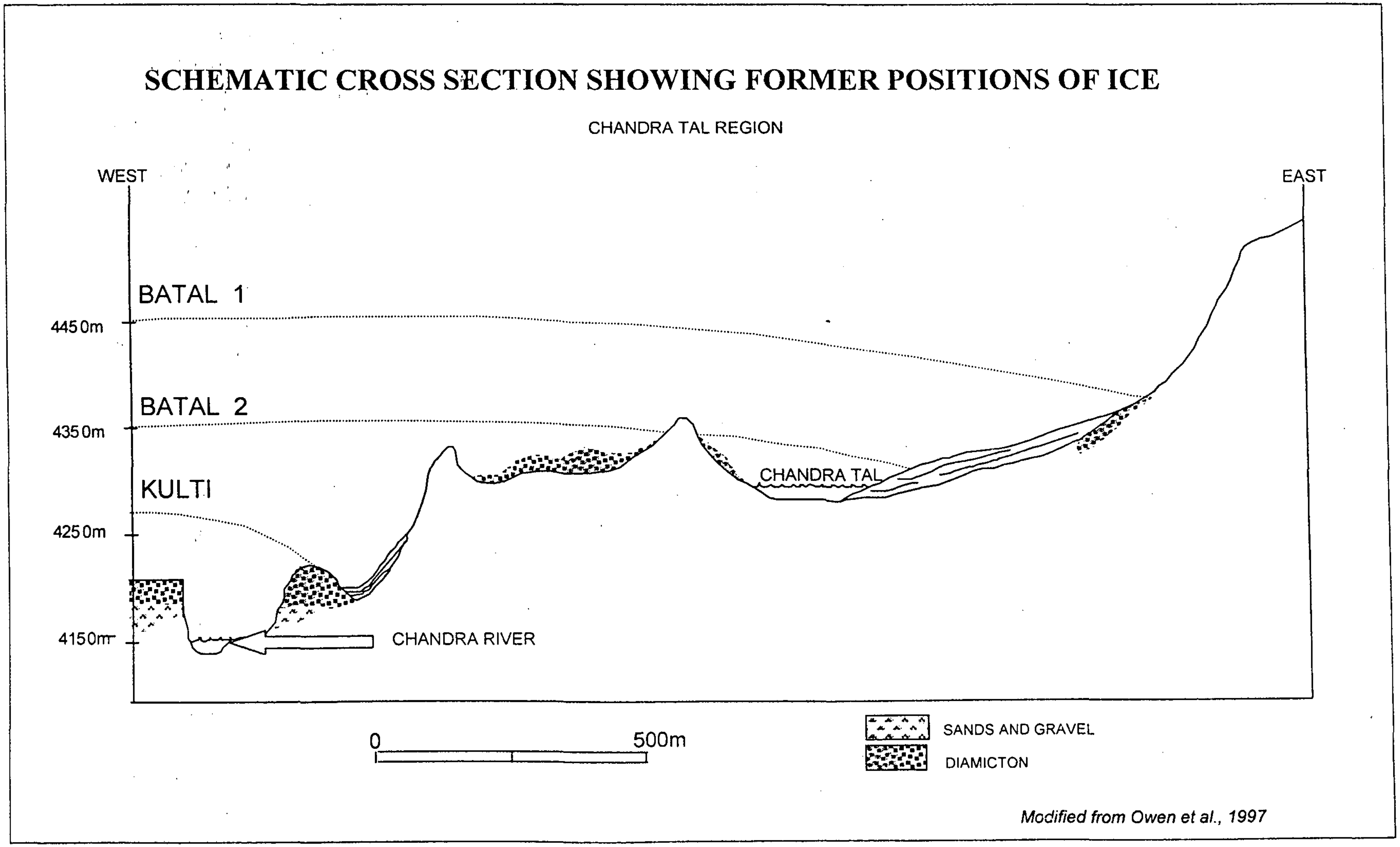
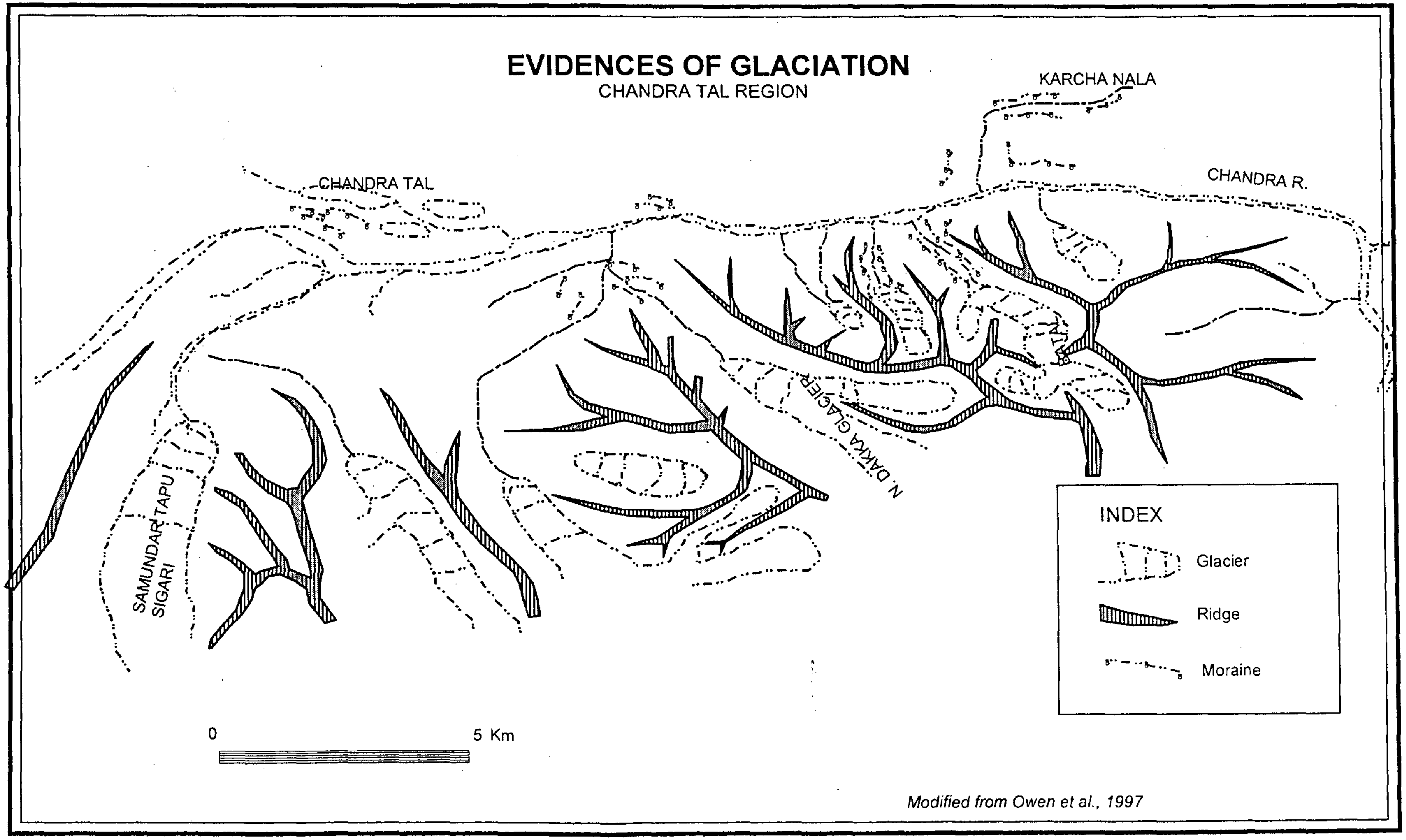

SCHEMATIC CROSS SECTION SHOWING FORMER POSITIONS OF ICE
CHANDRA TAL REGION
WEST
EAST
BATAL 1
4450m
BATAL 2
4350m
KULTI
4250m
4150m
CHANDRA TAL
CHANDRA RIVER
0
500m
SANDS AND GRAVEL
DIAMICTON
Modified from Owen et al., 1997

*Figure: 22*



*Modified from Owen et al., 1997*

### 3.5.3 KULTI STAGE

This is the last among the three major glacial phases. The OSL dating suggested it to be younger than 36,900 ± 8400 years ago (Owen et al. 1997). Owen et al. later revised this date on the basis of radiocarbon dating, in 2001 and suggested that the deglaciation of this phase took place sometime in between ~12,000-9,000 years ago.

The lateral and end moraines of this glaciation are well preserved and less vegetated (this property varies with microclimatic variations e.g., the Kulti moraines in Kulti valley is more thickly vegetated than its counterpart in the upper Bhaga valley, or for that matter, in other drier area), with large boulder and thin surface soil. The locations of these moraines are not beyond 12 kilometers from the termini of modern glaciers, and their height suggests that the ice was not more than 60 meters thicker than at present. The Kulti may correlate with the last glacial maximum of the northern hemisphere ice sheets ca. 18000 years BP (Owen et al., 1996).

The glaciers advanced, from their present positions in tributaries valleys, to join the main or trunk valleys i.e. Chandra and Bhaga. There are many examples to prove the point, e.g. the Sonapani glaciers advanced down the Kulti valley into the Chandra valley, the Koa Rong glacier advanced through the Milang valley into the Bhaga valley, and the Batal glacier moved across upper Chandra valley (Owen et al., 1997) The movement of ice was sufficient to block river flow through the valleys that subsequently led to lake formation at various sites along the valley.

The deposition of the drumlinised moraines, which are found to the east of the Chandra Tal, is also explained by glacial advance during the Kulti phase.

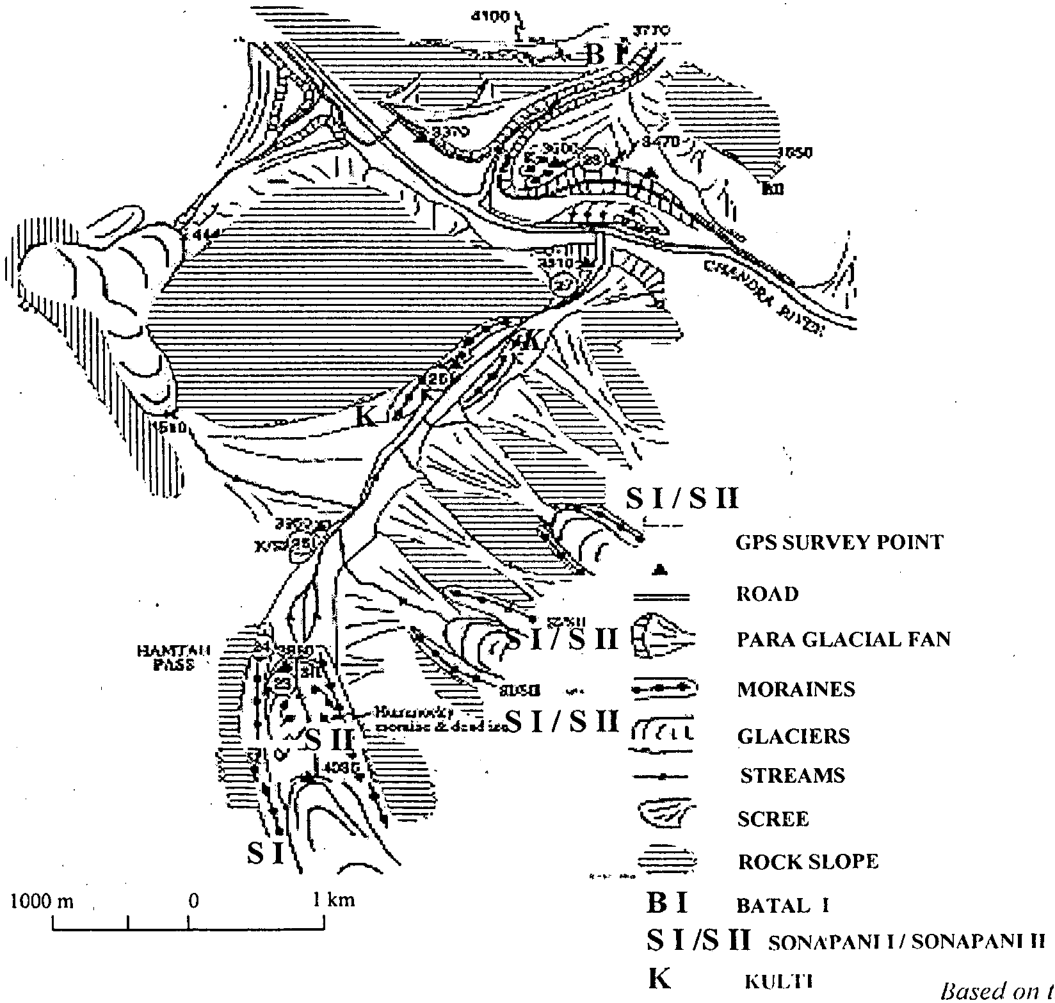
### 3.5.4 SONAPANI ADVANCES

The presence of two sets of sharp crested moraines in the area indicates the possibility of two minor glacial advances- Sonapani I and Sonapani II, in the recent past. The corresponding moraines are found within 5 kilometers and 2.5 kilometers, respectively, from the present glacier termini. These moraines are known for sparse vegetation, small lichens, thin rock varnish, and large boulders. By comparing the position of glacial snout of Sonapani glacier in 1905 (as reported in the paper of Walker and Pascoe, which was published in 1906) with that of today, Owen et al., (1996) has tried to prove that the glacier has been continuously receding since then. The Sonapani II moraines were, therefore, attributed to a late- nineteenth century advance. Owen et al (1997) has taken Sonapani-I as a representative of the Neoglacial (4500 years before present) event, and likewise Sonapani-II of the Little Ice Age. But, the prefers not to use these terminologies as the dating control for this area is very weak and further research may end up with some contrary results.

The morainic evidences of both advances are found intact at many places e.g., Chhatiru. The following geomorphic map of the place shows that the moraines are quite near to the present snouts of the glaciers. In many cases they even flank their sides (*See figure 23*).

*Figure: 23*

# THE GEOMORPHOLOGICAL MAP OF CHHATIRU



*Based on the study of Owen et al, 1997*

## 3.6 CHRONOLOGICAL CORRELATION WITH OTHER REGIONS

The western Himalaya and Karakoram mountains share a similar multi-glacial history, but the timing and causes of glaciations may not be essentially the same everywhere. Any comparison between them is fraught with danger since the timing of their advancement and retreat have not concretized yet. Although the newly developed dating techniques viz. OSL and radiocarbon dating, are being employed, they are still in the early stages.

As mentioned earlier, Owen et al. (1996,1997,2001) are accredited for establishing the glacial chronology of Lahul. Initially it was suggested to be very similar to the chronology of other neighbouring regions i.e. the middle Indus valley, Garhwal Himalaya and Hunza valley (*See table 4*). Like Lahul, these areas witnessed three major glacial phases, and many minor advances. The earliest glaciation (Shanoz), in the middle Indus valley was broad valley type, whereas the later phases of glaciations were less extensive. The glacial extent became more and more confined in successive phases of glaciation. But the dating results of radiocarbon techniques (Owen et al. 2001) proposed that Lahul Himalaya behaved differently, compared to its many neighbouring regions and their timing of glacial phases, and differed markedly due to its peculiar locational conditions. It is shielded from monsoon. The climatic regime, which is dominated by the Westerly, links it teleologically with the climatic conditions of the Mediterranean and Caspian Sea.

*Table : 4*

# CHRONOLOGIACAL CORRELATION OF LAHUL GLACIATIONS WITH NEIGHBOURING REGIONS

| | GLACIAL / NONGLACIAL | | LAHUL | MIDDLE-INDUS-GILGIT-HUNZA | | | UPPER INDUS | SWAT-KHOHISTAN | GADHWAL | TENTIVE TIMING |
|---|---|---|---|---|---|---|---|---|---|---|
| SERIES | STAGE | STADE | OWEN et al 1995 | DERBISHIRE et al 1984 | SHRODER et al 1993 | ZANG & SHI 1980 | CRONIN et al 1989 | PORTER 1970 | SHARMA & OWEN 1996 | YEARS AGO |
| HOLOCENE | | | SONAPANI II | PASY II | HISTORICAL | HISTORICAL | Individual Moraines | | BHUJBAS | 100 |
| | | | SONAPANI I | PASU I | LITTLE ICE AGE | LITTLE ICE AGE | | | | 1,000 |
| | | | | BATURA | NEOGLACIAL | NEOGLACIAL | | NEOGLACIAL | SHIVLING | 10,000 |
| PLEISTOCENE | Late Glaciation | | KULTI | GHULKIN II | DAREL SHATIAL MORAINE | HUNZA | | KALAM GLACIATION LATE STADE | BHAGIRATHI | |
| | | | | GHULKIN I | DAINYOR MORAINE | | | KALAM GLACIATION INTERMEDIATE STADE | | |
| | | | | BORIT JHEEL | | | | KALAM GLACIATION EARLY STADE | | 1,00,000 |
| | M-L IG | | BATAL II | YUNZ | VALLEY FILL III | YUNZ | STRONG EROSION ALLUVIATION | GABRAL GLACIATION LATE STADE | | |
| | Middle Glaciation | LATE SURGE | | | M '2' TILLS | | SATPURA TILL | | | |
| | | | BATAL I | | VALLEY FILL II | | VALLEY FILL | | | |
| | | EARLY SURGE | | | M '1' TILLS | | | GABRAL GLACIATION EARLY STADE | | |
| | INTER G | | CHANDRA | SHANOZ | UPPER JALIPUR VALLEY FILL 'I' | SHANOZ | BANTHUNG TILL | | | 10,00,000 |
| | EARLY G | | | | LOWER JALIPUR TILL | | | LAIKOT GLACIATION | | |

***Source : Owen et al, 1996***

The same is not true with the monsoon-dominated regimes. This is the reason why these regions have their own climatic history, not necessarily similar to the Lahul Himalaya (Owen et al. 2001). The authors drew a parallel between the natures of Lahul glaciation and the general timing of global climate change.

The model of Zheng (1989), which is based on the Milankovitch's proposition on climate change and tectonic uplift, predicts three major glaciations for the Himalaya, with minor advances subsequently (cited by Owen et al, 1997). But the same pattern of glaciation, as proposed in the model does not mean much for inference purposes. The local conditions of the region may have played an important role in determining the pattern of glaciation. Their role must be understood properly before making any comparision, as the importance of microclimatic variations on the behaviour of glaciers is as important as anything else.

The complexities are inherent in any attempt in fitting the region into a generalized scheme of glacial behaviour. It could be well understood by comparing the observation of Mayewaski and Jeschke (1979), with the ground realities. Having made the study of the fluctuations in glaciers throughout the Trans-Himalayan region, some scholars concluded that the glaciers have been on retreat, since about 1850. But there are evidences to show that the Bara Shigari Glacier advanced between 1860 and 1893, and it crossed the Chandra valley to block the Chandra River and produce a lake (Egerton, 1864; as cited by Owen et al 1996). It was proposed later by Owen et al

(1996) that the advancement of the glacier could be explained as a Sonapani-II phenomenon.

Owen et al, (1996) think that the other minor advancement i.e. Sonapani-I, of Lahul could be attributed to the Little Ice Age and correlated with the Shroder et al., (1993) and Zhang and Shi (1980) Little Ice Age moraines in the Hunza valley.

## 3.7 SUMMARY

The area has experienced three major glacial phases and two minor glacial advances. They have been given local name i.e., Chandra, Batal, Kulti, Sonapani-I and Sonapani-II, respectively. There are evidences in support of the view that the extent of glaciers got progressively narrowed in subsequent phases. A tentative explanation states that the rise of Pir Panjal Range might have blocked the inflow of monsoon into the region. The upliftment of the range was simultaneous with the occurrences of glaciations. But the timing of glaciation is widely debatable. The use of new dating techniques has come out with contradictory propositions on the various phases of deglaciation. Although there is no controversy on the tripartite pattern with two minor glaciation advances, yet their exact timing is all set to puzzle us in the near future.

## Chapter Four

# ROCK GLACIER

## 4.1 INTRODUCTION

Rock glacier is a peculiar type of landform found in the high mountains and latitudes. The importance of rock glacier, as an element of 'coarse debris supply system' (Mitchell et al, 2001) and 'geotectonic hazard' (Owen et al, 1998) is well established. But what is becoming more important is the realization that its changing behaviour could be used for the palaeoclimatic deciphering of those regions where glaciers are not abundantly available. Rock glaciers are one of the few less appreciated landforms, found in the glacial-periglacial landscape continuum.

The study of glaciations for the purpose of revisiting the palaeoenvironmental conditions has its own limitations. Although glaciers have been the major attraction for unraveling the mystery of the past climate, yet it is found only in the areas experiencing sub-zero temperature and getting fairly good amount of precipitation. The confinement of glacial features to fairly humid parts of the world is a major handicap for palaeoclimatic study of those regions, which are located in the semi-arid and low temperature regime. That's why one needs some additional palaeoclimatic indicators. The rock glacier may serve as one such indicator, in the areas of insufficient precipitation, but sufficiently lower temperature. It is equally important to mention here that some serious research on rock glacier is needed to make this indicator more sophisticated. Although, there is an appreciation of the relationship between climate change and the behaviour of rock glacier, yet we could not make out concrete conclusions about the nature of past climate from it. But inferences can always be drawn.

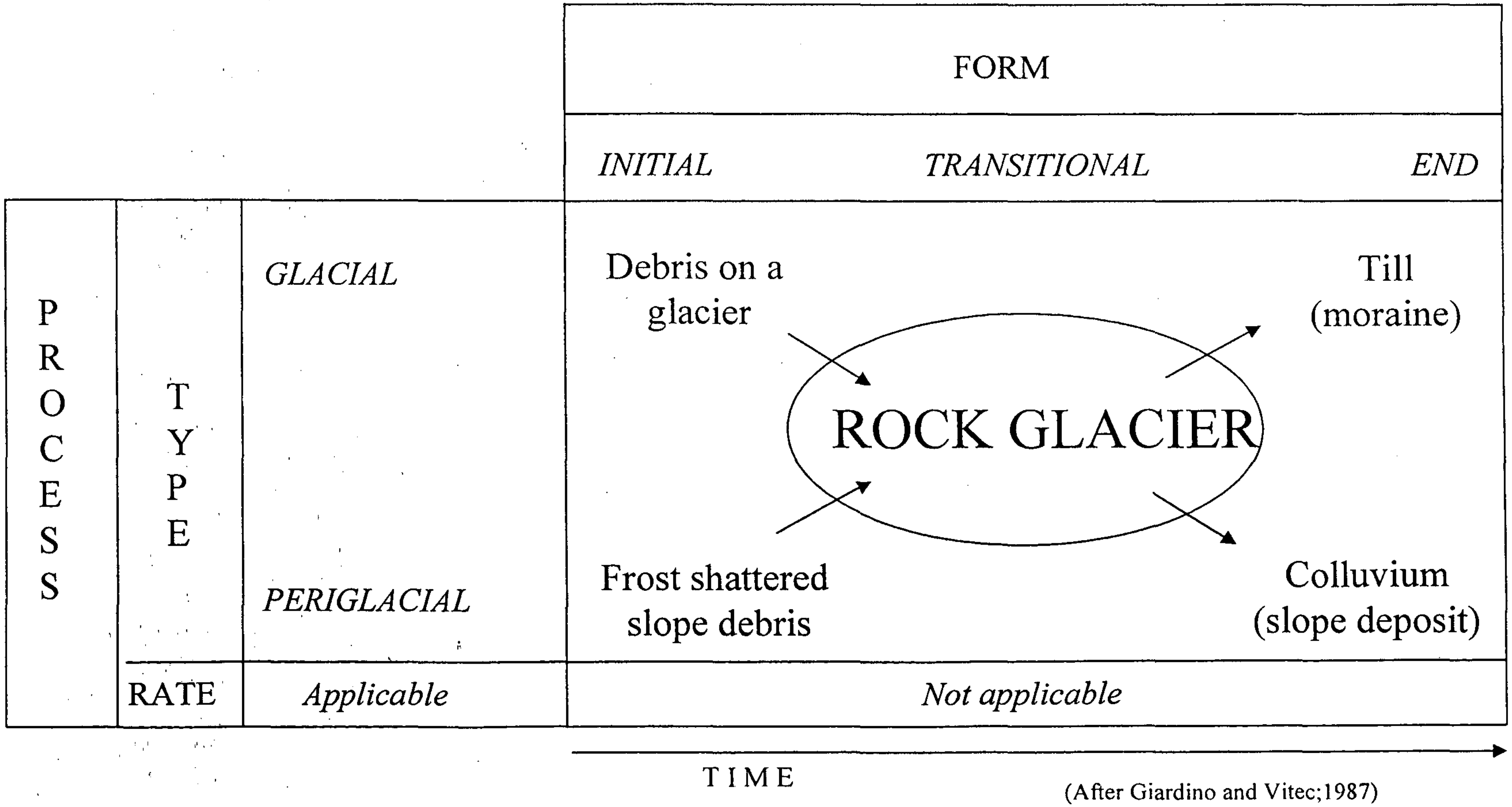
A rock glacier looks like a huge heap of poorly sorted, angular, and blocky to tabular debris. Its surface displays arcuate ridge and furrow topography, and thus has 'wrinkled' appearance. The sides, as well as front of this feature have steep slope. The whole mass is an unassorted mix of sediments and large rock fragments. This matrix of sediment and rock fragments show cohesion due to the presence of ice, which is found either in the form of ice core or interstitial ice. The deformation of the internal ice (available either in the form of ice-core or ice lenses) causes movement of the debris. The resultant movement is generally slow as well as differential, i.e., the whole body of this feature does not move simultaneously. Different parts move at different speed and time. The variation in the time and speed of movement is well displayed by its lobes (a feature found on its surface). The rate of movement ranges from less than 1cm per year to greater than 130cm per year (Giardino et al, 1988)

The definition of rock glacier is a widely debatable issue. The controversy on the definition is based on the various bases adopted by scholars for individual purposes, and the indiscreetness of the feature. This landform is rather found in continuum and merges unnoticingly into adjacent features, making it quite difficult to draw a line around it. The demarcation of boundary becomes all the more difficult as this landform represents a transition phase than an end product. Giardino et al., (1988) have made clear the linkage between rock glacier, on one hand, and initial and end landforms, on the other hand (*See figure 24*).

Among the various bases of definition, the morphological and genetic aspects are the most important. The debate between the proponents of these two streams of thought has already been highlighted in the first chapter.

*Figure - 24*

**THE EVOLUTIONARY LINKAGE OF ROCK GLACIER WITH OTHER LANDFORMS**



(After Giardino and Vitec;1987)

This study is based on the morphological definition of the landform. The other basis of study could have been genetic. But the interpretational differences between the multiple and various mechanisms involved in rock glacier formation makes genetic classification 'inherently faulty' (Vitec et al., 1987).

There are two states of rock glaciers, i.e. active and inactive or fossilized. The movement is unnoticed in the later state. In active state, rock fragments keep falling off its frontal ramp and the rocks at the ramp lack varnish. Giardino et al, (1988) have suggested that the movement of rock glaciers must be considered from a rheological point of view, wherein two states are merely two impermanent phases in the life of a rock glacier. The lack of observed movement is nothing but the indication of unfavourable condition, when the ice completely melts out from the debris. The inactive state of the landform is not irreversible. As and when climate changes and becomes favourable for the redevelopment of ice, in the interstices of the sediments and rock debris, the so-called 'fossilized', or inactive rock glacier becomes active. But it should be noted here that if the ice core, if any, of a rock glacier is lost once, it is lost forever. The reactivation is entirely dependent on the development and maintenance of interstitial ice. The attempt to divide rock glaciers as active and inactive becomes very complex in view of the fact that there are considerable variations in the rate of movement. Scholars have suggest that the concept of dividing rock glaciers on the basis of this aspect should be abandoned in favour of spatial and temporal continuum of form and movement (Giardino et al, 1988)

The time of post glaciation is especially favorable for the development of rock glaciers. The over steepened slope, which is very conducive for erosion and gravitational transfer of rock waste, is exposed after the retreat of glaciers. The removal of ice results in sudden stress release, which subsequently triggers various geomorphic responses. These responses are the attempts of landforms to attain equilibrium in a new set up and vary according to the lithological character of a region, or a part thereof. But, the lithological variation affects only the degree and nature of instability. No matter what may be the lithology, every region attains instable or metastable condition after the retreat of ice. The response to unloading is thus felt everywhere, although in varying intensity. The geomorphic responses are either in the form of immediate or delayed catastrophic failure, deep-seated rock mass deformation, and progressive slope adjustment by frequent rockfall activity giving rise to pro-talus ramparts. They result in rapid and extensive modifications of landforms and generation of rock waste, which may give birth to rock glaciers (Ballantyne, 2000).

There are two ways in which this debris gets converted into rock glaciers.

- First, the debris of rock may be impregnated with ice lenses in permafrost conditions and subsequently attains movement due to the deformation of the ice-debris matrix (as in the case of the rock glaciers at Baralacha).
- Second, if the debris that covers an ice-core left behind by retreating glaciers, later attains movement due to the deformation of the core. These glaciers are generally found near moraines or cirques (as in the case of morainic rock glaciers of Milang and Kulti valleys).

## 4.2 ROCK GLACIERS IN CHANDRA, BHAGA AND UPPER YUNAM BASINS

It is essential to be familiar with the personality of the area, in order to understand the distribution of rock glacier in the Chandra, Bhaga and upper Yunam basins. Although, the topic has already been dealt with in the second chapter, but for recapitulation purpose, let us put it in nutshell. The area, containing the Chandra and Bhaga basins, is located in between the Pir Panjal (Lesser Himalaya) and the Zanskar (Greater Himalaya) ranges of the western Himalaya. The third basin i.e., upper Yunam is located further north, in the trans-Himalayan zone. The increasing aridity towards north and east makes the entire stretch of upper Bhaga, upper Chandra and Yunam, a high altitude cold desert. The glaciers, although present everywhere, diminish towards north.

Rock glaciers are abundant in this region but only a few studies have been undertaken on their nature and bahaviour. These have been reported at higher elevation (more than 3200m) and to the north of 32°N latitude (Mitchell et al, 2001). Owen et al (1995) made the mention of rock glaciers in Lahul Himalaya, after conducting a study in the Milang valley. This was followed by few more observations but they were sketchy and descriptive. The study of rock glacier was never their prime concern hence they made only cursory reference to it.

The discussion on the distribution of this rock glacier should be concerned with two basic inputs i.e. moisture availability and sediment supply. The moisture, which is made available through precipitation, is needed for the formation and maintenance of ice in it. The presence of ice is vital to keep it active. But, precipitation should not be more than 250mm per yr (Mitchell, Taylor and Osmaston; 2001). It means that a perfect balance is needed between aridity and moisture availability. The sediment supply, which is determined by rock type, geology and environmental factors, is equally important.

The southern part of the Chandra and Bhaga basins is made up of high-grade plutonic or metamorphic rock of High Himalayan Crystalline (HHC) and low-grade meta-sedimentary rocks of late Precambrian to Paleozoic age (Thakur, 1992). The Zanskar Shear Zone brings the intensely folded meta-sedimentary rock of the Tethyan shelf that now forms the Zanskar Range, against the high Himalayan Crystalline (Searle, 86) The rocks located to the north of the Zanskar shear zone are susceptible to macrogelivation i.e. breaking of rocks into large boulders. This variation in the nature of rock is important in the determination of the type of rock disintegration, with respect to the generation of the specific clast sizes for talus (Mitchell et al, 2001).

The region has both types of rock glaciers i.e., talus derived or protalus and morainic or glacial. While the morainic rock glaciers are prominent in the south, the protalus rock glaciers are frequently found in the upper Bhaga valley.

There is a possibility that the climatic amelioration, in the postglacial period, resulted in the formation of morainic type rock glaciers. It took place when the glaciers where receding from their earlier positions and the amount of ice was gradually decreasing in the cirques and valleys. The thinning of ice exposed the hitherto ice covered surface. These newly exposed valley sides were vulnerable to severe erosion and mass wasting, which resulted in massive sediment flux. The two simultaneous phenomena i.e., gradual thinning of ice and massive release of sediments from valley sides, later resulted in the overwhelming proportion of debris and little ice. The ice, a reminder of the glacier, became completely covered with sediment and formed the ice core of the rock glacier. This kind of rock glaciers is found near moraines.

The protalus rock glaciers abound the upper Bhaga and upper Yunam valleys, and they seem to have little direct connection with glaciers. There is very much possibility that ice, in the debris, is found in the form of 'ice lenses'. Its origin is influenced by periglacial condition of the region.

To have a better evaluation of the relationship between local environment and rock glacier of the Chandra, Bhaga and upper Yunam basins, we need to pick up some of the important rock glaciers for case study purpose. Although, there has been reporting on the presence of this landform in these basins (by Owen et al, 1995; Taylor et al, 2000; Mitchell et al, 2001) yet substantial information is lacking. We have only vague idea about rock glacier-environment relationship.

The author visited some of the rock glaciers of the region. Few of they are very important in terms of their size and location, and have thus been picked for the purpose of case study. It is not claimed that the author has collected all the information provided here but at most of the places he did make his observations, in order to verify and enhance the existing knowledge base. It should be mentioned here that exclusive research on rock glacier of the region has been lacking and thus conclusive statement cannot be expected at this stage. Nevertheless there are quite a few research papers (especially on the nature and extent of glaciations) wherein we find some important information on its presence in different parts of the region. It is equally important to take a note of the fact that as this study in one of the first attempts on rock glaciers of this area, the effort may lack sufficient conviction and depth of analysis.

## 4.3 ROCK GLACIERS IN MILANG NALA

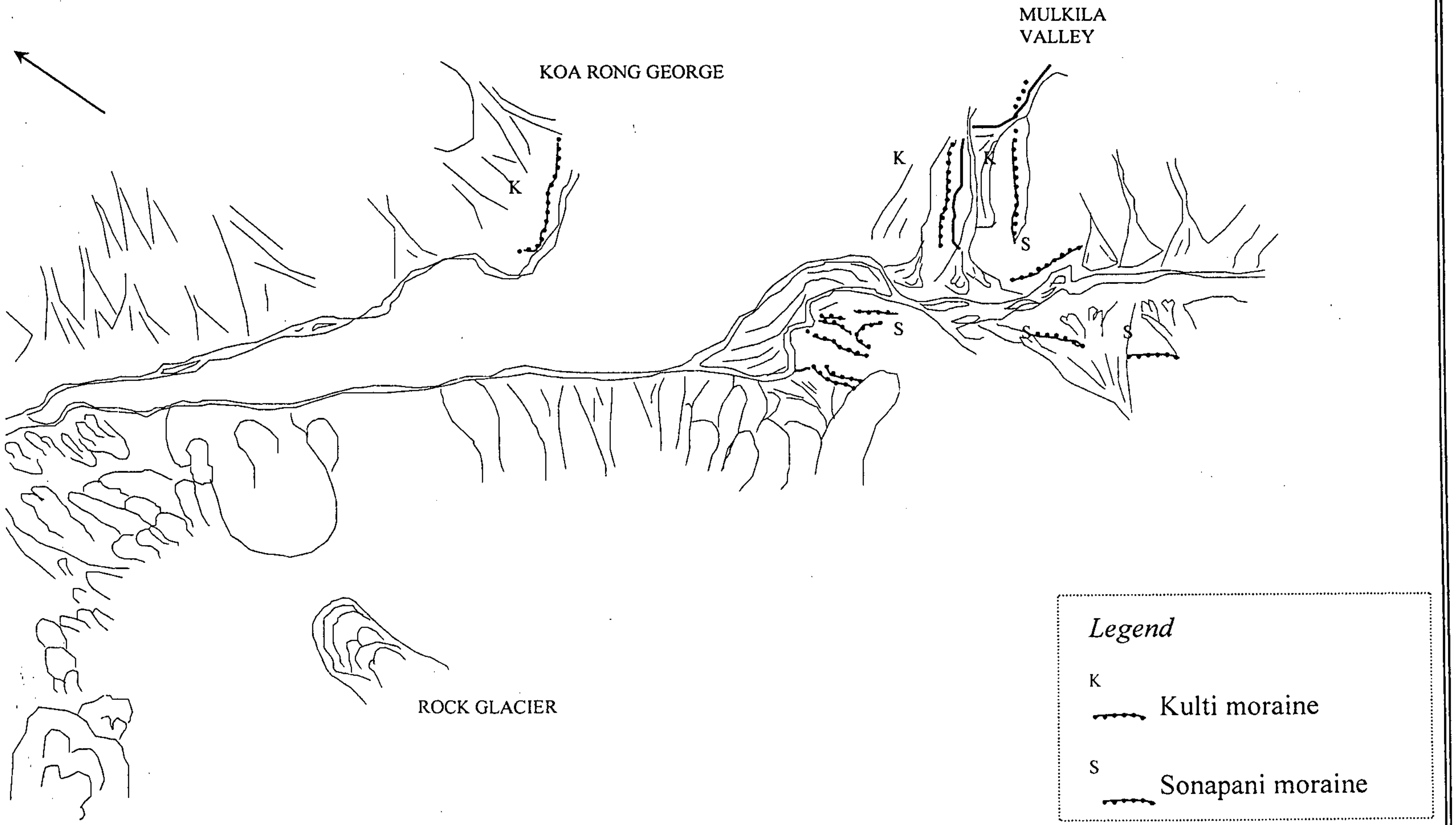
Owen et al., (1995) first reported the presence of active rock glaciers in the lower Milang valley (*See figures 25 & 26*). Milang is a left bank tributary of Chandra. Its confluence with the river takes place near 32°40′ N latitude. The area situated to the south of the valley is generally devoid of this landform.

There are two rock glaciers on the western bank of the valley. They descend from a moraine, which separate them from two north-facing cirques. These cirques are the abode of present- day glaciers. The RILA (Rock Glacier Initiation Line Altitude) of the eastern rock glacier has been calculated as 4250m (Mitchell et al, 2001). It is flanked with lateral moraines whose altitude varies from 4300m-3900m. The lower slope (below rock glacier) is covered with debris flow lobes. These lobes could be located in the diagram. The talus cone is a dominant feature of the area as well. It is found even on the top of the rock glaciers. The surface of rock glaciers has a complex look. There are evidences to show that the direction of movement has been changing in the past.

The other rock glacier is located to the west of the larger one by a distance of about a kilometer. It is also marked with complex series of ridges on its surface.

*Figure: 25*

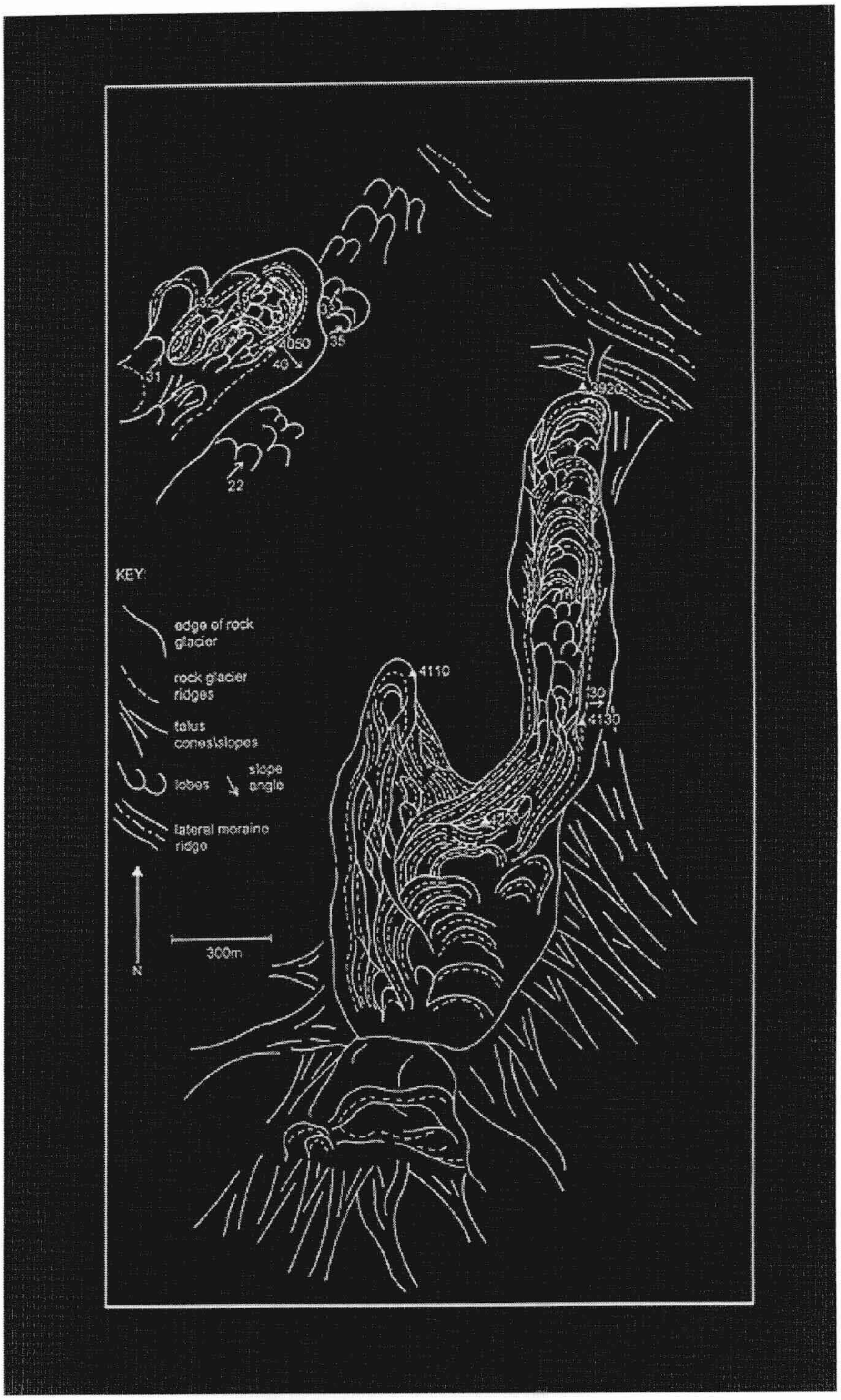
# GEOMORPHOLOGICAL MAP OF LOWER MILANG VALLEY



*Modified from Owen et al., 1996*

*Figure: 26*

# THE DIAGRAM OF ROCK GLACIERS IN LOWER-MILANG VALLEY



*Source: Mitchell et al., 2001*

The rock glacier could be noticed in the above-mentioned diagram. This, as well as the larger rock glacier, has active frontal ramp. They lack in vegetation and have a fairly high slope.

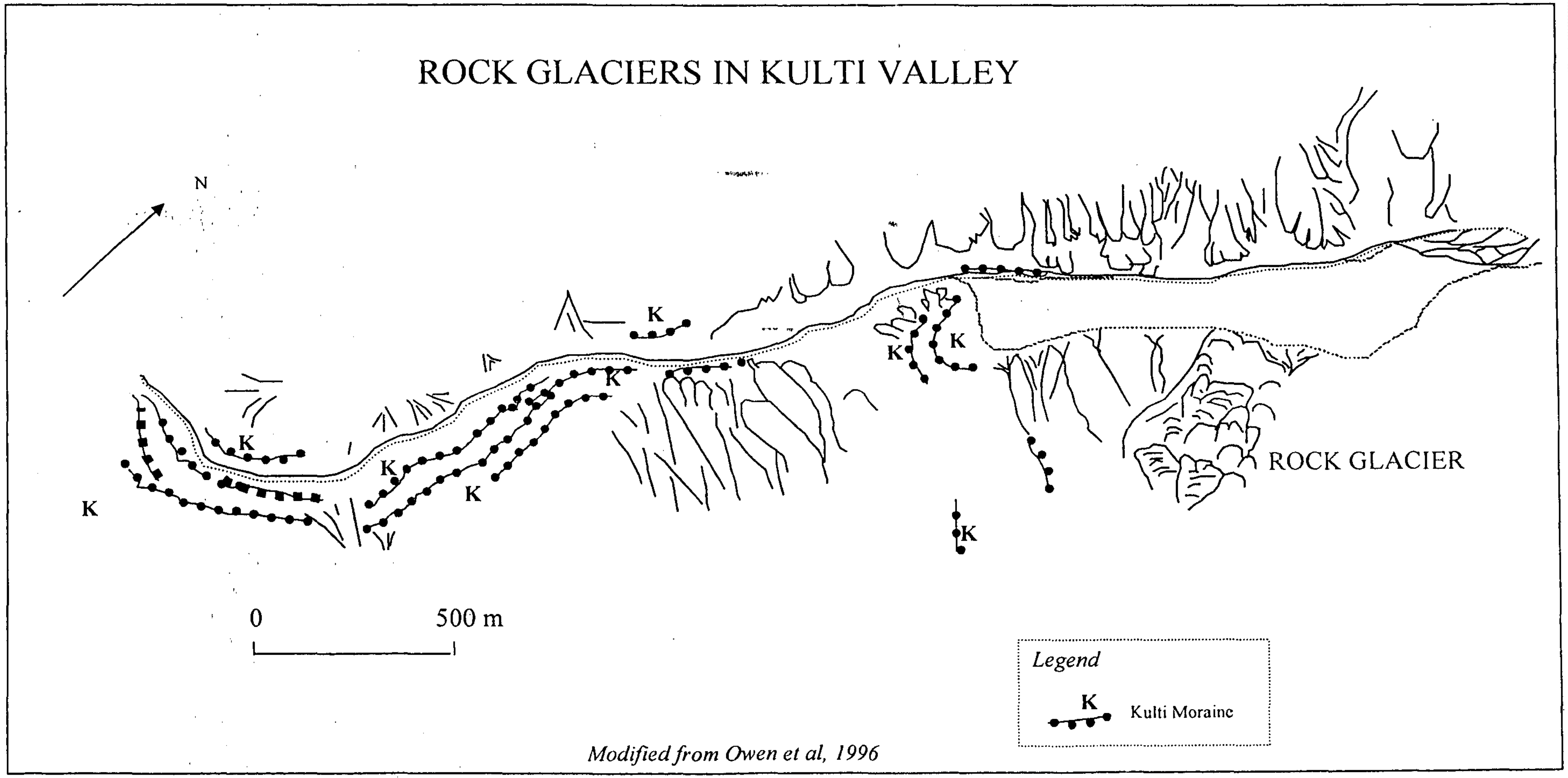
The origin of rock glaciers could be predicted on the basis of available geological evidences. The lateral moraine, which extends beyond the lobes of rock glaciers indicate towards larger extent of glaciers, some time in the past. The study of Owen et al, (1995) has fixed the limit of Kulti ice at 3610 metres. If this is true, then the rock glaciers are occupying the area left behind by receding glaciers. There is a strong possibility that the rock glaciers were initially developed as morainic type. This point is well emphasized by their nearness to moraines. These moraines have been ascribed to either Kulti or Sonapani glaciation (Mitchell et al; 2001).

## 4.4 ROCK GLACIERS IN KULTI VALLEY

This is an insignificant rock glacier of the region. Its location is at 32°25′N latitude. The first report on this rock glacier was provided by Owen et al, (1996) in a paper on the nature and extent of glaciation in the Lahul Himalaya (*See figure 27*). Although it was not the focus of the study and thus he did not give any description regarding this landform, yet he located it on the geomorphological map of the valley. The author has noticed the location of this rock glacier during the field trips in 2000 and 2002.

The Kulti is a right hand tributary of the Chandra River. Its flow is from north to south. The valley is famous for the glacial moraines of Kulti phase. They flank both the sides of the valley and are very prominent in the southern part.

*Figure: 27*



ROCK GLACIERS IN KULTI VALLEY

*Modified from Owen et al, 1996*

This is the same valley through which Sonapani glacier had been advancing and receding throughout the Pleistocene and early Holocene. Among the other important geomorphic features of the valley are the talus cone, solifluction and debris flow lobes.

The rock glacier is found on the western side of the valley. It's almost three kilometres away from the snout of Sonapani glacier. The glacier marks the northern limit of the valley, whereas the rock glacier is located in the middle. It is fairly large enough, and at some places its width is more than 400 metres. The sides and front of the feature are sharp, which indicates that the rock glacier is active.

The origin of this landform is linked with glacial recession. Although there has been a lot of glacial advances and retreat in the valley but the rock glaciers may not have originated before Kulti glaciation as the moraines of this phase are found on the much lower part of the valley.

## 4.5 ROCK GLACIERS OF BARALACHA LA

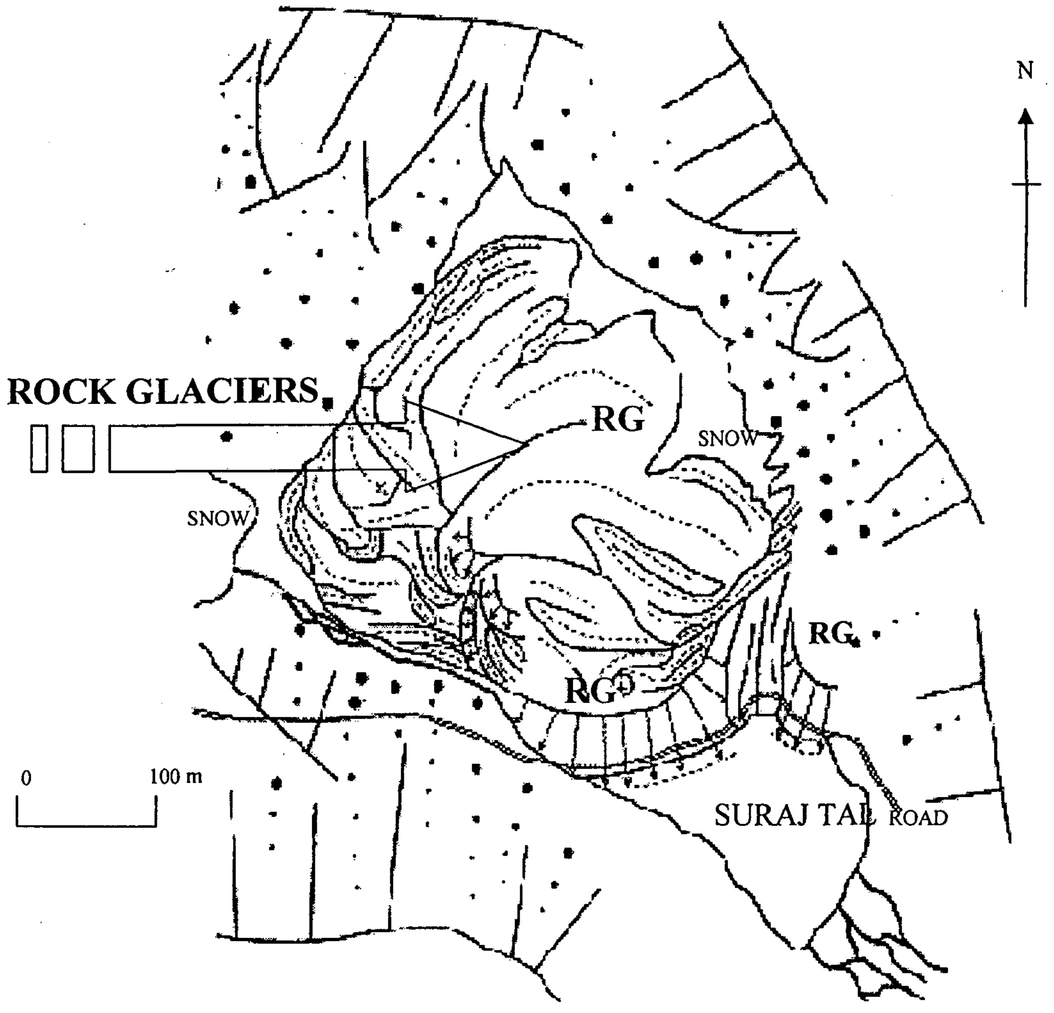
The upper Bhaga valley, Baralacha Pass and the upper Yunam valley are known for numerous rock glaciers (*See figure 28 & 29*). These are the areas of marked aridity and massive weathering. The slopes are unstable and covered with thick cover of sediments. The lack of vegetation is one important reason for unstable slopes that favour the development of this landform.

Rock glaciers in the upper Bhaga valley are located to the north of Patseo (3700m a.s.l.).

*Figure: 28*

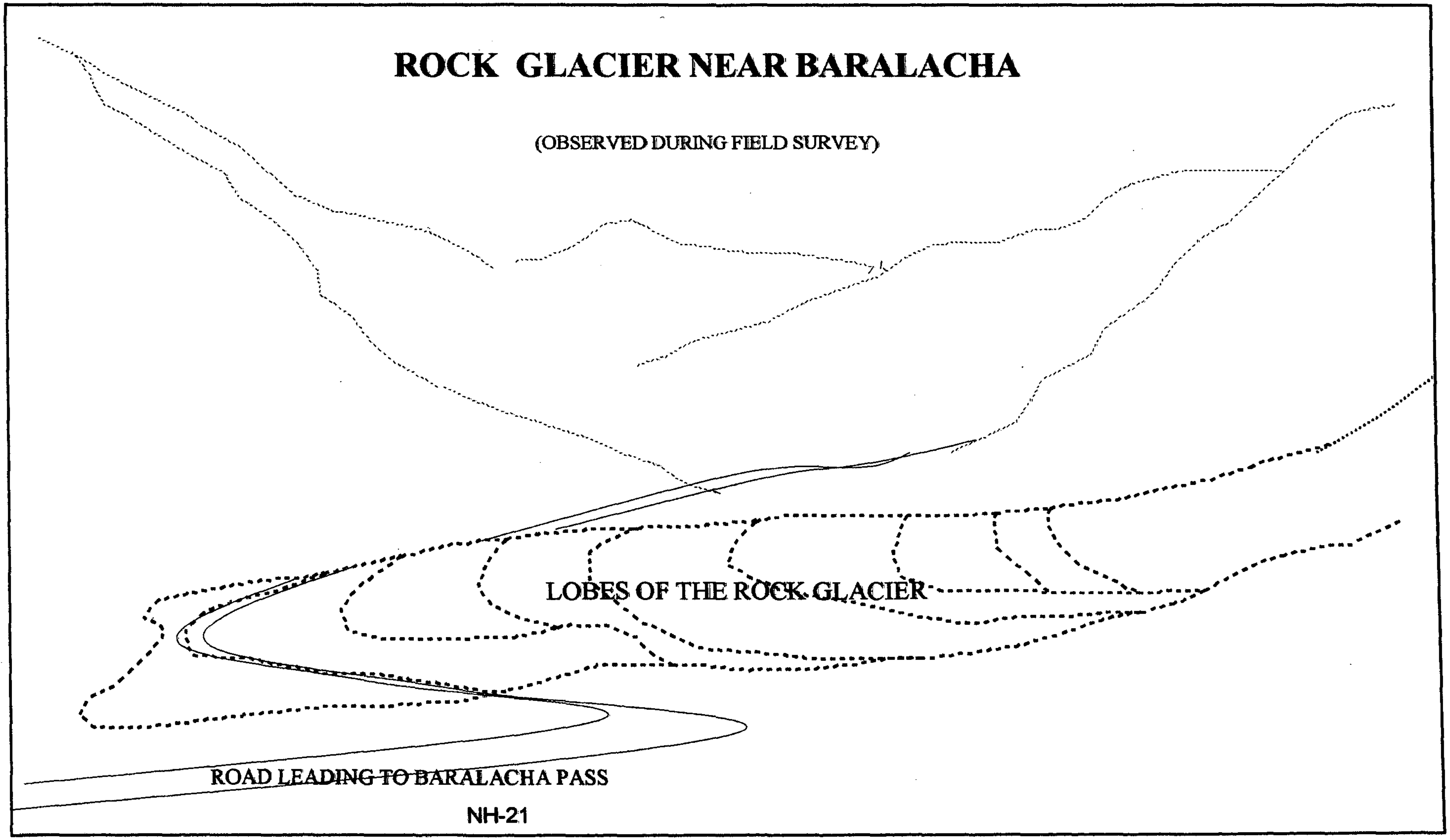
ROCK GLACIERS AT SURAJ TAL

(BARALACHA PASS)



*Modified from Mitchell et al., 2001*

*Figure -29*



**ROCK GLACIER NEAR BARALACHA**

(OBSERVED DURING FIELD SURVEY)

The size of glaciers diminishes and evidences of past glaciations become scarce from this place upwards. This doesn't essentially suggest that this area did not undergo glaciation in the Pleistocene and early Holocene. The suggestion of Mitchell et al (2001) seems logical that the glacial evidences are found buried under the thick mantle of sediment. The possibility of heavy sediment supply, by mechanical weathering, which might have covered the glacial evidences, cannot be ruled out especially in the light of the fact that massive sediment cones are found throughout the region. The paraglacial processes might have generated an accelerated amount of rock fragments on valley sides and bottoms.

Moving up the valley, we notice quite a few small and large rock glaciers but the one found near Zingzingbar (4265m a.s.l.) needs special mention (*See Plate*). It is a talus derived and tongue shaped rock glacier, found in valley bottom. The height of its front is about 35m above the surface and rests on an old moraine. The sediment size is quite large and most of them are angular. Mitchell et al, 2001) have calculated its RILA at 4500m.

The stretch of the valley between Zingzingbar and Baralacha has a large number of rock glaciers. They become progressively more numerous and extensive towards the pass. Many of them show active movement. In terms of geology, the carbonates of the Lipak Formation and arenaceous rocks of the Kuling Formation dominate the area near the pass (Sharma, 1986; Thakur 1992).

Among the various rock glaciers of the region, the one of special mention is located on the northern side of Suraj Tal at Baralacha La. The frontal ramp of the rock glacier has the slope of about 35° to 40°and it is more than 45m high from the valley surface. The size of sediment of it is smaller than the blocky nature of rocks found on the surface elsewhere. The rocks found over the surface of the rock glaciers sometimes exceed more than 1 metre in diameter. The blocky nature of debris could be explained by the nature of local rock i.e., low grade metamorphosed sandstone. It yields very easily to the weathering processes and breaks up into large rock fragments. The abundance of fine sediments at the ramp shows that the feature is still active and advancing. The contention that the Tal was formed due to its advancement, which blocked the Bhaga, seems true as rocks still fall off its body (Mitchell et al, 2001). The rock glacier is flanked with high cliffs from two sides. Its breadth could well illustrate the huge size of the rock glacier, which is more than 300m. A depression, partially filled with permanent snow, is found between the rock glacier and the talus of the valley wall. It marks place of rock glacier's origin. The RILA thus coincides with the depression and its height is at about 5000m a.s.l. The surface of the rock glacier is especially noticeable for the complex arrangement of small ridges. They are found in both positions i.e. longitudinally, as well as vertically, to its axis.

## 4.6 ROCK GLACIERS IN THE UPPER YUNAM VALLEY

The aridity of the upper Bhaga and Baralacha further increases into the valley of Yunam. The conditions responsible for the genesis of rock glacier continue to the north of the pass. Although, there are some important rock glaciers beyond Baralacha, this study has confined itself up to a place called Sarchu. This is located on the northern boundary of Lahul district. Beyond it Laddakh begins.

The valley of upper Yunam witnessed the same phases of glaciation, as did the area located to the south of Baralacha (Taylor et al, 1999). We find mention of rock glaciers in the study of glacial history of the area. The most important of them are located near Kelang Seri (*See figure 30*).

The rock glaciers align the western bank of the river. The lobes can be noticed in the map. There origin seems to be related with talus cones of the region. But it is premature to say anything with certainty till further investigations come out with more information in this regard.

## 4.7 ROCK GLACIERS NEAR CHANDRA TAL

The Chandra Tal area has already been mentioned in the earlier discussion on glaciations. The mention of rock glacier comes from the study of Owen et al (1997) on the glacial history of the region. Three lobes of rock glaciers have been depicted on the eastern shore of the lake (*See Figure31*). They are found among scree and debris flow and their lobes reach the lake from east. Its origin is not very clear. Ridges of sediments are found on their surface. The fronts show the evidences of 'life'.

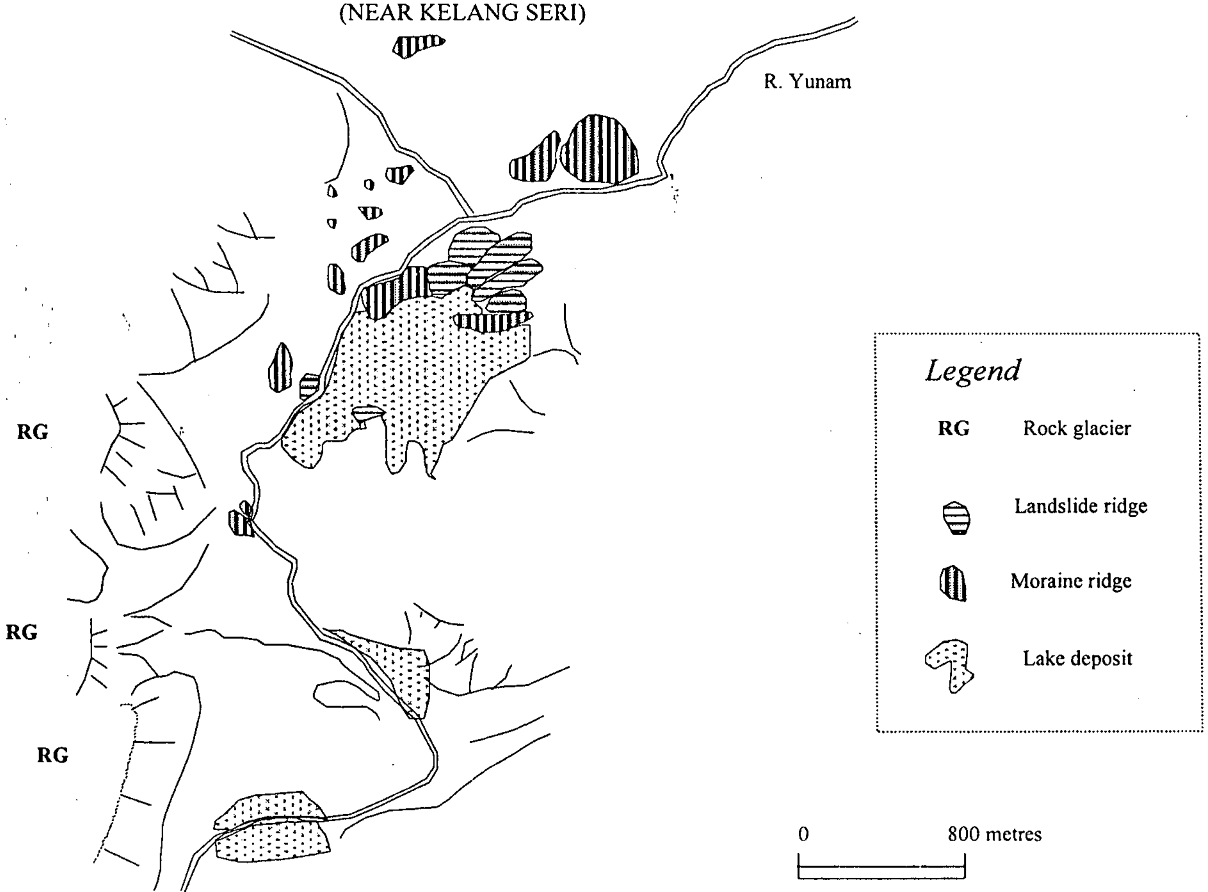
## 4.8 SUMMARY

Before making any attempt to explain the distribution of rock glaciers in the study area (i.e., Chandra, Bhaga, and upper Yunam basin) one should concede that the adequate explanation could not be provided till some conclusive study is undertaken on this landform.

*Figure: 30*

GEOMORPHOLOGICAL MAP OF UPPER YUNAM VALLEY

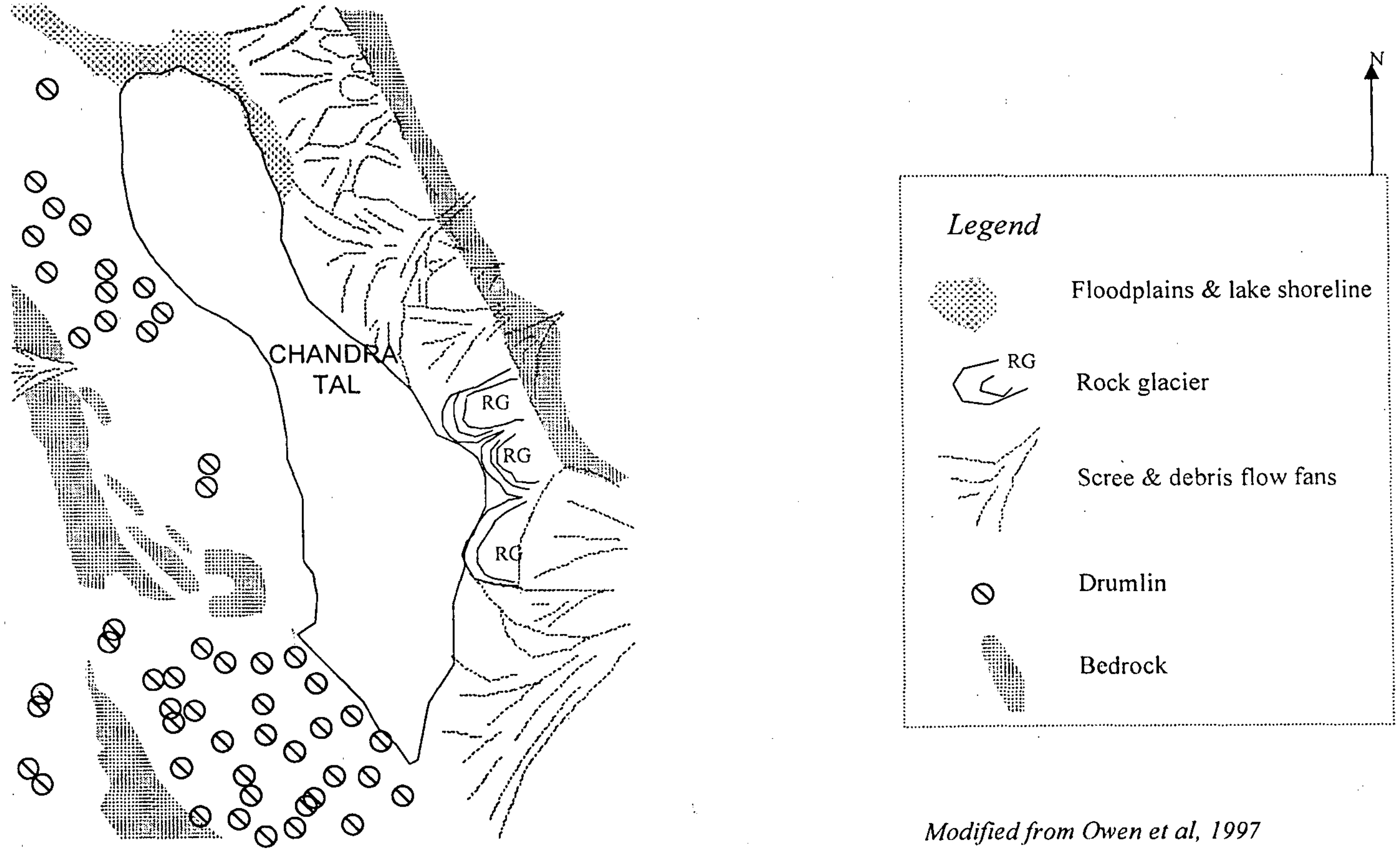
(NEAR KELANG SERI)



*Modified from Taylor, 1999*

*Figure: 31*

GEMORPHOLOGICAL MAP OF CHANDRA TAL REGION



*Modified from Owen et al, 1997*

The origin and nature of the feature is generally decided by the climatic history and geology of the region. The association of rock glaciers with glaciations is very clear at those places where the moraines are found very near to them (e.g., lower Milang valley and Kulti valley). The role of aridity is also illustrated by the fact that this landform is not found to the south of the Rohtang Pass. The attenuation of rainfall, to the south of the Baralacha Pass, makes the conditions favourably arid for its development in the upper Bhaga basin. The study of Mitchell et al (2001), has fixed the Milang valley as the southern climatic boundary of rock glaciers distribution, but the veracity of this statement is doubtful as the rock glaciers are found even in the Kulti valley, which is located to the south of this limit and also opposite the Rohtang Pass.

The attempt to explain the distribution on the basis of glacial history of the region has its limitations. An entirely different factor is responsible in the upper Bhaga valley. It is rather sediment supply, which is dominant hare. The rocks disintegrate into larger blocks through the process of mechanical weathering. The debris is later impregnated with ice lenses and turns into rock glacier.

The above-mentioned explanation may be dangerously simple and needs further field verifications and measurements. It is all the more important as the rock glaciers are rather transitional landforms than the end products and their blurred distinction with other geomorphic features makes their identification difficult in field.

Chapter Five

# SUMMARY AND CONCLUSION

The Chandra, Bhaga, and upper Yunam basins are characterized by youthful topography. While the first two basins fall in between the ranges of Greater and Lesser Himalaya, the upper Yunam basin is located to the north of the Himalayan mountains (or in the Trans-Himalayan zone). The region has high elevation, which is well illustrated by the fact that the elevation range of 15,000-20,000 feet (4573 metres-6098 metres) has the maximum share (62%) in the total area of the region. While the mean height of contours is 17,693 feet (5394 metres) the maximum and minimum values are 21,500 feet (65549 metres) and 10,000 feet (3049metres), respectively.

The physiographic variations could well be noticed between the river valleys and the Central Triangular Mass. This is a part of the Great Himalayan Range and forms the abode of large glaciers. The Chandra (136 km) and Bhaga (64 km) rivers are mark its right and left boundaries. The Yunam flows to the north of the Baralacha Pass and its upper stretch is known for dissected topography, and a further downstream, as a misfit river.

The relative as well as absolute location and relief of the area affect its climate. The temperature is controlled altitudinally and the higher areas have lower temperature regime. But the precipitation, which is low, is mainly controlled by altitude as well as latitudinal location. It decreases gradually towards the upper Bhaga and Chandra basins and the upper Yunam basin experiences the minimum amount. It is but natural that the monsoon gets attenuated after crossing over the mechanical barrier of the Lesser Himalaya through mountain passes. The other circulation system that is responsible for precipitation is the western disturbance. Its share in the total amount of precipitation is more than that of monsoon. The maximum precipitation is experienced in the month of March. The months of July and August experience the maximum temperature. The months, from May to September have pleasantly high temperature. The temperature goes below the freezing point, in the months of December, January, February, and March. The months of October and November fall in the period of transition, from summer to winter. The temperature goes down well below freezing point for over two or three months in a year. Thus the region is favourable for periglacial processes.

The vegetation is scanty and trees are confined to the lower parts of the Chandra and Bhaga valleys. Shrubs and grasses dominate the non-glaciated areas. There are large glaciers everywhere and are very important part of the landscape. They continuously feed the numerous streams of the region and thus increase their denudational activity manifold. The character and bahaviour of streams are determined by the peculiarities of melt water. The fluctuation in discharge, which carries a large amount of load, is both seasonal and diurnal. Although small streams are many, the large streams (the Chandra, Bhaga, Jankar and Yunam) are limited in number.

The evidences of glaciation abound the region. These are found mostly in the form of glacially related land features e.g. palaeo-cirque, U-shaped valleys, truncated spurs, moraines, drumlins etc. The possibility of various glacial phases has been well established by the moraines of various ages and glacially eroded benches, which flank river valleys today. The glaciers predated the present day river valleys. Although, the glacial chronology of Lahul Himalayas has not concretized yet, as it is based on various dating techniques and a fair idea is evolving. The relative chronology of the area has been established using morphostatigraphy, lichenometry, stage of soil development, thickness of rock varnishes, stage of vegetation development and the effect of weathering processes. The study of thick sediments and landforms considerably assist in the assessment of former ice positions and extent.

The evolution of the region is polyglacial, with three major glacial phases, and two minor advances. The names of these phases have been given after those localities (type-site), where the evidences of particular glacial phases are found in abundance. The sequence of major glacial phases has been identified, as the Chandra, Batal, and Kulti. The other two minor advances have been named as Sonapani I, and Sonapani II. The successive phases of glaciation got progressively narrowed and constrained into the pre-existing valleys. The Chandra was the first and the most extensive glaciation. Its evidences are found at high elevation (more than 38,00 metres). It was followed by the Batal glaciation. This stage could be divided into two sub-types on the basis of the altitudinal position of landforms. The peculiar characteristics of this glaciation, which was marked by an oscillating regression or a re-advance, created two sets of landforms, superimposed on each other, at some places. These two parts or sub-stages of the Batal glaciation are called as Batal I, and Batal II. Optically stimulated luminescence (OSL) dating indicates that glaciers probably started to retreat between 43,400 ± 10,300 and 36,900 ± 8,400 years ago during the Batal stage. The Kulti was the third important glaciation phase. It is younger than 36,900 ± 8400 years ago. The lateral and end moraines of this glaciation are well preserved, and less vegetated. The moraines of this phase are found not beyond 12 metres from the present position of snouts. Besides the above-mentioned major glaciations, the area experienced two little advances, the Sonapani-I and Sonapani-II. The moraines of this age are sharp crested with sparse vegetation and are found not more than 5km and 2.5km away from the snouts of glaciers. These advances are supposed to be the local variant of the Neoglacial (4500 years before present) event, and Little Ice Age, respectively. It is important to note that the chronological correlation between the glacial history of this region and other similar regions is not possible at this stage, due to the lack of exact dating of glacial phases of Lahul.

Rock glaciers are an important feature of the region. They are found at various locations but their nature and bahaviour have not been properly studied. Although not restricted, yet in most the cases, they are found at higher elevation (more than 3200m) and to the north of 32°N latitude. The upper reaches of Bhaga valley (particularly between Baralacha and Zingzingbar) are especially suited for such landforms. This could be explained with the increasing aridity and heavy sediment supply. The rocks located to the north of the Zanskar Shear Zone are susceptible to macrogelivation i.e. breaking of rocks into large boulders. This variation in the nature of rock is important in the determination of the type of rock disintegration, with respect to the generation of the specific clast sizes for talus. The larger block of rocks could be easily impregnated with ice, under suitable climatic conditions. The semiarid condition, due to decreasing precipitation towards north, encourages the transformation of rock debris into rock glaciers, which are mostly of protalus type. The most of them have sharp edged sides and ramps, indicating their active state.

Some important rock glaciers are located to the south of this limit. These are found in association with glacial moraines of past glaciations. The decreasing aridity and rising temperature in the post-glaciation period could be accounted for their evolution.

When the glaciers were receding, the supply of sediment increased manifold, as the newly exposed slopes had started adjusting with the new environmental conditions. When the proportion of debris increased in the depleting ice of receding glaciers, a matrix of sediment and ice resulted, which was completely different from glacier. It had ice core within the thick veneer of sediment. This new feature came to be known as morainic rock glacier. It is found near moraines.

The salient findings of the study on the relationship between environment and rock glaciers of Lahul can be recapitulated as follows:

(a) There are two kinds of rock glaciers in the region- morainic rock glacier and pro-talus rock glacier. While the former is directly associated with the receding glaciers and have ice cores whereas the later is not directly linked with receding glaciers and represents favourable environmental conditions for the development of ice lenses.
(b) This feature has been observed at only those locations, which have periglacial conditions.
(c) The role of aridity is important in its evolution, as it is not found to the south of the Rohtang Pass, where amount of precipitation is high. The attenuation of rainfall makes the conditions favourably arid for its development in the upper Bhaga basin.
(d) Besides climate, there are other factors which play important role in the evolution of this feature and most important among them is the amount and nature of debris production, controlled by the type of rock.

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# PLATES

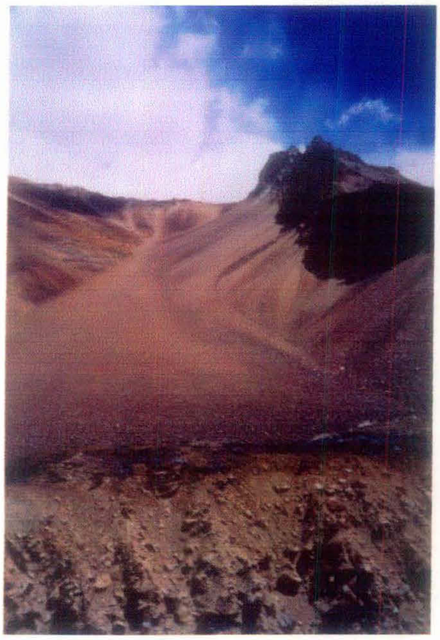

PLATE 1: This landform is located to the north of the Baralacha La. The effect of intense weathering is quite visible on this landform. The reddish colour suggest that chemical weathering is prevalent here due to the recent exposure of rocks. The lower portion of the photograph shows glacial deposits (a mix of sediment and angular fragments of rock).

PLATE 2: Flow slide at Darcha is supposed to have evolved post Batal Glacial, on release of ice pressure from the bedrock.

PLATE 3: Confluence of River Chandra and Bhaga at Tandi. High terraces originated during the maximum expansion of ice cover, as represented by thick glacial sediments in the left foreground and lateral moraine ridges in the middle background.

PLATE 4: Braiding of rivers is a common feature in the region although the river is in formative stage. The over-loaded streams with very high discharge fluctuation, frequently shed their burden at the earliest opportunity. This braiding is the result of the Batal Glacier advance in to the main Chandra Valley.

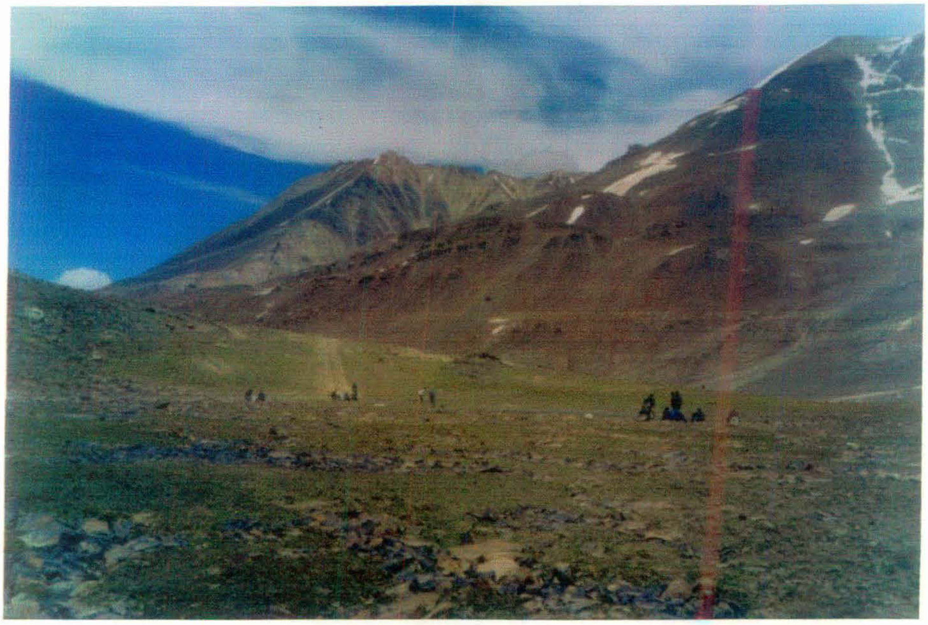

PLATE 5: Evolution of patterned ground is encountered above 4500m in the region. A periglacial landform at the Baralacha Pass.

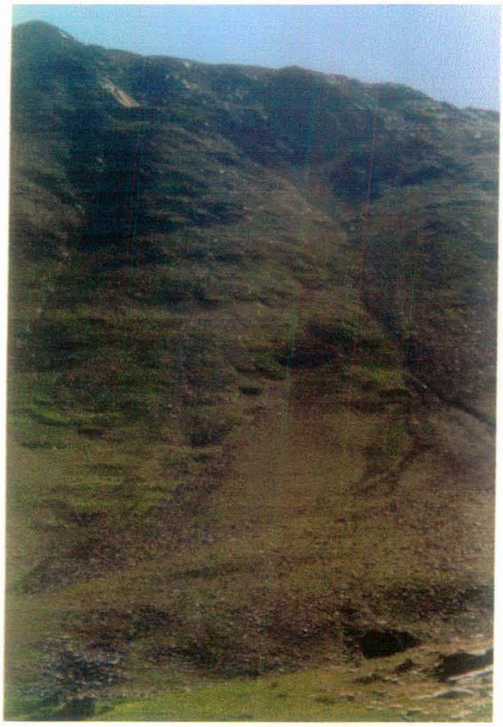

PLATE 6: Solifluction lobes above Batal at an altitude of 4400 m. Frost-shattered sediments are modified both by periglacial and slope processes in the region.

PLATE 7: The drumlins are seen on the left of photograph near the Chandra Tal at 4200 m. These are related to the Batal Stage Glacial episode. The Samundri Glacier in the background is famed for its proglacial lake and high glacial benches on Samudri Tapu

PLATE 8: The Chandra Tal lake formed at the palaeo-ablation valley, behind rock-bar as seen on the right background. Present source of water is from the subsurface seepage from the small glacier and snow-melt.

PLATE 9: An unconformity in the upper Bhaga Valley. Note that the weaker zone is now a course of a glacier and a stream. Strata on the right are sub-vertical, on the left it is sub-horizontal.

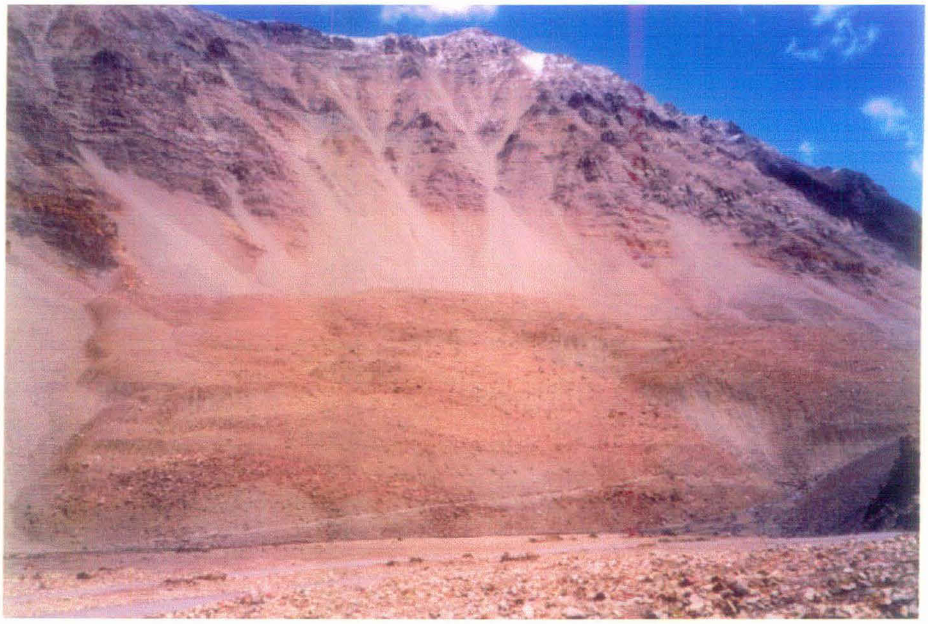

PLATE 10: This is a classical rock glacier observed to the southwest of the Baralacha La at 4800 m. The lobes that are clearly visible on its surface indicate the Cater-Pillar movement within it. Its highly lobate surface distinguishes it as a "Lobate Rock Glacier".

PLATE 11. Supra-glacial debris covered snout of the Batal glacier, with its snout and recent terminal moraines. Note that this glacier has retreated almost thirty meters in last three decades as visible form the recessional moraines in front of the snout.

PLATE 12: Frontal position of rock glacier near the Suraj Tal at Baralacha La (4895 m). This is highly active rock glacier which blocks the National Highway 21 due to falling boulders and sediments. People in the centre for scale.

PLATE 13: The Lingti Plain has been incised by the river that makes a canyon through it. These sediments are of both glacial and glacio-fluvial in origin. Neotectonic activity on the terraces are visible at its junction with the Chherup Chhu.

PLATE 14: This big boulder doesn't seem to be a part of the local geology of the Lingti area. Perhaps it was brought all the way by glacier, from the Zanskar Normal Fault. The ice-shed was located to the south of this fault-line.

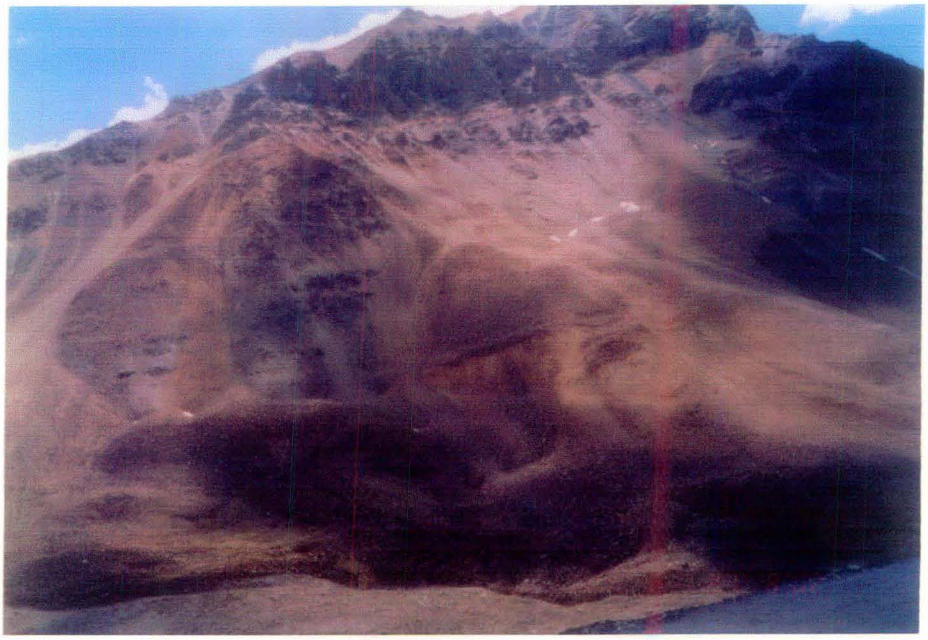

PLATE 15: A pro-talus rock glacier above Zingzingbar. These are distinguished as pro-talus rock glaciers. There may possibly be a periglacial connection in its evolution.

PLATE 16: Lobate rock glacier in front of Suraj Talis seen here on the side of the Suraj Tal. The front is approaching the lake and there is a possibility that the lake evolved when it had blocked the flow of the Bhaga sometime after the retreat of glaciers in the area.

PLATE 17: This is a beautiful example of roche muotonnee at Baralacha La. The front of the landform is the lee side of it. It shows the direction of ice movement from the pass to valley. There are many in all three directions.

PLATE 18: A complicated structure with intense folding during tectonic movement. The volcanic intrusive of Baralacha are famous in geological literature.