GEO-ENVIRONMENTAL STUDIES OF THE KHASI HILLS WITH SPECIAL REFERENCE TO LANDSLIDES.

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I Rajiv Kumar Dutta Chowdhury hereby declare that the subject matter of the Thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the Thesis has not been submitted by me for any research degree in any other University/ Institution.

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Chapter 1

Introduction

Chapter 1

Introduction

In Environment Resource Management, Geomorphology is a vital component whose influence on the pattern of development at a particular place is immense. Invariably when man utilize land, he has to accommodate its relief, materials and water resources to his purposes, for which he has to understand the geomorphology of the area he desires to harness. Geomorphic knowledge plays a valuable role in the management of land resources, which means planned utilization of land and mitigation of Geo-hazards. It emphasizes the land-man interactions in which Geo-Environmental processes and socio-economic activities interplay. Knowledge of the processes, which design landforms, is necessary for understanding landscapes. Thus, we can see that there is a direct interaction between Geomorphology and environment.

Environment has different connotations to different people depending upon their perceptions. Landscape approach to environment considers various attributes of environment and produce thematic maps for land resource utilization. Geomorphology traditionally focuses on the study of landforms and the processes of their formation. But, of late, it has made major contributions by providing the basic data and concept for the creation of man-made landforms, having long term stability. The linkages between Geomorphology and climate or hydrology have received much attention. But there has been little systematic study of the interrelationship between Geomorphology and living organisms, particularly 'man'. Man has established himself as a Geological agent by causing consequences of industrialization, which often degrade the environment.

Urbanization and development are related to topographic, hydrographic and socio-economic features. So, Geomorphology always comes in the forefront wherever environmental exploitation takes place. As a result, Geomorphological studies have begun to consider ecological factors in more depth. Within the contemporary concern for environmental management, many problems relate to the interactions between man, land and water. Environmental Management recognizes a need of an integrated approach for rational utilization and conservation of land and water resources. This is possible only if the characteristics of the terrain to be used are known. Thus Geomorphology plays a pivotal role in all developmental programmes and projects. The knowledge and information of the geomorphic attributes of an area form an important database before any developmental activity is initiated to have minimum environmental imbalances. The land resource management differs in different geomorphic domains. As a result environmental management strategies also vary to mitigate a common Geo-hazard from one geomorphic domain to another.

Environmental degradation is inevitable under the normal operation of natural geomorphic processes. In general, these processes do not degrade the environment beyond its resilient capacity and the resultant scenario is in equilibrium state at any given point of time. However, environmental imbalances soon overtake whenever this equilibrium state is disturbed by the unplanned and unscientific anthropogenic activities.

The understanding of geomorphology of the area to be harnessed is the basic step in any environmental appraisal study. The slope and relief characteristics, the pedological characteristics, the climatological and hydrogeological conditions and geology are some of the parameters that control the landform configuration and denudational history of a particular area. These parameters are interlinked with each other and any one of them may assume dominance over the others in shaping particular landforms. These parameters also determine the suitability of a location for construction of dams, railways, highways, electrical power lines, industrial complexes, townships, irrigation-distribution of channel networks, defence, strategic installations, etc. In a way Geomorphology helps in rationalizing and integrating developmental schemes with the land resource.

Thus the importance of Geomorphology in any developmental activity cannot just be overruled. Environmental Management calls for understanding the geomorphology of an area before the land is used as a resource. The main idea is to identify individual landforms or landform complexes as either favourable or unfavourable to a particular type of economic activity. In areas where developmental activities underestimate or ignore geomorphological characteristics, it is bound to create socio-economic conflicts and serious environmental imbalances.

It is in the light of this relationship between Geomorphology and environment that the present study on landslides in Meghalaya has been conceived to understand the geomorphology along with the lithological characteristics of the landslide prone areas to minimize the landslide occurrences.

The North Eastern region of India comprises mainly of mountains, hill ranges and narrow valleys. The soils of the highlands are becoming increasingly denuded and deforested and have reached the most degraded state due to over exploitation by human interference. The incidence of disaster caused by landslides has been on the rise in recent times. Though there are many landslides in uninhabited areas, disaster is said to occur only if landslides take place in an area where men live or areas of rapid pace of development in a hilly region.

A hazard is a phenomenon associated with geomorphic and geologic processes that can produce a disaster when a critical threshold is exceeded and can result in significant loss of life and property. The distinguishing mark of a geologic hazard compared with other natural damages is its short duration.

The serious measures taken to abate imminent hazards arise in the form of investigations that seek to identify hazardous conditions. It is true that if all potentially dangerous areas were considered, there would be few places for settlement. Geomorphology is the study of land-water system. It is the science, which is more concerned with the study of landforms. Geomorphology provides scientific basis to the study of terrain particularly the sources or causes of geo-hazards and geomorphic risks associated with it.

Landslide includes all varieties of mass movements on hill slopes. It can be defined as the downward and outward movement of slope forming materials composed of rocks, soils and artificial fills or a combination of all these along the surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another under the influence of gravity. Landslides are frequent where developmental activities or constructional activities have modified slope profiles particularly making the profile segments steeper in sections. This makes the slope unstable with a tendency to fall as and when the equilibrium is disturbed.

Detailed studies are necessary to assess and calculate such factors as the size and shape of the unstable mass, the nature and composition of the rock types and their structures, the attitude of joints and bedding features and the water characteristics of the area. Thus a combination of Geologic, Geomorphic and Geotectonic studies with soil and rock mechanics is necessary. These data can then be evaluated in terms of a total benefit –cost ratio for the project to determine the level of safety index – the quantitative analysis of the resistive forces versus the shearing forces. When this ratio is 1.0, the area is stable, but generally a safety of more than one is necessary and desirable.

Hazards due to landslides and mass movements are a common phenomenon especially in a tectonically fragile and sensitive mountainous terrain like the North-Eastern part of India. Among the various natural hazards, landslides are treated as the most widespread and damaging hazard. The landslide causes loss of life and property, damage to natural resources (vegetation, land, soil, etc.) and hampers developmental projects like roads, dams, communication lines, bridges, etc. For instance, the damage caused by landslides in the Himalayan range is estimated to cost more than US $ one billion besides causing more than 200 deaths every year.

The high susceptibility to landslides of highlands of North-Eastern India is mainly due to complex geological setting with contemporary crustal adjustments, varying slopes and relief, heavy rainfall along with the ever increasing human interference. The unplanned construction of roads and buildings due to financial, time and other constraints may have increased the landslide susceptibility.

Mitigation of landslide disasters can be successful only when detailed knowledge is obtained about the expected frequency, character and magnitude of mass movement in an area. To take a quick and safer mitigation measure and future strategic planning, identification of landslide prone areas and landslide hazard zonations are important.

The phenomenon of landslides is less studied than other geologic hazards such as earthquakes, volcanic activity and floods. However, this is changing because a new awareness is emerging about the dangers of landslides and the problems encountered as we expand our habitat more and more onto hillsides.

The state of Meghalaya is one with an undulating topography having high hills, deep valleys and gorges. The state is situated on a plateau, which is the north eastern extension of the Indian Peninsular Shield. The state falls upon a part of major seismic zone and the zone of heaviest rainfall. All these factors bring on very high and large scale instability of slopes. Moreover ongoing indiscriminate developmental activities mostly along the road networks are greatly modifying the slopes and making them prone to landslides as the stability of slopes get affected.

The over burden and rock mass strength controls the initial development of a hill slope and the evolution of slope profile continues as long as rock mass strength in terms of lithology and rock index properties does not change. In the state of Meghalaya till now no such study has been undertaken.

1.1 Literature Survey

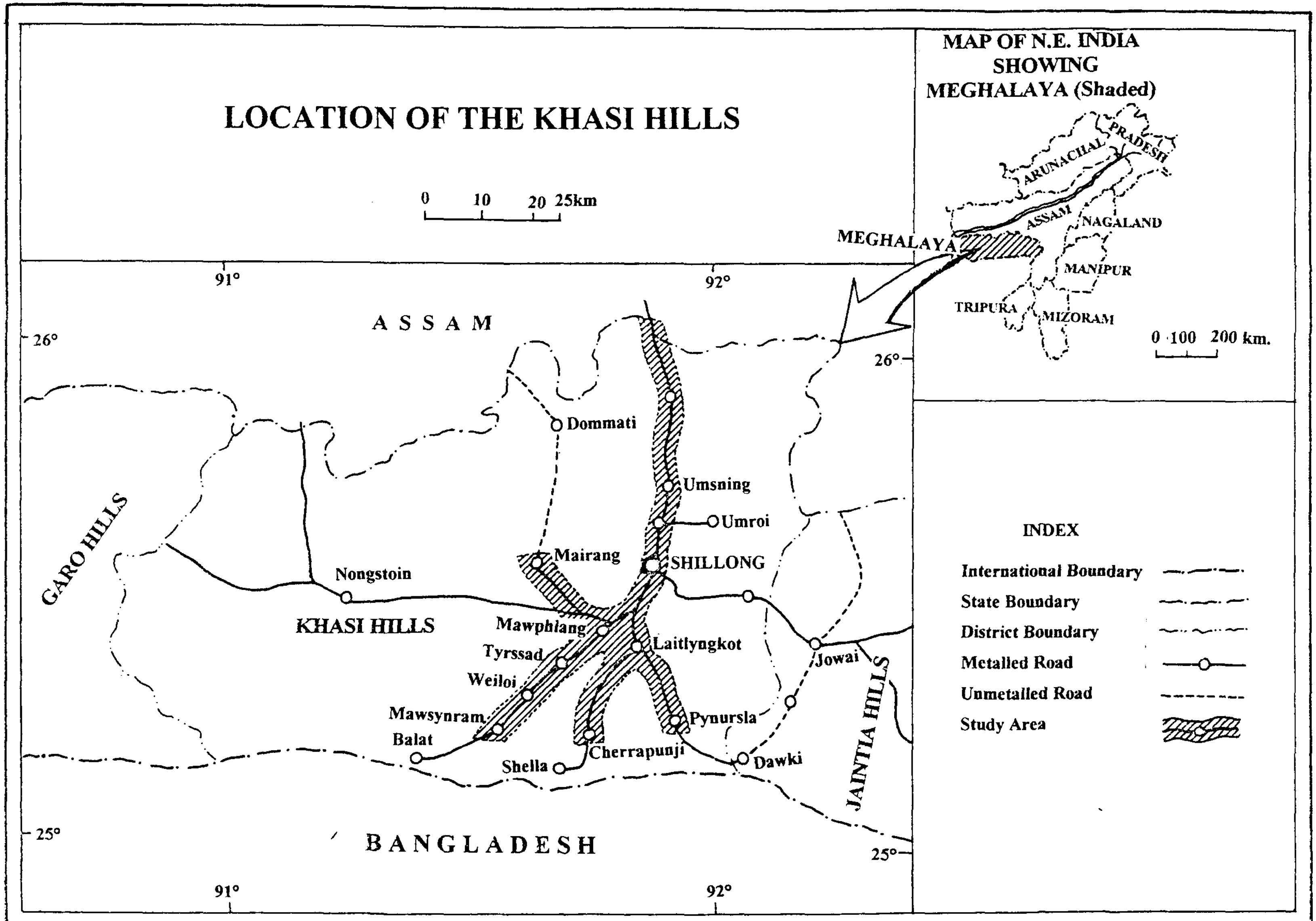
Geomorphology is an interfaced discipline between geology and geography. As a result, the study of Geomorphology has attracted geographers as well as geologists, each with diverse objectives. The geomorphological studies of the late 1800's and early 1900's had strong influence of geology but around mid 1900's geomorphologists like Andersson (1906), Smith (1935), Kesseli (1946), Bryan (1950), etc. strongly advocated an empirical approach or descriptive approach to geomorphology. Zakrzewska (1967) however, opinioned that simple descriptive geomorphology is incomplete without the genetic information, for which integration of geology with geomorphology was a prerequisite.

At the same time qualitative Geomorphology was gradually incorporating quantification mainly through the efforts of Horton (1932), Smith (1935), Strahler (1950), Schumm (1956), Chorley (1959), Leopold (1964), King (1966), Durry (1967), etc. This transformation proved to be the turning point in the study of geomorphology because by this time it was recognized as an important component of environmental studies. In the Indian scene, significant contributions had been made by Singh (1969), Dixit (1976), Rai (1994) and many more.

As far as Meghalaya is concerned, Oldham (1858) was the pioneer to establish the Geology of this region from the Geological Survey of India. Subsequently Medlicott (1869), Das Gupta (1934), Evans (1964), Gogoi (1975), etc. gave the geological account of the area. A very generalized regional physiography has been given while discussing the geological framework of the north-eastern India.

Here are some accounts of the different studies that have been carried out related to slope instabilities throughout the world.

The disastrous flow slide in colliery spoil at Aberfan in the United Kingdom was studied by Bishop (1969). He focused attention on the problems of the disposal of waste from mining and quarrying operations in the U.K. and led to legislation to control tips and soil heaps of materials specially fly ash. High pore-fluid pressures in the debris were invoked by Bishop's method to account for the relative mobility of the debris, and its rapid solidification when they escaped. Skempton and Weeks (1976) carried out investigations in the Seven Oaks road construction (South East England). They found out that the landslipped nature of the scarp slopes was not properly appreciated at the preliminary investigations of the road construction, and some instabilities were triggered, which led to the abandonment of a number of engineering structures. They proposed the realignment of a section of the road affected by landslides due to solifluction. Binger (1948) reported that during the construction of the Panama canal, problems faced by the workers were the landslides that triggered during the canal excavations. The canal was closed repeatedly due to slides for the first two years of operation (1914-1916). Subsequently in the 1950s and 1960's the canal was more than doubled in width and the troublesome areas removed. The reasons for the slides were overstep design slopes, inflow of water from river and stream diversions and the placement of spoil heaps too close to the edge of cuttings. R.K.Rai et al (1994) focused and studied about the geo-environmental hazards in and around Shillong city, the capital of Meghalaya. They put forward various views and recommendations regarding the proper management and mitigation of these hazards. They also worked and evaluated the Geo-hazard zonation in the Umiam basin of Meghalaya. Rajiv Kumar et al (1998) were of the view that landslides in the Himalayas are mainly caused by the slip along the joints, bedding planes, weak planes, etc. in the jointed rock mass. G.S. Mehrotra et al (1998) analysed the slope stability of Malti landslide (Uttarkashi, Garhwal Himalayas). They prepared the geological mapping of the area and identified cracks and major discontinuity planes of the slide area. They calculated the 'factor of safety' of the slide area. Anil Kumar et al (1998) identified landslide prone areas of Garhwal Himalayas using Remote Sensing and GIS techniques. The results were presented in the form of Landslide Hazard Zonation maps. V. Jagannathan et al (1998) devised the landslide zonations of Wynad area (Kerela) by a geo-environmental approach. All causative



LOCATION OF THE KHASI HILLS
0 10 20 25km
MAP OF N.E. INDIA
SHOWING
MEGHALAYA (Shaded)
ARUNACHAL PRADESH
ASSAM
NAGALAND
MEGHALAYA
MANIPUR
TRIPURA
MIZORAM
0 100 200 km.
91°
92°
26°
25°
ASSAM
GARO HILLS
KHASI HILLS
JAINTIA HILLS
BANGLADESH
Dommati
Umsning
Umroi
Mairang
SHILLONG
Nongstoin
Mawphlang
Laitlyngkot
Tyrssad
Weiloi
Jowai
Mawsynram
Balat
Pynursla
Cherrapunji
Shella
Dawki
INDEX
International Boundary
State Boundary
District Boundary
Metalled Road
Unmetalled Road
Study Area

MAP NO. 1

factors like Geology, Geomorphology, weathered zone, slope, ground water, rainfall, land-use and Geo-technical factors were assigned relative values based on their proportionate role in slide initiation.

1.2 Area of Study

Meghalaya plateau being a hilly terrain the data collection was restricted to certain selected sites (along National Highway and other important roads; map 1). The sites of landslide prone zones were identified with the help of BRO and GSI using 1:50,000 Topographic sheets (table 1). Preliminary surveys of the sites were done along the roads.

Table 1: Topographic Data used for present research work

Sl.No	Toposheet No.	Scale	Source
1	78 N/16	1:50,000	Survey of India
2	78 O/13	1:50,000	Survey of India
3	78 O/14	1:50,000	Survey of India
4	78 O/15	1:50,000	Survey of India
5	78 O/11	1:50,000	Survey of India
6	78 O/10	1:50,000	Survey of India

The state of Meghalaya is a plateau except the narrow belts in the northern and western parts. The latitude-longitude extension of the state is between 25° 47" N to 26° 10" N latitude and 89°45" E to 92° 47" E longitude. The height varies from 150 m. to 1961 m. above m.s.l. The plateau is characterised by great diversities in relief. It is marked by highly dissected and irregular terrain on the northern and western side and steep and regular slopes on the southern side. Maximum surveys have been conducted along the Guwahati-Shillong highway (NH-40) upto Pynursla, Shillong-Cherrapunji, Shillong- Mawsynram and Shillong-Mairang road. Every year quite a few landslides occur on these highways, induced due to heavy rainfall, (Meghalaya receives the highest amount of rainfall in the world). Moreover, this region is tectonically unstable. The history of uplifts and subsidence has curved the nature of landscape in Meghalaya. The plateau has been subjected to a number of tectonic disturbances. It has been tilted, twisted, submerged and uplifted many times in the Geologic past. The regional geology of Meghalaya along with the geology of the study area has been discussed in detail in the next chapter.

1.3 Objectives

The following are the objectives of the research work:

i) To study the geological parameters such as the geological structures and lithological characteristics of the rocks of the area.

ii) To study the geomorphic processes and their effects on hill slope evolution along highways and other vulnerable areas prone to landslides.

iii) To study the Geo-technical parameters such as the rock mass strength and characteristic slope angles of corresponding terrain units in the landslide prone areas.

iv) To identify the critical zones with high slope instability and demarcation of landslide prone zones.

v) To suggest suitable remedial measures and proper environmental management plan to minimize the losses occurring due to landslides.

1.4 Methodology

The following methodologies have been adopted:

i) Preliminary survey of the study area (along roadside) has been completed.

ii) Study of aerial photographs, satellite imageries and toposheets have been done and pre-field thematic maps are prepared.

iii) Study of the lithological characteristics and the structural properties of the litho units have been completed in the field and their correlation done.

iv) Selected Geo-technical parameters both for rocks and soils have been evaluated in the field as well as in the laboratory and also slope profiles were prepared for the various landslide spots particularly along road stretches.

v) Detailed field studies of some of the areas were carried out and lithological maps are prepared for those areas.

vi) Interpretation of data has been carried out and relationships between slope profiles and strength properties have been established.

vii) Critical landslide zones have been identified by the interpretation of primary geo-technical, geological and morphological data using Selby's Rating Technique.

viii) Analysis of primary generated data along with compilation of geological, morphometric and other related maps were completed.

ix) Presentations of research work in written form (thesis).

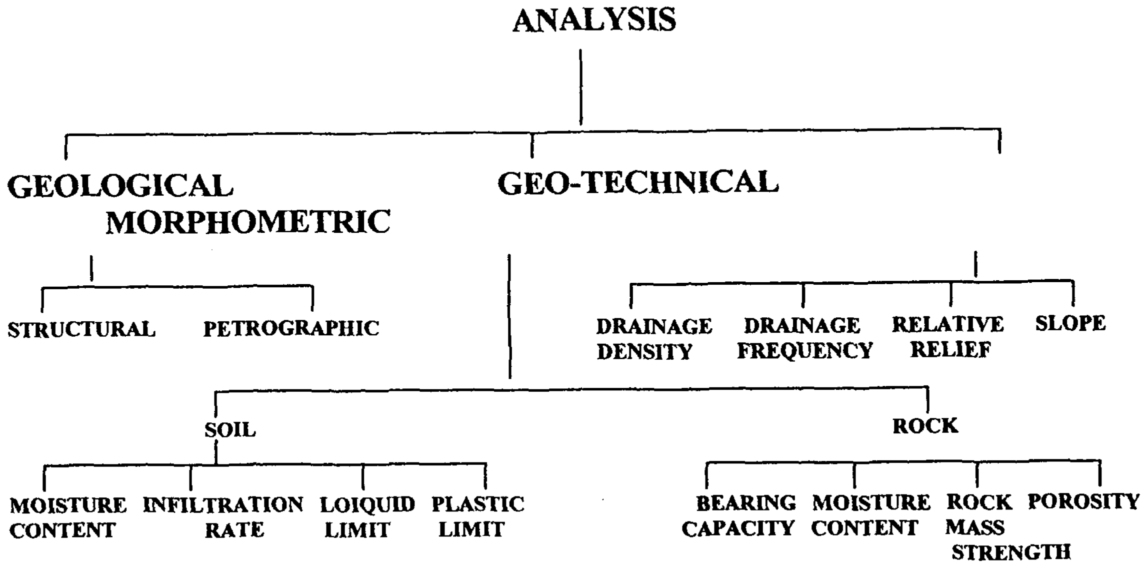
Table 2 represents how the analytical research for geological, geomorphological and geo-technical parameters were carried out.

1.5 Database

The various database are generated from primary (field work, survey and laboratory analysis) and other secondary sources e.g. for geological map, climatic data and topographic sheets.

A Landslide Hazard Zonation map is basically a predictive tool providing spatial information about the landslide susceptibility zones of an

Table 2: Methodology of the present research work



area. The importance of such a map lies in their utility for economically feasible landuse, location of dams, bridges, housing complexes, alignment of roads, etc. and undertaking measures for mitigation of hazards and ecology of the state of Meghalaya as a whole.

With these objectives in mind, landslide hazard zonation study has been carried out in the main highways of the state of Meghalaya to evaluate the degree of landslide susceptibility at different places in the terrain. In order to have specific information about the nature of slope instability in the state, a reconnaissance survey along the major highways of the state has been carried out. The present research work describes the details of the landslide areas investigated on the major highways of the state along with the preparation of Relative Hazard Risk Zonation maps of these highways adjoining both uphill and downhill slopes. The thesis also describes the details of the various terrain evaluation factors like Geology, Structure, Slope, Drainage and Landslide maps on 1:50,000 scale prepared with the help of Toposheets, Satellite Imageries, extensive field surveys and available literatures. Finally Landslide Hazard Zonation maps have been prepared by synthesizing various terrain evaluation factor maps.

1.6 Limitations

Although at the beginning every effort was made to conduct the study without leaving any stone unturned, but certain limitations forced the researcher to skip some study areas. Drawbacks such as the unavailability of toposheets of the border areas (international border with Bangladesh) deprived the progress of Thematic Mapping.

1.7 Chapter organization

The entire research work has been organized into seven chapters.

The first chapter has been dealt with some introductory remarks regarding the importance of the subject of Environmental Science, Geology and Geomorphology, their interrelation and significance of study. The statement of the problem of the present research initiative has also been discussed along with the selection of the study area. Various objectives have been pointed out keeping in mind the severity of the problem. The researcher went through numerous publications, journals and books related to disaster management, environmental geology and geomorphology. All these have helped the author to get a vivid idea regarding the way of approach and adopted methodology to tackle the research topic. These have been laid down in a phased manner in this chapter and finally the chapter scheme of the entire thesis has been tabulated.

The second chapter is solely concentrated on the geology and structural pattern of the region and Meghalaya as well as the present study area in detail. The geological mapping of the region has already been done by various workers from the time since first initiated by Oldham (1858).

Considering various limitations, the researcher has gone only for the geological mapping of selected zones of the study area. A detailed idea about the structural pattern of selected areas has also been given in this chapter. The macroscopic and microscopic characteristics of the rock types encountered in landslide areas have been analysed. Petrogenesis of the various rock types including "Modal Analysis" of rocks in thin sections of landslide areas has also been analysed and discussed in this chapter.

Chapter three deals with the geomorphic processes active in the study area and their impact on the surface morphology leading to slope instability. The climatic factors such as rainfall have been derived for selected stations of the area.

The morphological characteristics of the study area including Relief, Slope and Drainage analysis have been elaborately dealt with in the fourth chapter. The study of these morphometric features not only provided the variation occurring in topographical landscape but also brought to light the approaches needed for the interpretation of the complex form of landscape and road networks. The morphometric maps have been prepared in 1:50,000 scale and produced separately keeping in mind the nature of the problem and the depth of the research work.

The natural havoc caused by mass wasting and more particularly landslides have been evaluated and discussed in chapter five. For proper understanding of the lithology and soil types and their behavioral pattern, geo-technical analysis of the rocks and soils have been carried out including Porosity, Permeability, Rock Mass Strength, Bearing Strength, etc. These parameters have been analysed in sophisticated laboratories of the Civil Engineering Department, Indian Institute of Technology, Guwahati, for the determination of accurate and authentic results and have been presented in tabular form along with graphical representation wherever relevant.

Chapter six finally evaluates the Landslide Hazard Zonation rating with the demarcation of susceptible areas. It also discusses new, efficient and reliable methods for the mitigation and management of landslides prone zones. The researcher stressed the need for the implementation of new improved mitigation measures discarding the old and outdated ones and also called for constant regular monitoring of landslides along these busy roads and highways.

At the end, chapter seven deals with summary and conclusions along with a brief about the research findings and recommendations for properly tackling the landslide menace and reduce disasters.

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Chapter 2

Geology and Structural Characteristics of the Study Area with Geology of the Khasi Hills

Chapter 2

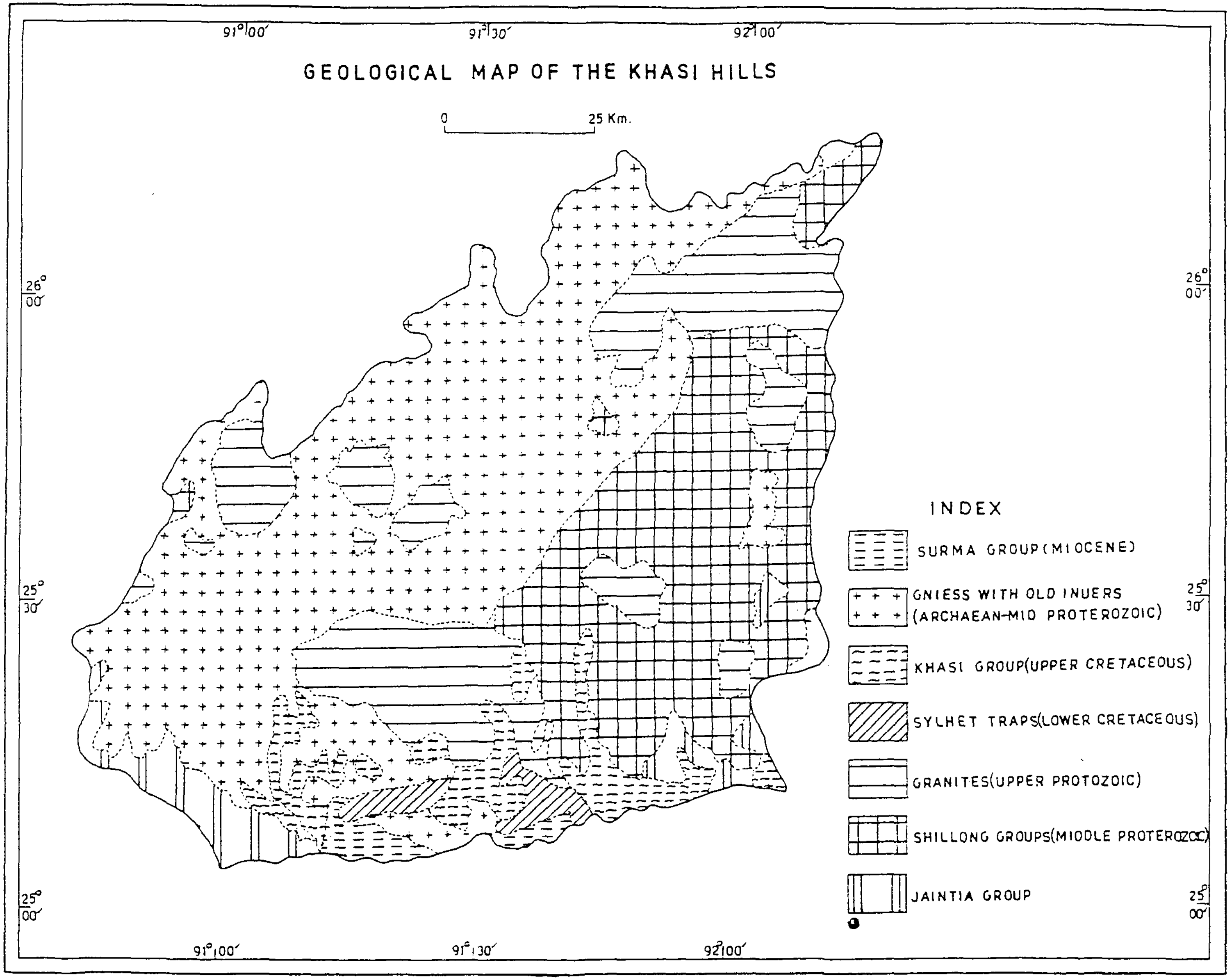
Geology and Structural Characteristics of the Study Area with Geology of the Khasi Hills

The geographical area of Meghalaya is 22,429 sq. kms. Physiographically, it is a part of the Peninsular Shield lying south of the north-eastern segment of the Himalayas. The Meghalaya massif is a geomorphic arc bounded on all sides by faults. The southern boundary is the famous Dawki fault. The northern boundary is marked by Brahmaputra lineament. To the west the massif is detached from the main Indian Shield by the north-south trending Rajmahal-Garo lineament. The eastern boundary is a NE-SW lineament separating the massif from the sediments of Bengal-Assam shelf. As such the Meghalaya massif is a horst, forming a plateau region block uplifted to its present height-about 600m. to 1900m. above m.s.l.

Meghalaya represents remnant of the ancient plateau of Pre-Cambrian Indian peninsula. It forms a prominent geomorphic unit stretching across the Garo Hills, Khasi Hills and Jaintia Hills in east-west direction. The different stratigraphic sequences are shown in table 3 .

Archaean Gneissic Complex is exposed in the central and northern part of Meghalaya plateau (map 2). The rocks are composed of para and ortho-gneissic magnetics and sedimentary types. They mostly contain Biotite-Gneiss, Biotite-Granulite, Amphibolite rocks. Rocks like Pyroxene-Granulite and Mica Schist also occur in some places.

Shillong Group of rocks comprising of Quartzites, usually friable with sub-ordinate Phyllite, Quartz-Schist, Conglomerate, etc. are exposed in the central and eastern parts of Meghalaya. The Granite Group along the axial


91°00′
91°30′
92°00′
GEOLOGICAL MAP OF THE KHASI HILLS
0
25 Km.
26° 00′
25° 30′
25° 00′
INDEX
SURMA GROUP (MIOCENE)
GNIESS WITH OLD INUERS (ARCHAEAN-MID PROTEROZOIC)
KHASI GROUP(UPPER CRETACEOUS)
SYLHET TRAPS(LOWER CRETACEOUS)
GRANITES(UPPER PROTOZOIC)
SHILLONG GROUPS(MIDDLE PROTEROZOIC)
JAINTIA GROUP

MAP NO. 2

region of the Shillong group of rocks around Mylliem is known as Mylliem Granite. Several other granites such as South Khasi Batholith, plutons etc. are intrusive into the Gneissic Complex in different parts of Meghalaya.

Sylhet trap occurs along the southern border of the Shillong plateau and is about 600m. in thickness. The Sylhet trap is mostly comprised of Basalts, Alkali Basalts and Rhyolite Acid Tuff.

Cretaceous-Tertiary sediments form the Khasi and Jaintia group of rocks and occupy the south-east and south- west of Meghalaya. The sediments are generally Sandstone, Shale, Limestone and Mudstone. The rocks of Jaintia group consist of
Calcareous Shale, Sandstone and Limestone.

Garo Group (Chengapara Formation) consists of poorly cemented fine grained Micaceous Sand, Brown Sandstone and Clays. It occurs in the extreme south -west of Meghalaya (Balat).

Recent Alluvium overlies the Tertiary rocks along the southern and western borders of the Garo Hills in isolated patches. The deposit of Recent Alluvium consists of beds of pebbles with coarse loose sand and Brownish Clay.

The whole of north-east India is known to have been subjected to many disturbances in the Geologic past. The collision tectonics of the Indian and Eurasian plates have greatly complicated the crustal structure of the whole region. The Himalayan boundary along the north and the opposition of the Naga-Patkai and Arakan Yoma folded ranges together with the Shillong massif and the synclinal Brahmaputra valley contributes a highly complex landform.

The effect of plate collision in this part of the earth is therefore of a

Table 3: Stratigraphic sequence of the rocks found in Meghalaya

Geological Age	Group Name	Formation	Rock Type
Recent	Newer Alluvium	Unclassified	Sand, Silt, Clay
----Unconformity----			
Pleistocene	Older Alluvium	Unclassified	Sand, Clay, Pebble Gravel & Boulder
----Unconformity----			
Oligo-Miocene	Garo Group	Chengapara Formation (700m.)	Sand, Silt, Clay & Marl
		Baghmara Formation (530m.)	Feldspathic Sandstone, Pebble, Conglomerate & Clay
		Kopili Formation (500m.)	Silt, Clay & Sandstone
Eocene	Jaintia Group	Simsang Formation (1150m.)	Siltstone, Sandstone
		Shella Formation	Sandstone, Limestone
		Langpar Formation	Calcareous Shale Sandstone, Limestone
Upper	Khasi Group	Mahadek Formation (150m.)	Arkose (glauconitic)
		Bottom Conglomerate (25m.)	Conglomerate Arkose
		Jadukata	Sandstone Conglomerate
----Unconformity----			
Jurassic	Sylhet Trap	—	Basalt, Alkali Basalt, Rhyolite, Acid Tuff
----Unconformity----			
Pre-Cambrian	—	Intrusive (acid & basic)	Epidiorite, Dolerite, Basalt
----Unconformity----			
Archaean	—	Gneisses	Biotite Gneiss, Biotite-Hornblende Gneiss, GraniteGneiss,Migmatite Mica-Schist, Biotite- Granulite

high degree. Recent researches point out the fact that this area is affected by a number of forces: seismic, tectonic and magnetic which is referred to as a seismo-tectono-magnetic or STM belt. This clearly points out that the forces interacting in this area generate a huge amount of energy that tend to accumulate over time and released from time to time in the form of earthquakes. It has also been asserted that the compressional forces acting along the north-south axis play a great role in the tectonism of the region culminating in its instability. The Meghalaya plateau as a part of the region has a long story of erosion, sedimentation, folding, diastrophism, intrusions, movements of land and sea emissions, which points out that this region is seismologically active. The convergent plate margins in this area reflect a weak crustal construction. The existence of basins that allowed accumulation of sedimentary deposits coupled with organic remains resulted to a low density continental crust. Besides, it is also noteworthy that these basins have been aligned parallel to the margins of the pre-existing lines of weakness, thus influencing the structure and nature of the lower strata. This resulted in the formation of alternate thick and thin continental crust, which subjected to the various forces. The estimated thickness of the crust in the Shillong massif is 40 kms. compared to the adjacent Surma and Assam valleys which is 22 kms. and 27 kms. (approx.) respectively. Due to the acting compressional force, the thinner crust fractured and collapsed, while the thicker ones remained intact and the resultant was the upliftment and subsidence. The interplay of these forces are recorded and now they represent themselves by fractures or fault lines. In this connection, the Surma and Brahmaputra valleys on either side of the Shillong massif, fractured and collapsed. The thick massif on the other hand did not fracture but instead was uplifted. This corresponds to the constant plate movement, which has slowed down but yet to be terminated.

2.1 Regional Geology of Meghalaya

The state of Meghalaya in Geological terms is the north-eastern extension of the Indian Peninsular Shield, which forms a Kratonised Plateau Wedge between the Himalayan and Patkai-Arakan Yoma mobile belts. The state is near to the Karbi Anglong district of Assam forming a composite tectonogeomorphic unit or domain. This unit is coined as the "Shillong Massif". The north eastern structural grain of this massif continues into the Brahmaputra plains and forms magnificent monadnocks mostly in between Kamrup and Karbi Anglong districts of Assam.

The first person to initiate geological mapping in Meghalaya was Oldham in 1858. This was after the establishment of the Geological Survey of India (GSI) in 1851. He was later followed by Medlicott in 1869. In the post independence period large areas of Shillong Massif have been mapped by officers of the GSI. and the geology of the massif is very well established by now. The compiled geological framework of the massif has been given by Chowdhury and Rao (1975) and Mazumdar (1976), The generalized stratigraphic succession is shown in table 3. The different lithostratigraphic groups present are described below:

2.1.1 Gneissic Complex:

This complex is exposed in the central and northern parts of the massif. This unit has two names to its credit- the "Archaean Gneissic Complex" and " Pre Cambrian Gneissic Complex" (Banerjee 1964). The Geological Society of America recognizes that the word 'Archaean' is to be used only for rocks which are older than 2500 million years and that too only if geochronological data is available. As no such data are available for this region, this complex is being referred to as "Pre Cambrian Gneissic Complex". It comprises of gneissic members as well as schistose rocks of varying composition. The dominant variety- the Gneissic Group is represented by Biotite-Gneiss, Biotite-Granulite, Biotite-Hornblende-Gneiss, Quartz-Sillimanite-Gneiss, etc. On the other hand the schistose variety are represented by Amphibolite, Mica-Schist, Quartz-Sillimanite-Schist, Metabasite, etc. The mineral assemblages within the Gneisses and Schists indicate that they were formed under high pressure-temperature conditions of regional metamorphism.

The structural pattern shown by the gneissic terrain is that of a complex nature exhibiting polyphase folding concurrent to multistage metamorphism. The Geologists identified three phases of folding.

i) the first phase is isoclinal constituting broad recumbent-reclined folds exhibiting an E-W trend of axial surfaces.

ii) the second phase is the superposed tight isoclinal folds having ENE-WSW and NE-SW axial surfaces.

iii) Broad N-S trending warps mark the third phase.

The dominant fold surfaces within the complex show NE-SW, E-W, N-S and NW-SE strikes in different sections due to the complex folding. The NE-SW strikes are parallel to the Eastern Ghats trend of Orissa and E-W strikes with Satpura trend (Banerjee 1964). The Gneissic Complex was kratonised prior to the initiation of the Shillong Basin.

2.1.2 Non-Porphyritic Migmatitic Granitoids

This group of rocks is seen to occur throughout the Gneissic complex in all scales in the form of veinlets, interfolial permeation, patches, small irregular bodies and lenses. These rocks prominently shows diffused boundaries with the rocks of the gneissic complex sometimes producing

"Nebulites". The Granitoids show three important variants and represent mobilizates of Mehnert (1968). These mobilizates have not penetrated the Shillong Group of rocks implying that the migmatisation is prior to the formation of the Shillong Group of rocks.

i) Dioritic Mobilizates: This rock is spotted and speckled. The spots are due to the presence of aggregates, clots and knots of Biotite, Epidote, Hornblende, Magnetite, Quartz, Plagioclase, Sphene, etc. This texture is the result of irregular arrangement of the above minerals. The other constituents of the rocks are the same minerals that form the clots, but they are randomly oriented.

ii) Grano-Dioritic Mobilizates: As the mafic constituents reduce in proportions (particularly hornblende) and the relative increase of Potash Feldspar and Quartz, the Dioritic Mobilizates advances to the Granodioritic phase, whereas the texture remains the same with the Dioritic Mobilizates.

iii) Granitic Mobilizates: This variety constitutes typical granites devoid of foliation. They are medium grained representing the youngest Plutonic Migmatites. This forms the dominant migmatitic type within the Gneissic Complex forming domes.

2.1.3 Shillong Group

The Gneissic complex is overlain by the Shillong Group with an unconformity comprising friable Quartzites along with subordinate Phyllites, Siltstone, Slate, Quartz-Sericite-Schist, etc. The rocks occur in an NE-SW elongated tract in the Khasi Hills and extend upto the north west fringe of Karbi Anglong district of Assam. The Shillong Group of rocks is of low grade metamorphism except at few places, which shows high grades. The primary sedimentary structures are still seen intact in the rocks including

Bedding, Laminations, Current Bedding, Ripple Mark penecontemporaneous deformational structures, etc.

The Shillong Group display sub vertical dipping with local reversals from west of Mawphlang to Barapani and its NE extension, away from this zone, the dips are of gentle rolling nature. Such folding represents "Intermediate crestal type folding".

2.1.4 Khasi Greenstone

This rock type occurs as isolated patches of linear bodies in the Shillong Group of rocks. These rocks have intruded both in the argillaceous and arenaceous facies of Shillong group. The Khasi Greenstone is mainly represented by Dolerite, Epidiorite and Amphibolite. The Khasi Greenstone has so far not been recorded from outside the Shillong Group. These metabasites appear to have been emplaced along tensional fracture systems.

2.1.5 Porphyritic Granitoid

The Porphyritic Granitoid occurs as plutons of large dimensions throughout the massif. Some of the important plutons identified are:

- i) Bartha Langso Pluton
- ii) Kharkouta Pluton
- iii) Kyrdem Pluton
- iv) Mawdoh Pluton
- v) Mylliem Pluton
- vi) Nongpoh Pluton
- vii) Nongrang Pluton
- viii) Rambrai Pluton
- ix) Rongeng Pluton
- x) South Khasi Pluton

xi) Baut Bazar Pluton

xii) Kaziranga Pluton

The compositions of these plutons include potash rich large megacrysts of Microcline in a groundmass of Plagioclase, Quartz, Biotite and Microcline and hence representing Porphyritic texture. The plutons are dome shaped and some shows intrusive relationship with Shillong Group of rocks (South Khasi and Mylliem). The age of these plutons varies from 479±26 m.y. to 690± 19 m.y. and they do not show any systematic geographical age progression. Locally crude foliation is exhibited by the plutons with homophanous nature at places. Some of the plutons have straight boundaries with the country rocks viz., Gneissic complex and the Shillong Group indicating diapiric emplacement to the Porphyritic plutons of Assam, representing late tectonic events. According to Mazumdar (op. cit) the materials for these plutons were spread in the lower levels of the crust as thin sheets of appropriate composition, the event occurring after the Khasi Greenstone was emplaced.

2.1.6 Lower Gondwana Group

The Gondwana group occurs in Singrimari area, in the western tip of Garo Hills approximately within 4 kms. of Indo-Bangladesh border. The outcrop is exposed over a length of 1 km. and a width of 400m. just to the east of Mancachar road. The first report of the occurrence of Gondwana rocks in the area was given by Fox (1939).

Talchir and Karharbari Formations represent the Lower Gondwana regime. Talchir Formation includes rock types such as Basal Tillites, Sandstone with Conglomerates, Siltstone and Shale. Karharbari Formation include coarse to very coarse grained Sandstone with Conglomerate, Siltstone, Shale and Coal. The Talchir Formation is lying unconformably over the Gneissic Complex and Granitoids. The Karharbari Formation follows it conformably. The Gondwana beds show a general strike of N-S with dips ranging between 10°-20° towards west. The beds get concealed under the thick Brahmaputra Alluvium west of Singrimari.

2.1.7 Sylhet Trap

In a narrow E-W patch between lat. 25°15'N and 25°12'N and long. 91°15'E and 92°15'E volcanic rocks are exposed. As they conform to the trap rocks of Deccan plateau formed as a result of fissure eruptions they are given the name Sylhet Traps (Medlicott 1869). They are exposed at a stretch of about 80km. in length and 4km. in width at the southern tip of the Shillong Plateau. The traps are confined to the south of the Raibah fault. The maximum thickness of the flows exposed is about 550m-600m. The trap rocks lie over the Upper Cretaceous-Eocene sedimentary sequence. The sediments and the trap form a monocline that becomes a flexure. At some places the sediment cover has been eroded away exposing the traps as inliers.

Basalts and minor Alkali Basalts (Nepheline Tephrites), Rhyolites and Acid Tuffs predominantly comprise the Sylhet Traps. They occur as flows and average thickness ranges between 5m-7m. Flow Breccias have developed at the top. The traps show the following textural variations:

i) Non Porphyritic

ii) Micro Porphyritic

iii) Mega Porphyritic

The vesicles (Amygdaloidal structure) are filled by secondary Quartz, Calcite and Zeolites. Basalt dykes are fairly common within the flows and adjoining to the Gneissic Complex. The dykes occur as swarms within the trap rocks, their general trend being NNE-SSW, NE-SW and E-W in the

Khasi and Garo Hills. Lamprophyres (alkaline rocks) also occur as dyke bodies in association at places, possibly related to the same event. The age of the Sylhet Traps are considered to be equivalent with that of the Rajmahal Traps of Pre-Upper Cretaceous (Krishnan 1982). The radiometric age vary from 92 $\pm$ 3 m.y. for the lower part to 138m.y. from different parts of the Sylhet Traps as deduced by the officers of the GSI.

2.1.8 Ultramafic Carbonatite Complex

The Sung valley in East Khasi Hill District houses the Ultramafic Carbonatite Complex that is an oval shaped body covering about 26 sq. km. forming a bowl like depression. It is intrusive into the Proterozoic Shillong Group. On either side of the complex the Mylliem and Kyrdem Plutons acts as the country rocks. The complex is emplaced along the junction of two prominent lineaments trending E-W and NNW-SSE among which the latter appears to be a major fault. Fission track method of age dating of Apatite from these rocks has given an Upper Cretaceous age (84$\pm$ 13 m.y. to 90$\pm$ 10 m.y.) for the complex. The complex has evolved from a major igneous activity in the Massif just after the Sylhet Traps erupted with a little time gap between the two events. The major rock types developed in the complex are Serpentinite, Pyroxinite, Syenite, Carbonatite etc. The body shows zoning and partial development of ring structures. Quite a number of faults trending NE-SW traverse through the complex.

2.1.9 Cretaceous-Tertiary Sedimentary Sequence

This sequence occurs along the southern fringe of the Shillong massif. It is a thick and extensive sedimentary sequence, which is continuous with the Cretaceous-Tertiary sequence occurring in Bengal Basin. The sequence have been divided into four groups:

i) Khasi Group

ii) Jaintia Group

iii) Garo Group and

iv) Dupitila Group

The interformational contacts within the pile is continuous without any sedimentological or faunal break. Geologists from the GSI working recently has placed the contact between the Cretaceous and the Tertiary at the base of Langpar Formation of the Jaintia Group based mainly on Palaentological studies.

i) Khasi Group: The Khasi Group represents the Cretaceous section of the pile represented by Jadukata Formation, Bottom Conglomerate and Mahadek Formation. The Jadukata Formation lies nonconformably over the Sylhet Traps representing an Arenaceous Facies, which is comprised of Conglomerate at the base overlain by Pebbly Sandstone, coarse grained Sandstone with Carbonaceous Streaks. This formation is restricted only to the north of the Raibah fault forming the limit of the palaeo-shore line. The progressive transgression of the shore line towards the north is confirmed by the presence of thick conglomerate beds, lying north of Raibah fault. This formation has been given the name-Bottom Conglomerate. The Mahadek Formation overlies the Jadukata and Bottom Conglomerate Formations exhibiting a continuous contact. This formation is well exposed in Mawsynram area. The Mahadek Formation represents an Arenaceous sequence made up of fine pebbly sandstone at the base grading upwards to medium to coarse grained sandstone which is mainly Quartzwacke. The upper part of Mahadek Formation is mainly greenish in appearance due to the presence of Glauconite.

ii) Jaintia Group: A change in the depositional environment is marked on the onset of the Jaintia Group, which is best developed in the Cherrapunji area. Traces of this formation are found as far as Um Rilang (25°43'N and 91°47'E) to the west of Umiam lake in Khasi Hills and Darugiri (25°40'N and 90°50'E) in Garo Hills. The Calcareous Facies commences from this formation deposited in a stable shelf segment of the basin. This group is divisible into three formations: Langpar formation Shella Formation and Kopili Formation.

The Langpar Formation represents the beginning of the Tertiary era of the sedimentary pile of the Shillong Massif. It is over the Mahadek Formation making a gradational contact. The Langpar Formation is represented by Carbonaceous Siltstone, Calcareous Shale, and Sandy Limestone marking a distinct change in Sedimentary Facies. The base of the Langpar formation marks the boundary of Cretaceous –Tertiary sequence in Meghalaya. The Shella Formation lies conformably over the Langpar Formation comprising alternations of three Sandstone and Limestone members. These have been designated successively as the Lower (Therria Sandstone/ Lakadong Limestone), Middle (Lakadong Sandstone/ Umlatdoh Limestone), Upper (Nurpur Sandstone/ Parang Limestone/ Siju Limestone and Sylhet Sandstone/ Limestone) members. The Shella Formation definitely represents a distinct calcareous facies deposited in a shelf environment. Kopili Formation maintaining a gradational contact succeeds this formation. The rock types in this formation include alternations of thin Sandstone and Shale with minor thin beds of Limestone. A Shale horizon containing phosphatic nodules is present at the base of Kopili Formation.

iii) Garo Group: The Upper Tertiary sequence in Meghalaya is represented by the Garo Group, which is well exposed in the Garo hills. This group is being divided into three formations: Simsang Formation, Baghmara Formation and Chengapara Formation. These three formations are similar in lithology and faunal aspects with the Barail, Surma and Tipam formations of Assam-Arakan Basin. The oldest that is the Simsang Formation overlies conformably over the Kopili Formation representing a cycle of massive festoon cross bedded sandstone and siltstone members. The succeeding Baghmara Formation has gradational contact with the underlying Simsang Formation, which is mainly confined, to the eastern tracts of Garo Hills. This formation is consisting of impersistent beds of Feldspathic Sandstone with minor Mudstone, Pebbly Sandstone-Conglomerate, Massive Clay and Silty Clay-Sand beds. The Chengapara Formation, which overlies Baghmara Formation also, maintains a gradational contact with it comprising poorly cemented fine grained Micaceous Sand, Blue to Brown Siltstone and Clays with thin beds of Marls at the base. The top of the Chengapara Formation is marked by a prominent Angular Unconformity in the western part of Garo hills and is very well exposed in the Tura -Dalu road near Nokehi and north of Mahendraganj.

iv) Dupitila Group: The Dupitila Group lies unconformably over the Chengapara Formation representing the Mio-Pliocene stratigraphic sections. This group is consisted by alternations of coarse Feldspathic Sandstone with Mottled Sandy Clays and thin layers of Pebbles of Vein Quartz.

2.1.10 Quarternary and Recent Deposits

Older Alluvium unconformably overlies in isolated patches on the eroded top of the Tertiary rocks confined mainly along the southern and western borders of Garo Hills and also along the southern flanks of Khasi Hills. These patches consist of assorted Pebbles with coarse loose Sand and Brownish Clay. The patches usually occur as flat topped hillocks and mounds with red soil cover. On the other hand the Recent Alluvium occur in river valleys consisting of fine silty sand and light to dark grey clay with rare pockets of coarse sand and pebbles. The sands invariably contain abundant Mica. The recent alluviums are mainly confined to the northern flanks of Garo and Khasi Hills.

2.2 Geological Succession of the Khasi Hills

The study area includes the Archaean Gneiss (basement), rocks of Shillong Group, Khasi Greenstone, Porphyritic Granite, and Cretaceous and Tertiary Sediments. The geological succession of the Khasi Hills is given in table 4.

Table 4: Geological Setting of Khasi Hills

Recent Sediments	
----------Unconformity----------	
Tertiary	
----------Unconformity----------	
Pre-Cambrian	Veins and Pegmatites Mylliem Granite Khasi Greenstone Shillong Group (Upper division)
----------Unconformity----------	
	Shillong Group (Lower division)
----------Unconformity----------	
Archaean	Gneiss (Basement Complex)

2.3 Description of the rock types encountered

During the field visits the researcher encountered the following rock types in the study area. Laboratory analyses of the particular rock types were carried out. Their mesoscopic as well as the microscopic characteristics were studied and the rock types identified.

2.3.1 Quartzite: Two types of Quartzites are found to occur- the Younger and the Older Quartzites. The Younger Quartzites are mostly Sericitized, not compact, more or less appearing like Sandstone, when highly weathered. But in the landslide area of Sohiong (West Khasi Hills) and Mawphlang the

Older Quartzites are present (map 3). They are very hard and compact showing colour variations from white to light pink. These Quartzites are Feldspathic, that gives a shining lusture on a freshly broken surface. Colour Banding is observed parallel to the foliation.

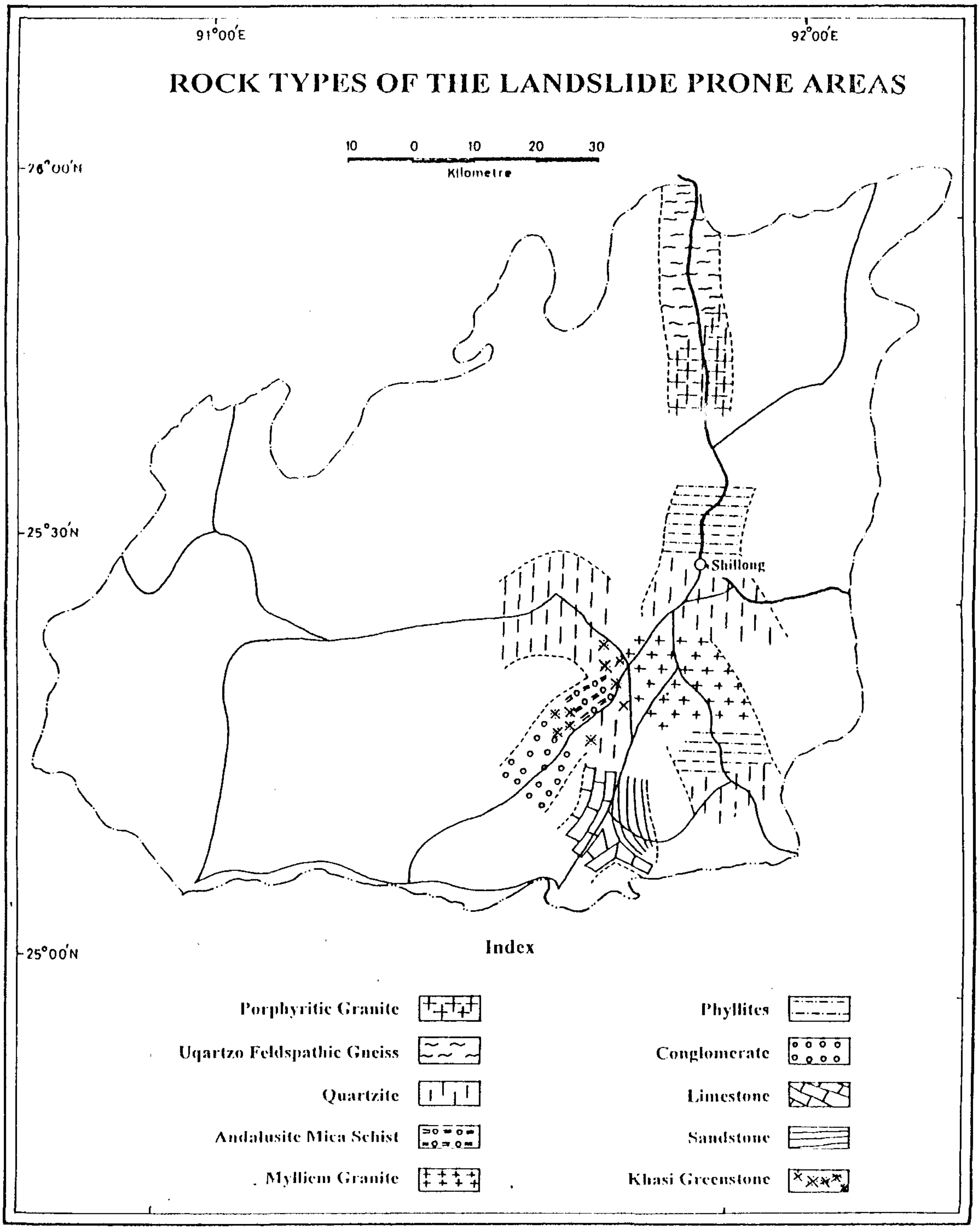
Microscopic Characters: The Quartzites constitute inequigranular subrounded Quartz. The grains vary from medium to coarse. Pressure Lamellas are seen to have developed. The development of crenulated boundaries of Quartz grains are seen in recrystallised Quartzites (plate 1). The coarse grains are elongated containing inclusions of Apatite, Muscovite, Pyrite and fine irregular lines of dusty materials. Modal analysis has been done for estimation of the constituent minerals (table 5). Other constituent minerals include:

Muscovite: It occurs as Mica flakes coated with iron along the cleavage traces. Interference colour is high. Muscovite is non-pleochroic showing parallel extinction.

Biotite: One or two flakes of Biotite are encountered at places in Quartzites. It occurs in small flakes, dirty brown in colour. It shows parallel extinction and contains inclusions of iron along cleavage traces.

Magnetite and Haematite: Magnetite occurs as subhedral and irregular grains and shows metallic lusture under polarised light. Haematite occurs in irregular patches, which is reddish under polarised light, seeming to be an alteration product of Magnetite.

Zircon: Zircon appears as minute inclusion in Quartz with Subhedral to Euhedral outline. It is colourless to pale yellow with high relief and showing straight extinction.



91°00'E
92°00'E
ROCK TYPES OF THE LANDSLIDE PRONE AREAS
10 0 10 20 30
Kilometre
26°00'N
25°30'N
25°00'N
Shillong
Index
Porphyritic Granite
Uqartzo Feldspathic Gneiss
Quartzite
Andalusite Mica Schist
Myllicm Granite
Phyllites
Conglomerate
Limestone
Sandstone
Khasi Greenstone

Map 3

Table 5: Modal Analysis of the Quartzites (Volume Percentage)

Minerals	With feldspathic impurities	With micaceous impurities
Quartz	88.9	89.2
Plagioclase	6.0	1.2
Microcline	0.8	0.1
Biotite (& chlorite)	-	6.0
Muscovite	0.5	2.0
Sericite	2.9	0.3
Iron Ore	0.9	1.0
Epidote	-	0.2
Total	100.0	100.0

Origin of Quartzites: The Quartzites are the dominant rock types of the study area. They are composed of sub-rounded to rounded Quartz-grains (plate 1), cemented by sericitic siliceous and hematitic material. The Quartzites are regionally metamorphosed. They are well bedded and hard. The general strike of the bed is NE-SW with a moderate dip towards south-east. Occasionally the rocks are gritty to conglomeratic. The rounded and sub-rounded Quartz grains indicate their long fluviatile transportation. The gritty and conglomeratic Quartzites have been formed by rapid deposits of Arenaceous sediments. The Sericite is formed probably by alteration during metamorphism of clay minerals deposited along with sands and other cementing materials viz. fine Quartz and Iron Oxides. The Magnetite seems to be a detrital mineral. The constituent Quartz grains are seen to be embedded in a finer matrix giving the rock a Granoblastic texture.

2.3.2 Granite: Granite is very coarse grained and Porphyritic in nature. Phenocrysts are of Potash Feldspar (Microcline) embedded in the groundmass of Quartz, Plagioclase, Biotite and Potash Feldspar itself. The Granite is greyish white to light pinkish in colour. The pink colour is due to the predominance of Microcline. Quartz is more lustrous in the Grey Granite than the pink variety. The texture is Coarse Grained Porphyritic.

Microscopic Characters: The Mylliem Granite is essentially composed of Potash Feldspars with Quartz, Plagioclase and Biotite as subordinate minerals. The Potash Feldspars are Microcline and Orthoclase, Microcline being the dominant one. Modal analysis has been done for the constituent minerals (table 6).

Microcline: Microcline occurs as large colourless, Subhedral grains. Cross-Hatch twinning is common (plate 2). Cracks and cleavage traces of Microcline are filled up by Plagioclase to form veins and strings. Microcline usually contains inclusions of Plagioclase, Quartz and Biotite. The Quartz grains are elongated in nature. Microcline shows first order grey interference colour.

Orthoclase: Orthoclase occurs as Subhedral to Anhedral grains, both as phenocrysts and as small grains. It is colourless to cloudy due to the alteration to Sericite. It is twinned according to Carlsbad law (Plate 3).

Plagioclase: The amount of Plagioclase present is lesser than Potash Feldspars. It mostly occurs as tabular and prismatic grains, with Subhedral outlines. Plagioclase occurring as inclusions in Microcline show a clear rim around a central unaltered to less altered darker core (plate 4).

Quartz: Quartz occurs as small to large colourless Anhedral grains. Quartz constitutes around 50 % of the rock. In general the Quartz is clear and fresh. Fractures are present in some grains. First order grey interference colour,

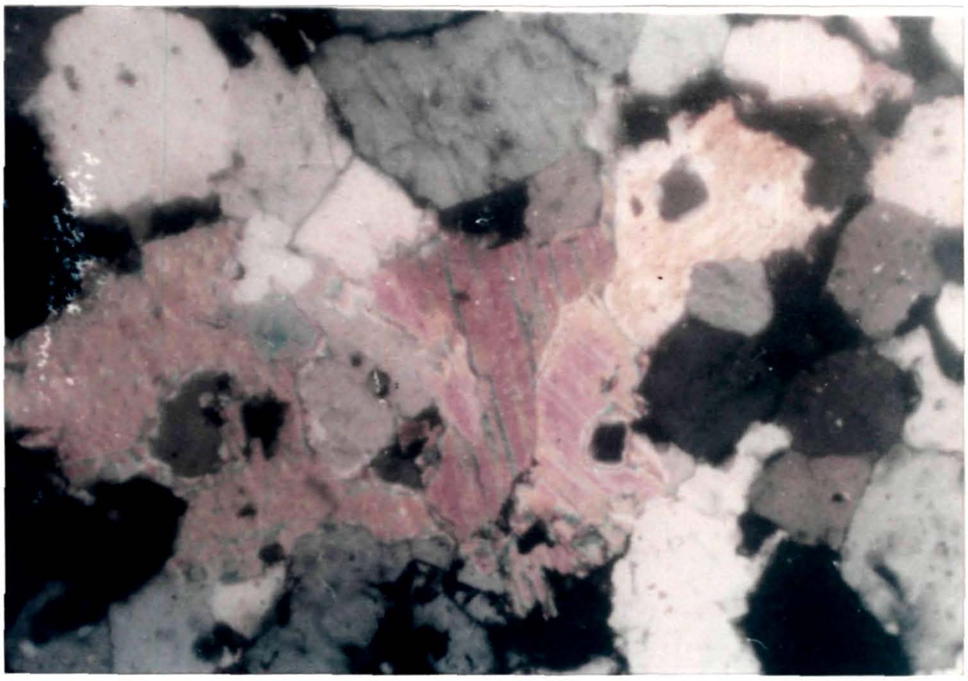


Plate 1 Development of Crenulated boundaries of quartz grains in Quartzite

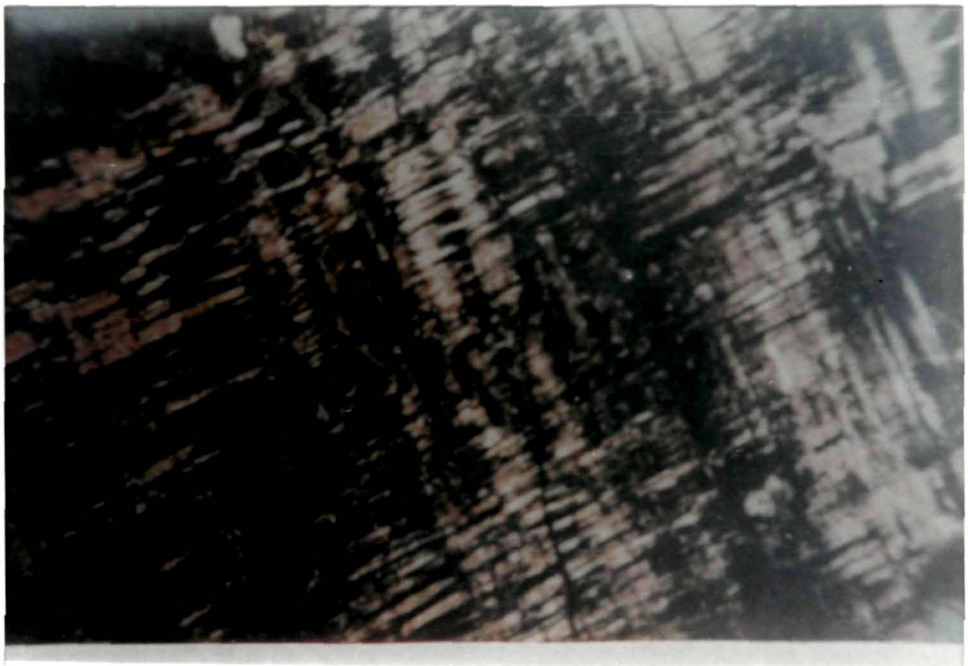


Plate 2 Cross-hatch twinning of Microcline in Granite

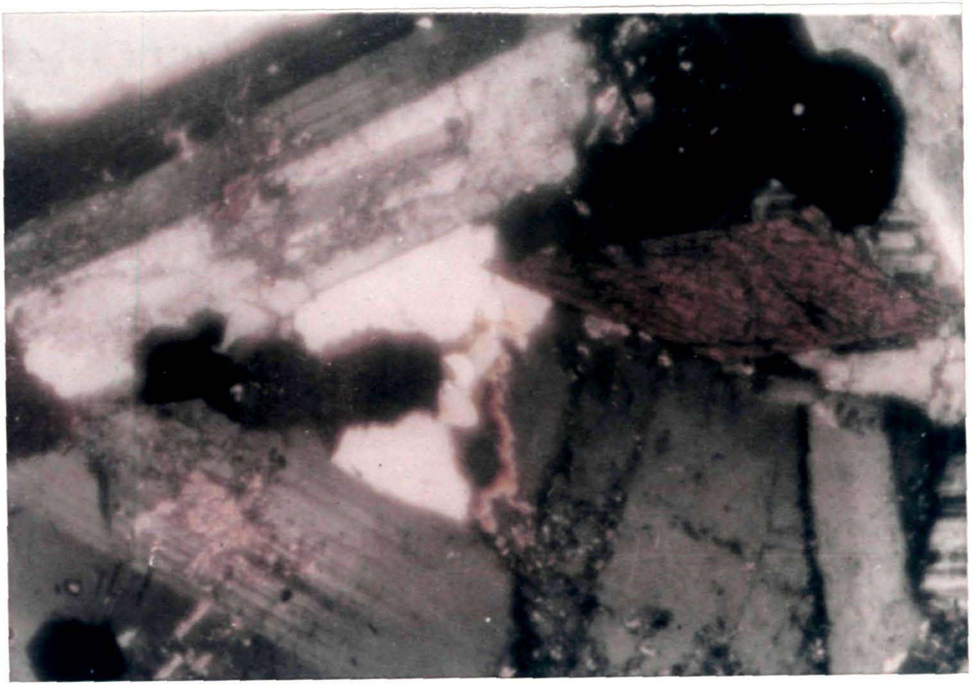


Plate 3 Carlsbad twinning of Orthoclase in Granite

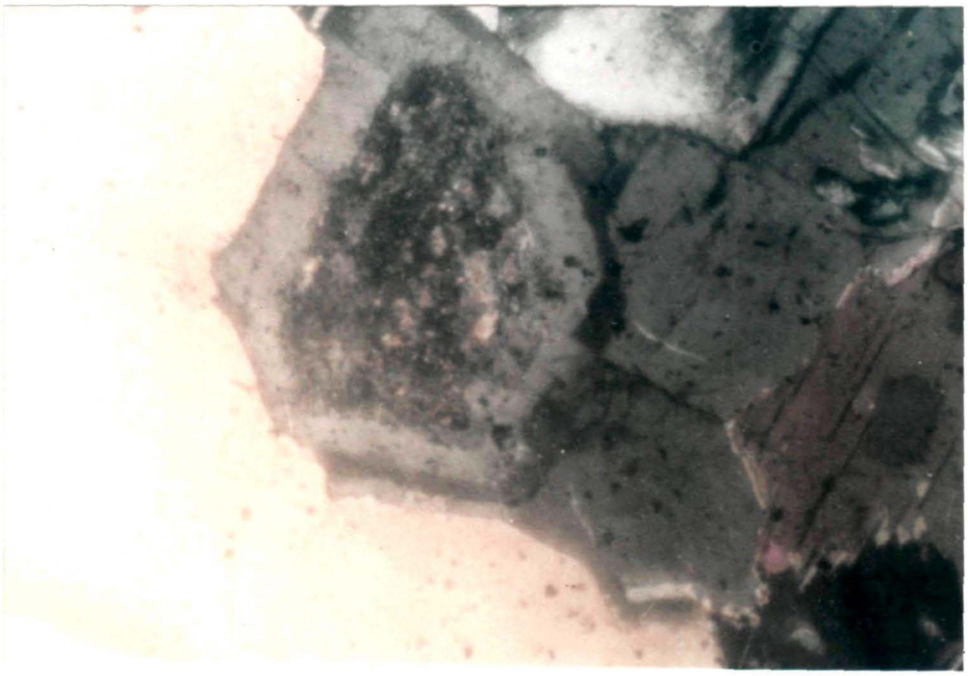


Plate 4 Plagioclase occurring as inclusions in microcline showing a clear rim around a central unaltered to less altered darker core.

uniaxial positive nature, undulose extinction and low relief are common optical characteristics.

Biotite: Biotite generally occurs as prismatic grains. They are light greenish brown to dark brown in colour and pleochroic. It shows straight extinction. Biotite grains are often altered to Chlorite. The alteration being active along the margin as well as along the cleavage traces of the grains, inclusions of Zircon, Apatite and Plagioclase are observed in them. Some prismatic grains show bending of cleavage lines, which may be due to local shearing effect suffered by the Granite.

Magnetite: They occur as accessory minerals in cubes and irregular outline. It is also found as inclusions along the cleavage traces in Biotite. The mineral is opaque with metallic lusture under reflected (polarised) light. A few grains alter to Haematite, which show reddish brown colour under reflected light.

Chlorite: Green Chlorite is secondary after Biotite. It is seen along the cleavage traces of Biotite, along which alteration is pronounced. Slight strain effects are also seen in some Chlorite grains.

Sericite: It appears as dusty or dirty aggregates and in minute scales in Plagioclase. It is secondary after Plagioclase. It shows red and blue interference colours.

Origin of Granite: The Granite is intrusive into the Shillong Group of rocks and have caused thermal metamorphic effects on them. The geological setting and the field evidences favour a magmatic origin of the granite in the study area.

a) Field Evidences: 1) The junction between the Granite and Quartzites of the Shillong Group is sharp and is well seen at the field. The existence of a sharp contact between the Granite and the country rocks point out an

Table 6: Modal Analysis of Granite (Volume Percentage)

Sample	Slide No. 1	Slide No. 2	Slide No. 3	Average
K. Feldspar	57.7	52.4	31.3	48.7
Plagioclase	16.5	16.4	28.4	20.5
Quartz	11.3	15.5	20.3	15.8
Biotite	12.0	11.4	11.8	11.7
Iron	0.6	1.4	2.2	1.4
Accessory	2.0	2.8	1.0	1.9
Total	100.1	99.9	100.0	100.0

intrusive nature of the Granite.

2) The concordant and discordant apophyses and veins of Granite that penetrate the metasediments indicate an intrusion of a granitic magma into the metasediments.

3) The country rocks are thrown into minor folds of disharmonic nature near the contact of the Granite body. Faulting and shearing are also common features. These features in the older rocks indicate magmatic emplacement of the granite.

4) Presence of xenoliths of Khasi Greenstone in granite indicate a later intrusion of Granitic magma.

5) The Potash Feldspar phenocrysts are well formed, Subhedral to Euhedral and display distinct Carlsbad twinning. The size of the phenocrysts are uniformly coarse at the margin of the Granite body as well as towards the central part. A uniform coarse grained Granite is suggestive of intrusive origin (Dasgupta 1934).

6) The phenocrysts of Potash Feldspar at place show a sub-parallel arrangement which is taken to indicate a flow direction. The xenoliths of basic rocks, those that are elliptical or linear in shape, have a tendency to

align themselves parallel to the flow direction defined by the phenocrysts. The Potash Feldspars are seen to bow around the rounded xenoliths indicating the mobility of the magma and the obstruction of the flow of linear minerals.

7) Evidences of physical deformation in Granite are not observed. So the linear structures in Granite can be assumed to be of primary origin and produced by the movements of Granitic flow till it has solidified.

8) From the study of the structures of the Shillong Group of rocks around the Mylliem Granite it is seen that the metasediments from all sides dip towards the Granitic body. The strikes of the rocks are more or less parallel to the margin of the Granite, except those where the Granite bulges out and have cross cut relationship with the metasediments. It may be stated that the Granite has moulded the structure of the wall rocks at the time of its emplacement.

9) The Quartzites are thrown into open asymmetric minor folds at the contact of the Granite. The fold axes plunge 16° to 20° towards the Granite. Development of folds in the wall rocks at the contact of the Granite is a sign of forceful intrusion of the Granite.

10) The Schistose Peletic rocks which lie at the margins of Granite (Umthli) show the development of Andalusite porphyroblasts. These porphyroblasts seem to have developed due to the thermal effects of the Granites.

11) The longitudinal and cross joints in the Granite at Umthli are well developed and persistant throughout. Both sets are vertical or steeply dipping. Coating of hydrothermal minerals suggest that these joints were formed immediately upon consolidation of the Granitic magma (Rahman 1987).

b) Petrological Evidences: 1) Contact metamorphism without gradation is a good evidence of magma. The Quartzite near the Granite experienced thermal effects. As a result recrystallisation of Quartzite near the Granite took place, so that the Sericite present in the Quartzite has altered to Muscovite and the recrystallised Quartz show a compact mosaic appearance with pressure lamellaes and strain shadows, while away from the Granite this high temperature effect is absent.

2) Zonally arranged inclusions of Plagioclase and Quartz are seen in phenocrysts of Potash Feldspars. These zonal arrangements of inclusions of the early formed minerals are regarded as an example of truly magmatic crystallization (Rahman 1987).

3) The presence of complex twins in Plagioclase such as Albite, carlsbad, combination of these two and others is suggestive of magmatic derivation (Rahman 1987) of the Granite.

4) Granites originated by the consolidation of magma and occurring as plutons generally show predominance of microperthitic Feldspars. The Granite present in the study area satisfies this fact also.

5) According to Goodspread textural features like Subhedral crystal outline with sharp boundaries for the early formed minerals and Euhedral shape of phenocrysts are considered to be evidence of magmatic crystallization. In the Mylliem Granite too, the early formed minerals like Biotite, Plagioclase, Zircon and Apatite occur as Euhedral to Subhedral grains whereas the Potash Feldspar phenocrysts show proper crystal outlines.

6) Inclusions of Biotite, Plagioclase, Zircon and Sphene have sharp margins and not affected by the host Potash Feldspar, i.e. they maintain a physico-chemical harmony with Potash Feldspar. Such characters of Zircon are typical in rocks of magmatic origin (Rahman 1987).

7) Predominance of Microcline-Microperthite over Microcline and Orthoclase is characteristic of this Granite.

2.3.3 Quartzo-Feldspathic Gneiss: The Quartzo-Feldspathic Gneiss is generally massive, coarse to medium grained and colour is pink to grey. The variation in colour is due to the proportion in content of Biotite to that of Quartz and Potash Feldspars. Foliation is poorly developed and no linear structure is visible. Large spheroidal weathered blocks cover the rock exposures that have been subjected to sliding on NH-40 between Umling and Nongpoh.

Microscopic Characters: The rock is essentially composed of Quartz, Potash Feldspars (Microcline), Plagioclase, Biotite and a very small amount of Muscovite. Zircon and magnetite are accessories. Chlorite and Sericite are secondary minerals present in the rock. Modal analysis has been done (table 7) for the constituent minerals.

Quartz: The Quartz grains are Xenoblastic, coarse to medium grained. Crushing effect is seen in some grains where the grains show wavy extinction. The grains display first order grey to pale yellow interference colour Grain boundaries are regular. Quartz veins at places follow the foliation planes, which mimic the minor folds. Quartz veins traversing the foliation are also not uncommon.

Potash Feldspars: Microcline is the Potash Feldspar found in the rock. The grains are Sub-Idioblastic to Xenoblastic in form. They are commonly coarse grained with low relief. Fractures are well developed and sericitization took place along the fractures. They grains show first order grey interference colour. The most prominent among the twinning observed is the Cross-Hatch twinning.

Plagioclase: The Plagioclase grains are Sub-Idioblastic in form. They show Polysynthetic twinning. The interference colour is of first order grey. The extinction angle is 10°- 15°, so the Plagioclase is Oligoclase. Some grains appear cloudy and turbid due to alteration.

Biotite: The Biotites are yellowish brown flakes. They are Pleochroic from yellowish brown to brown. The grains are short prismatic flakes. Cleavage is distinct and extinction is straight. The grains display high order interference colour. The grains show a rough parallelism among themselves (plate 5).

Magnetite: The minerals remain dark in polarised light and show Anhedral form with a metallic lusture in reflected light. It is Isotropic under cross nicols.

Sericite: These are altered products of Feldspar. They appear cloudy in ordinary light and shine in cross nicols.

Chlorite: They are altered products of Biotite and are found at the border of Biotite. They are green and show weak Pleochroism along with straight extinction.

Table 7: Modal Analysis of Quartzo-Feldspathic Gneiss (Volume Percentage)

Mineral	Slide 1	Slide 2
K. Feldspar	29.10	30.12
Quartz	36.30	38.21
Plagioclase	14.37	16.17
Biotite	19.11	14.10
Accessories	1.12	1.40
Total	100.00	100.00

Origin of Quartzo-Feldspathic Gneiss: The original nature of Quartzo-Feldspathic Gneiss is not clear. These rocks have undergone deformations

Plate 5 Biotite grains in Quartzo-Feldspathic -Gneiss showing rough parallelism among them.

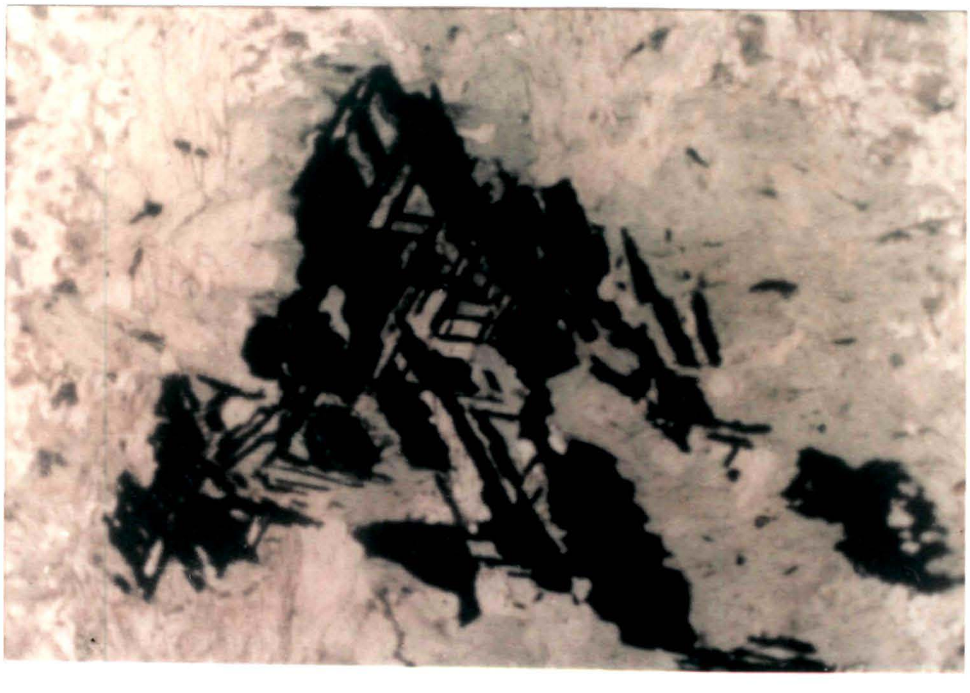


Plate 6 Skeletal structure of Pyroxene Cleavage retained by Magnetite in Khasi Greenstone.

and metamorphism along with metapeletic and Amphibolites interlayer. The rocks appear in two colours- pink and grey. The colour difference is due to Feldspar.

The Quartzo-Feldspathic Gneiss of the study area consists chiefly of Quartz, Potash and Plagioclase Feldspars, Biotite, along with some subordinate minerals. The mineral assemblages are uniform in the rock except in Biotite content leading to pink and grey colour varieties of the Gneisses. Although it is very difficult to say its origin in a single statement, the following evidences support that its source is close to sedimentary origin, than an igneous origin.

1) It bears a conformable structure and lithological relation with the other metasedimentary rocks of the area.
2) Thin lithological bands represent relict bedding and are conformable with the metamorphic country rocks.
3) The presence of subrounded detrital Zircons.
4) Quartz in considerable excess of Feldspar.
5) The presence of typical minerals like Garnet.
6) Field evidences show that bands of Garnet-Sillimanite bearing rock are interlayered with Quartzo-Feldspathic Gneiss. This may be an indication to the facts that in a sand-shale deposit, sands intercalated with Shale or Siltstone and when metamorphosed yield Quartzo-Feldspathic Gneisses interlayered with bands containing typical peletic minerals- Garnet and Sillimanite.
7) Segregation of minerals in parallel layers indicates the stratification or layering in the original rock.

The gradational contact of the pink Gneiss with the pink Granite indicates the K-metasomatism as indicated by Microcline porphyroblasts and relative decrease in Biotite proportions. The other type, i.e. the grey variety may represent least altered original sedimentary rock, which haveundergone metamorphic recrystallisation and reconstitution without significant metasomatism.

Some of the significant features regarding its origin based upon field and microscopic evidences are summarized as follows:

1) The rocks show a community of structural features common to all of them.

2) Compositional Layering in Quartzo-Feldspathic Gneisses.

3) The grain boundary relation between Quartz and Feldspar are of lobate and serrate type.

4) Myrmakitic, Perthitic and Anti-Perthitic intergrowths are common.

2.3.4 Khasi Greenstone

The Khasi Greenstones are Doleritic rocks, which occur as large and small intrusive bodies in the meta-sediments of the Shillong Group, showing concordant and discordant relation with them. The intrusion of the Meta-Dolerites into the Shillong Group took place towards the dying phase of regional metamorphism (Rahman, 1981) of the sediments of the Shillong Group. No appreciable contact effect was produced by the intrusions on the meta-sediments. The concordant bodies of the Khasi Greenstone trend, like the host sedimentary rocks, towards NE-SW. However, these concordant bodies may have locally transgressed across the bedding planes of Pelitic sedimentary rocks. The Khasi Greenstone is older than the Granite.

The Khasi Greenstones are in fact Metadolerites. They occur as dykes in the meta-sedimentary rocks of the Shillong Group. It is a medium to fine grained rock. The dominance of green coloured Amphiboles is responsible for the green colour of the rock.

Mesoscopic Characters: The rock is generally massive and medium grained, where needles of Amphiboles can be distinguished with the naked eye. Modal analysis has been done (table 8) for the constituent minerals. On the fresh broken surface the Plagioclase appears as white needles. The mode of interlocking among the constituent minerals still preserves the texture of an igneous rock.

Microscopic characters: The Khasi Greenstone is essentially composed of Hornblende and Plagioclase. Magnetite Ilmenite and Apatite are the accessories. Quartz, Epidote, Biotite, Chlorite and Sericite are the secondary minerals.

Actinolite –Hornblende (Amphiboles): Amphiboles are found in two forms, as large plates and as aggregates of small needles of fibres. Sub-Idioblastic to Idioblastic crystals of Hornblende is seen to occur in the highly recrystallised zone of Greenstone lying at the zone of close proximity of the Granite. Actinolite is generally pale green in colour with small minute fractures. The colour of Actinolite is not uniform throughout. Actinolite is moderately pleochroic. The most noticeable character is that the hornblende shows penetration twins.

Plagioclase: It occurs in Sub-Idioblastic, prismatic crystals as tabular grains and also as irregular patches. Plagioclase is sericitised and cloudy in appearance. They are highly altered to Sericite and Epidote-Zoisite.

Quartz: It occurs in small amount of secondary origin, formed due to the breaking down of Plagioclase and Pyroxene. It has colourless Anhedral grains of various sizes and shapes. Wavy extinction, 1^{st} order interference colour and uniaxial +ve nature are the common characteristics.

Magnetite: Magnetite is a very prominent accessory mineral occurring as inclusions within Actinolite or as separate grains, mostly with irregular outline. It is found to retain skeletal structure of the Pyroxene (plate 6).

Biotite: Few small tabular grains of Biotite appear in the rock collected from the landslide area at Mawphlang. They are secondary after Hornblende. It is mostly light to dark brown. It shows straight extinction.

Apatite: It occurs as elongated prismatic grains with transverse cracks. It is an accessory mineral found as inclusions in Plagioclase and Hornblende. It shows straight extinction and grey interference colour.

Chlorite: It is present as small patches along the cleavage or boundaries of Hornblende, hence it is of secondary in origin after Hornblende. It shows abnormal blue interference colour.

Epidote-Zoisite: They occur as small specks and granular aggregates. In thin section they show shades of light yellowish–green colour or sometimes appear as colourless. They appear to have resulted from the alteration of Calcic-Plagioclase or Hornblende. The assemblage show high order interference colour.

Sericite: It is the altered product of Plagioclase, which occurs as scaly and fibrous aggregates. The original prismatic form of plagioclase is retained by these scaly aggregates of Sericite.

Origin of Khasi Greenstone: The Metadolerites (Khasi Greenstone) is found as stock like intrusive body or dykes amidst the Quartzites of the Shillong Group. This is the metamorphosed basic igneous rock, the original rocks seems to be Pyroxene bearing basic rocks. Rahman (1958) says that the original rock was of gabbroic composition, while Dasgupta (1934) referred the original basic rock to diorite with Augite and Plagioclase as the essential constituents. However, this basic rock has undergone metamorphism since their intrusion into the Shillong Group and consequently it has been termed into Khasi Greenstone.

Table 8: Modal Analysis of Khasi Greenstone (Volume Percentage)

Mineral Constituents	Slide No. 1	Slide No. 2
Amphibole	57.8	55.0
Plagioclase	28.0	33.5
Quartz	4.7	3.7
Biotite	1.9	1.6
Iron	4.2	4.7
Accessories	4.4	1.4
Total	100	99.9

The metamorphism of the rock is well supported by the alteration of Pyroxene to Amphiboles viz. the Hornblende and the production of certain lower temperature minerals such as the secondary Quartz, Chlorite, Sericite and Epidote. Afterwards the sediments of Shillong Group were compacted and suffered burial metamorphism. These were intruded by basic igneous rock. This intrusive rock was of high temperature origin. After this intrusion, it was brought to a state of low temperature condition during which the high temperature Pyroxene minerals like Augite was transformed to comparatively lower temperature Amphibole, with simultaneous liberation of Iron Oxides and Quartz. The Labrodorite of the original rock was changed to Albite liberating Quartz and Calcium. The liberated Quartz, Iron Oxide and Calcium reacted to produce the Epidote present in the Khasi Greenstone.

The Khasi Greenstone (Krishnan 1950) includes varieties like Epidiorites, Amphibolites and Hornblende-Schist. The general green colour of the rocks and their very occurrence in the Khasi Hills motivated Medlicott to term them as 'Khasi Greenstone'.

The grade and type of metamorphism shown by the Khasi Greenstone are similar to the grade of metamorphism suffered by the adjoining sedimentary rocks. The Khasi Greenstone shows intrusive relations with the host rocks, i.e. the rocks of the Shillong Group. The rock has undergone regional metamorphism along with the sedimentary rocks.

2.3.5 Metapelitic Rocks:

The Metapelitic rocks form a minor fraction of the total rock types of the area and are more widespread along the NH-40 (Barapani area, Laitlyngkot-Umthli road stretch and Shillong –Mairang road). They are generally traced in thin bands but in the landslide spot at Barapani the band was quite thick (5-6m.). The Metapelites show a regional trend of NE-SW with angles of dip ranging from 25° to almost vertical.

The Metapelitic rocks in the study area have been identified into the following varieties.

i) Sericite-Muscovite-Quartz-Phyllite
ii) Muscovite-Biotite-Quartz-Schist and
iii) Andalusite-Mica-Schist
iv) Garnetiferous-Biotite-Sillimanite-Schist
v) Sillimanite-Garnet Gneiss
vi) Calc-Granulite
vii) Calc-Silicate

Muscovite-Biotite-Quartz-Schist variety of the metapelites was encountered in the landslide spot at Barapani while the other two varieties were encountered in the landslide spots at Umtyngar, Laitlyngkot and Tyrssad.

The mineral Muscovite in the Peletic rocks is present in slender flakes packed in certain bands alternating with thin bands of Quartz. In certain bands Muscovite appears in branches. Cleavages are distinct. The mineral is colourless and show high order interference colours and shows straight extinction. The Muscovite flakes follow the schistosity of the rock. Quartz is of fine grained variety associated with fine grained Sericite. They are found to arrange parallel to each other along the direction of schistosity.

In general the Metapelitic rocks are extremely fine grained, soft and friable and are fairly jointed with several sets of joints, the most prominent are being perpendicular to the foliation planes. The colours of the rocks are variable which ranges from grey, light brown, pinkish to buff. The rocks are finely laminated or foliated and show very good development of cleavage. At places the foliation is highly folded into a number of minor folds.

Origin of Metapelites:

Metapeletic rocks of the area include different varieties of Phyllites, Schists and Gneisses and it is very difficult to give a single mode of origin to the rocks. The following criteria indicates their sedimentary origin:

1) These rocks are associated with other Metasedimentary/Metapelitic variety in the area.
2) Lithological banding is seen in some Gneiss (Biotite Gneiss, although banding is not so prominent). It may indicate relict bedding.
3) They bear a conformable structural and lithological relation with the other Metapelitic varieties.
4) The bands are found to be elongated parallel to the lithological layering of the other rock types.
5) Presence of subrounded Zircon.

6) Quartz in considerable excess of Feldspar in some varieties of Schists and Gneisses.

2.4 Structural Pattern:

The meta-sedimentary rocks of the Shillong Group show a variety of Mesoscopic structures. Through a study of these structures the phases of deformation experienced by the rocks can be ascertained.

The structural complexity of deformed rocks are derived in part from the nature of the initial rocks, sedimentary or metamorphic, and in part from the deformation process. The principal factors concerned are:

1) Internal structural order and related physical properties of the rock body.

2) External forces and surface tractions acting upon the body during deformation.

3) Internal stresses resulting from reaction of the body to external forces.

4) Displacements, strains, rotations and differential movements of different domain within the body as a consequence of which the stresses become eliminated or reduced.

5) Internal structural order and related physical properties of the rock body after deformation.

In the present research work while determining the structural pattern of the rocks, emphasis has been given to the mesoscopic structures and fabrics observed especially in the Shillong Group of rocks. The mesoscopic structures investigated for the present study can be considered under the following heading:

1) **Planar Structures**: Bedding Planes, Current Beddings, Foliation, Joints, Faults, Schistosity and Cleavage..

2) **Linear Structures**: Folds, Mineral lineation, Slickensides and Crinkles.

The structural characteristics/patterns observed in the field along the surveyed highways are described below:

2.4.1 Planar Structures

Planar structures are developed during the flow stage where the platy minerals in a magma tends to become oriented with the largest face parallel to the liquid layers. The following planar structures have been encountered in the study area.

2.4.1.1 Bedding Plane: The lithologic layering or the original stratification planes can be recognised by distinct bedding in the rock types. They represent the dominant planar structures in the rocks. Both Quartzites and Phyllites are well bedded (plate 7). The Quartzites show thick bedding while the Phyllites are thinly laminated. The general strike of the bedding planes in the study area is in NE-SW and E-W direction.

2.4.1.2 Current Bedding: Current bedding is well developed in the Quartzites (plate 8), indicating shallow water deposition of the beds. The current show distinct truncated tops and tangential bottoms indicating normal sequence of stratification of the metasedimentary rocks of the area. This helps in finding out the top and bottom of the beds. It also helps in determining the direction of flow of water during the deposition of the sediments. These current beddings were tilted from their original attitudes of sedimentation by subsequent folding.

2.4.1.3 Cleavage: Cleavage is a secondary planar structure. It is well developed in the Phyllites, containing high amount of micaceous minerals. It is exposed on the Shillong- Mawsynram highway at a place called Kyrphei and also in Mawphlang. Prominent cleavage developed in these Phyllites includes Bedding Cleavage, Slaty Cleavage and Strain-Slip Cleavage (fig. 1).

Plate 7 Well bedded Quartzite rocks

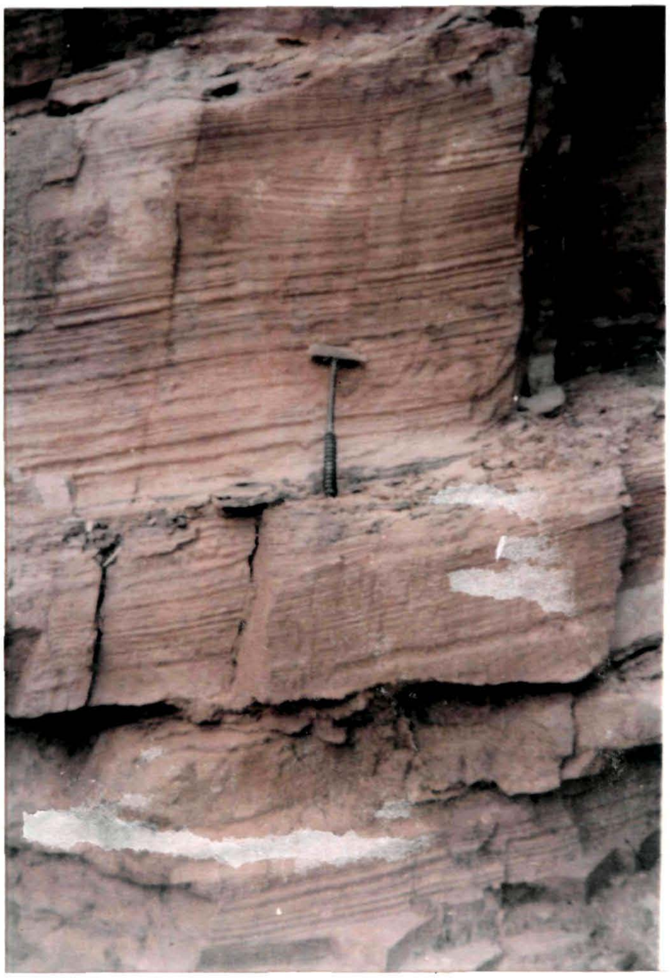
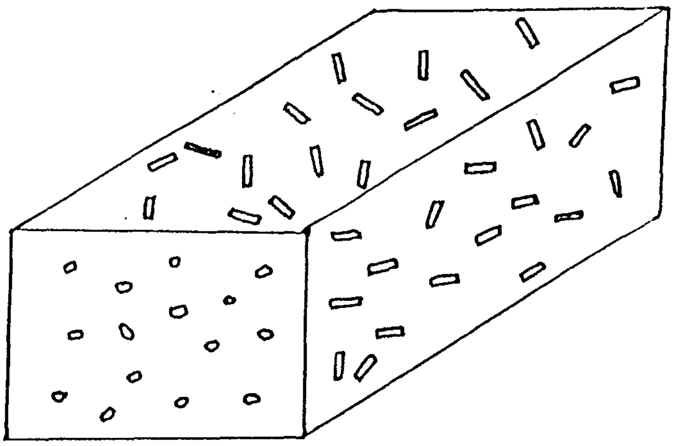
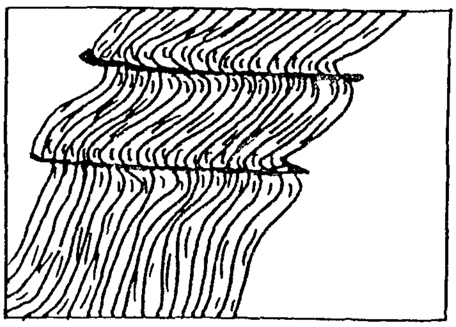


Plate 8 Current Bedding developed in Quartzites.



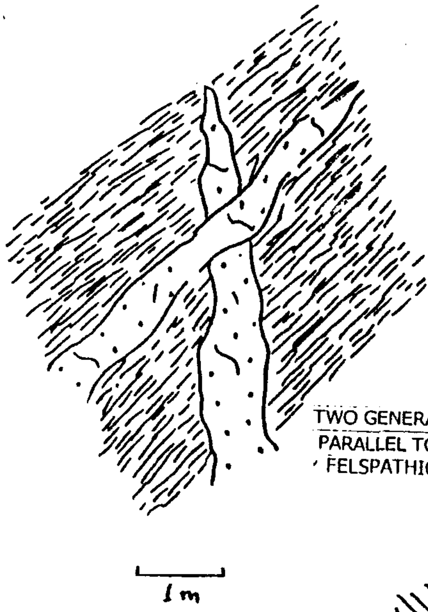
PREFERRED ORIENTATION OF LAMINAR, TABULAR OR ELONGATED MINERAL AGGREGATES

Fig. 2



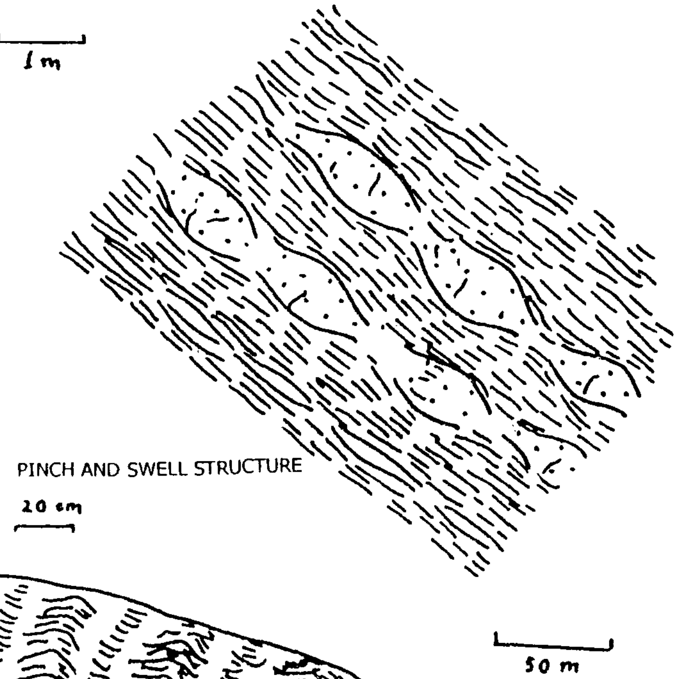
STRAIN SLIP CLEAVAGE DEVELOPED IN MICA SCHIST AFFECTING THE MAIN FOLIATION IN THE ROCK

Fig.1



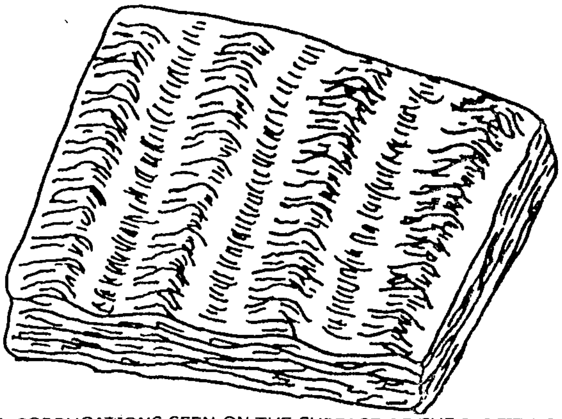
TWO GENERATION OF QUARTZ VAIN OCCURRING PARALLEL TO THE FOLIATION OF QUARTZO-FELSPATHIC GNEISS SHOWING

Fig. 3a



PINCH AND SWELL STRUCTURE

Fig. 3b



SMALL CORRUGATIONS SEEN ON THE SURFACE OF THE BIOTITE-QUARTZ-SCHISTS

Fig. 3c

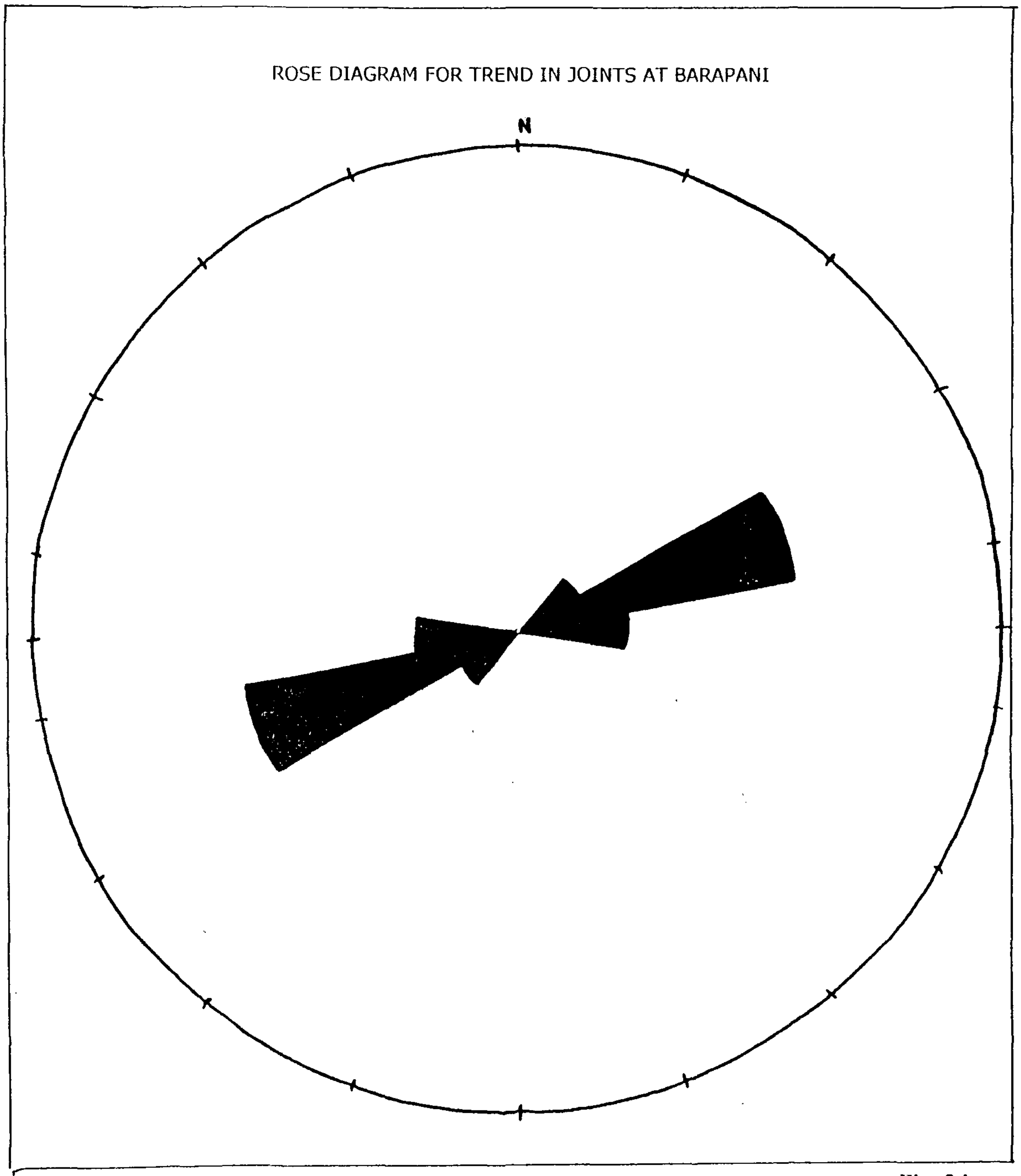


Fig. 3d

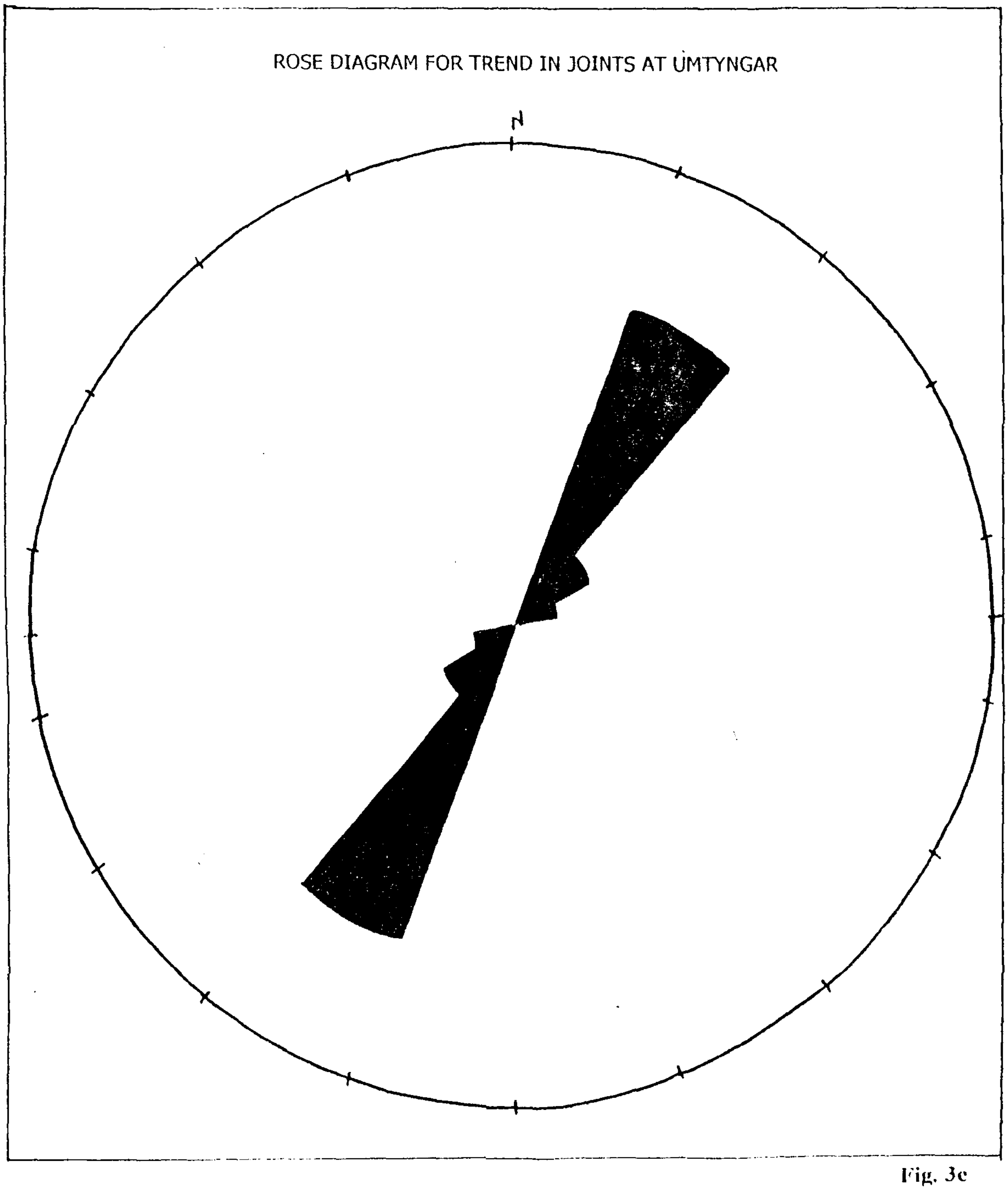


Fig. 3c

ROSE DIAGRAM FOR TREND IN JOINTS AT MAWPHLANG

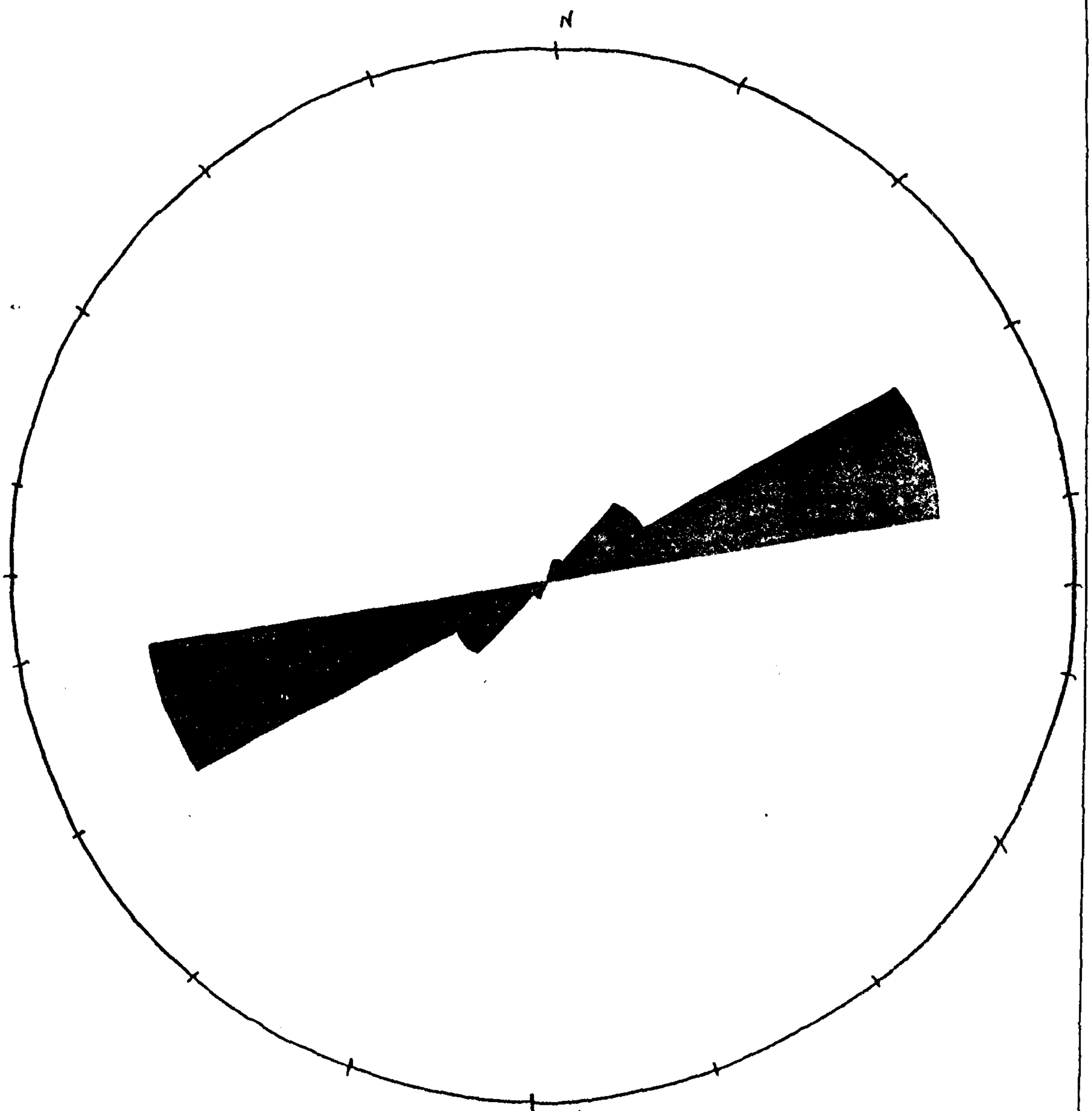


Fig. 3f

2.4.1.4 Schistosity: Schistosity is seen mostly in the Phyllitic rocks (due to the parallel alignment of the platy minerals). Minute flakes of Sericite-Muscovite have a tendency to orient themselves parallel to the bedding planes, in the low-grade Phyllites (Schists), along which the rock splits up into layers. The schistosity is often parallel to the bedding of the country rocks.

The Meghalaya Plateau is composed of numerous varieties of schistose rocks showing the typical crenulations or schistosity.

2.4.1.5 Foliation: Turner and Weiss (1963) defined the term foliation as "to cover all types of mesoscopically recognizable planar surfaces of metamorphic origin. Lithologic layering, preferred dimensional orientation of mineral grains and surfaces of localized slip might all contribute to foliation of different kinds".

In the rocks of the Shillong Group the preferred planar orientation of laminar, tabular or elongated mineral aggregates like Sericite and Muscovite and the lithological layering caused by metamorphic differentiation define the foliation (fig. 2). It occurs in the Phyllites and Schists.

Two generations of Quartz veins occur along foliation planes of Schists and Gneisses (fig. 3a). Small Quartz veins also occur parallel to the foliation of the Quartzo-Feldspathic-Gneiss developing pinch and swell structure (fig 3b). On the other hand small corrugations are seen on the surface of the Biotite-Quartz-Schists (fig. 3c).

2.4.1.6 Joints: In the initiation of landslides in a particular area major criterion involved is the presence of joints in the rockmass. The slope becomes more prone to slides if the rockmass is heavily and intricately jointed. In the study area joints are noticed in almost all the varieties of

Phyllites and Quartzites. In the field four prominent joint sets can be distinguished (table 9):

i) Longitudinal joints
ii) Cross joints
iii) Diagonal joints and
iv) Bedding joints

Out of the above four types, the Longitudinal Joints (plate 9a) and Bedding Joints are the most prominent ones. Distinct Joints can be observed in landslide areas of Umtyngar (Shillong-Cherrapunji highway) and Mawphlang (Shillong-Mawsynram Highway). Rose diagrams have been prepared for the different landslide spots to get an idea about the trend of the joints (fig. 3d-3f). The joint spacings are almost evenly distributed (plate 9b), the inclination vary from place to place, the dangerous ones being those that dip towards the roadside.

2.4.1.7 Faults: No major Faults have been encountered in the surveyed areas although traces of Fault Scarps have been identified in some places. Detailed field checks need to verify their occurences, which was difficult to go into much detail. On the 34 km.post of the Shillong-Mawsynram highway a crush zone is encountered. The trend of the crush zone is NE-SW, which is parallel to the Foliation of the metasedimentary rocks belonging to the Shillong Group of rocks. The rocks affected by the crushing include the quartzites and Andalusite-Sillimanite-Hornfels of the Shillong Group. The rocks in the zone of crushing are highly fractured and brecciated. A minor fault was detected, that may have developed due to the forceful injection of granitic vein into the Quartzites, at Umtyngar in the Shillong- Cherrapunji highway.

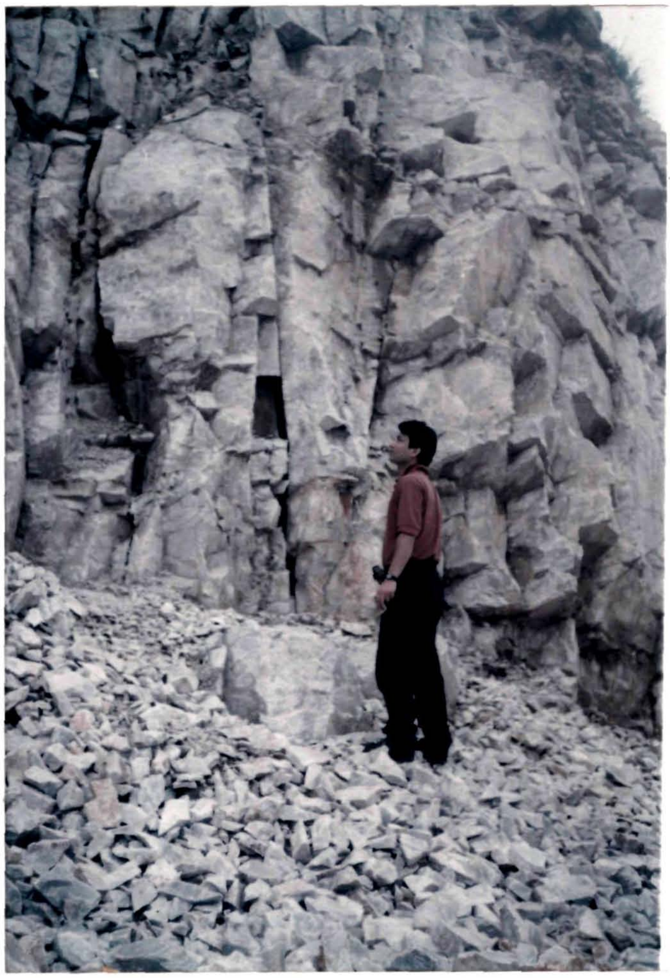


Plate 9 Longitudinal Joints in Quartzites.

Folds showing asymmetric Synclines and Anticlines having larger wavelength than amplitude '

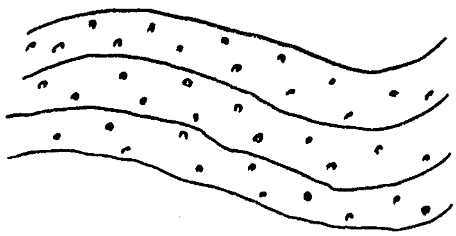


Fig 4a

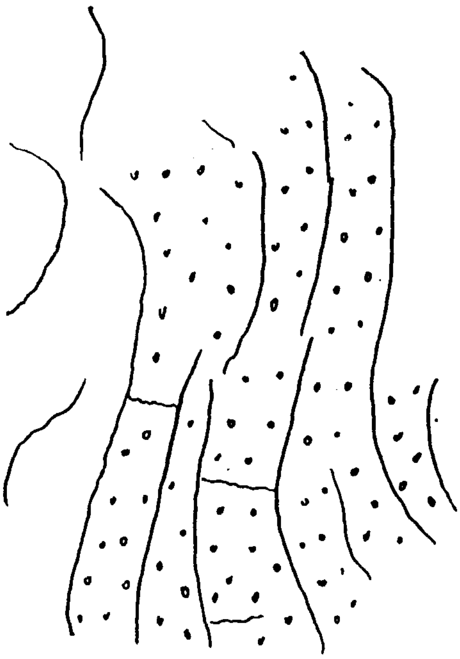
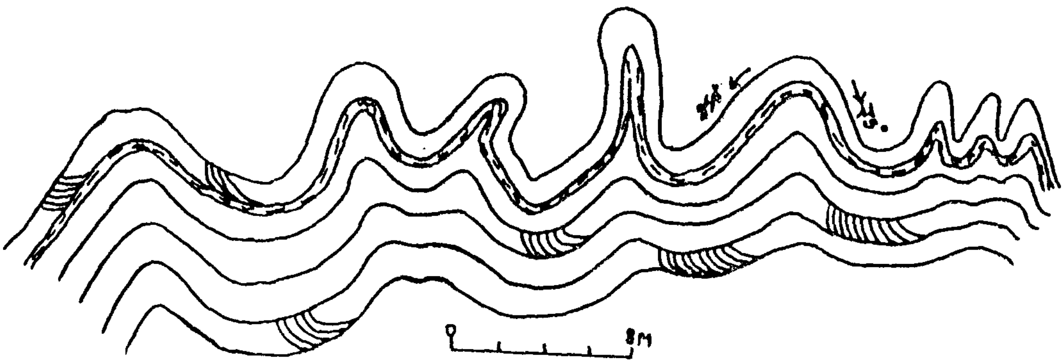


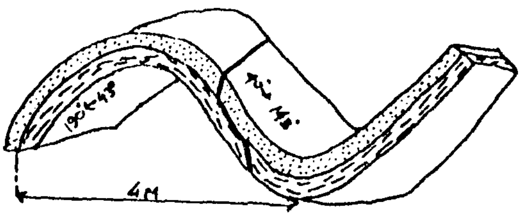
Fig 4b

0 1m



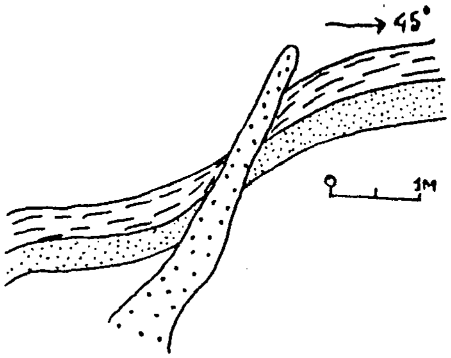
DISHARMONIC FOLD IN QUARTZITE-PHYLLITE-ROCK

Fig.4c



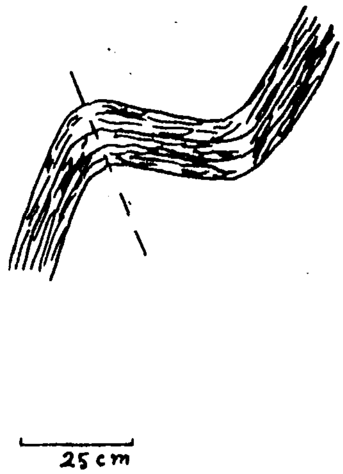
CONCENTRIC FOLD IN QUARTZITE-PHYLLITE ROCK

Fig. 4d



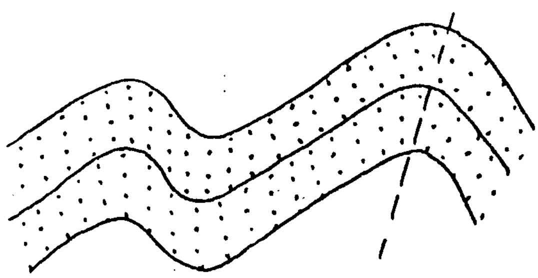
DRAG FOLD IN QUARTZITE PHYLLITE; A QUARTZ VEIN IN
EMPLACED ALONG THE AXIAL PLANE OF THE FOLD

Fig.4e



ASYMETRIC OPEN FOLD IN BIOTIC-SCHIST

Fig. 5a



SMALL SCALE ASYMMETRICAL FOLDS IN QUARTZITES WITH ALTERNATE LONG GENTLE AND SHORT STEEP LIMBS

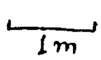
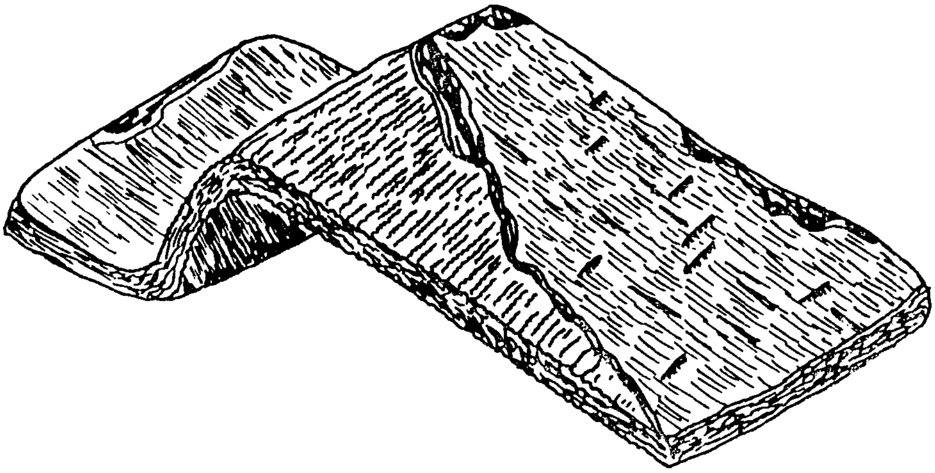
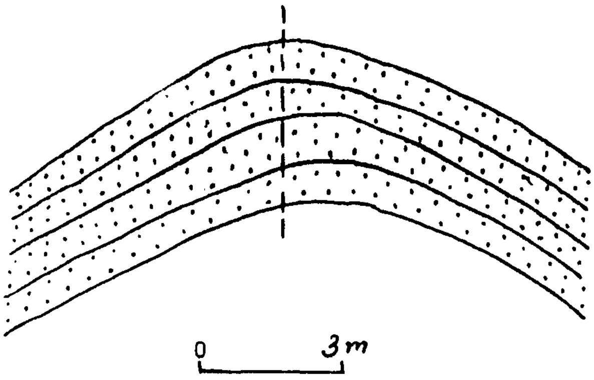


Fig. 5b



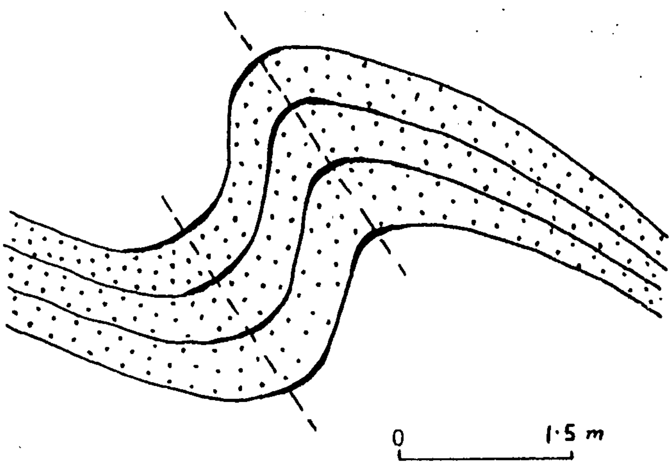
ASYMMERTRICAL SUB-ANGULAR FOLD (Chevron type) IN PHYLLITE

Fig. 5c



OPEN FOLD, WHICH IS ANTICLINE AND SYNCLINE IN MASSIVE QUARTZITES

Fig. 6a



COMPARATIVELY OPEN ASYMMERTRICAL FOLD IN SHEARED QUARTZITE

Fig . 6b

Table 9: Description of elements of Joints.

Landslide Spot	Joint Spacing in cm	Orientation in (°)	Joint Width in cm	Continuity
Jorabat	Massive	---	---	Non-Cont.
Umling	Massive	---	---	Non-Cont.
Barapani	5--10	25--32	0.2--0.3	Continuous
Umtyngar	30--50	60--75	1--2	Continuous
Mawphlang	60--75	75--80	1--2	Continuous
Tyrssad	Massive	---	---	Non-Cont.
Weiloi	Massive	---	---	Non-Cont.
Laitlyngkot	47--55	75--80	1--2	Continuous
Umthli	45--52	80--90	1--2	Continuous
Lumshoshur	50--60	67--72	1--2	Continuous
Lingkerdem	55--62	62--70	1--2	Continuous
Pynursla	55--65	60--70	1--2	Continuous
Sohiong	70--85	60--65	1--2	Few Cont.

2.4.2 Linear Structures

Linear structures are one dimensional features developed in rocks also during the flow stage. The different linear structures encountered in the study area are:

2.4.2.1 Folds: Folds of the first generation occur in almost all the Phyllites and Quartzites (Shillong Group) encountered. Major folds are mostly open folds, which have refolded bedding planes. These folds form asymmetric Synclines and Anticlines and have larger wavelength than amplitude (plate 10, also fig. 4a and 4b). Other varieties of folds include Disharmonic, Concentric and Drag folds in Quartzite-Phyllite rocks (fig. 4c, 4d and 4e). Asymmetric open folds in Biotite-Schist, small scale asymmetric folds in Quartzites and asymmetrical sub-angular folds in Phyllites (fig. 5a, 5b and

Plate 10 Folds forming Asymmetric Synclines and Anticlines having larger wavelength than amplitude.

5c) are prominent in the study area. In the observed cases the axes of the folds are usually parallel to the strike of the bedding planes of the associated formation trending NE. This may be an indication that the folds were responsible for the present orientation of the bedding plane surfaces. The folds are also noticed having gentle plunge. Tight Isoclinal Folds in Quartzites are observed in Umthli landslide prone area. Open folds are seen with Anticline and Syncline in massive Quartzites (fig 6a). Comparatively open Asymmetrical folds are also noticed in sheared Quartzites (fig 6b). These folded rocks are seen to be highly fractured. A few small scale folds affecting locally the general trend of the foliation plane are seen along NH 40 around Barapani area.

2.4.2.2 Slickensides: It is represented by striations often seen on the bedding and foliation planes of Quartzites and Phyllites. Such striations are usually parallel to the dip of the bedding planes of the rocks (plate 11). This indicates their development due to slip along the dip of these planes. The Slickensides form the youngest linear structures developed in the Shillong Group of rocks.

2.4.2.3 Mineral Lineation: Mineral Lineation is represented by the dimensional orientation of the minute needles and flakes of micaceous minerals in the Quartzites and Phyllites. In the Quartzite mineral lineation is developed along the bedding, while in the Phyllite it is more strongly developed on Schistosity.

2.4.2.4 Crinkles: Crinkles are rare and are developed in Phyllites on the Schistosity Foliation Planes. The axes of the Crinkles define a lineation in the rocks of the Shillong Group.

Lineament studies from Satellite Imageries, Aerial Photographs and Topographic maps with intensive field visits have revealed long and persistent lineaments. These Lineaments are probably the manifestations of deep seated fracture systems having repeated reactivation. The various Lineaments have been grouped under four classes:

i) N-S trending
ii) NE-SW trending
iii) NW-SE trending and
iv) E-W trending

Of the above four, NE-SW and E-W trending are predominant in the study areas. After field varifications, the Lineaments are found to be that of Fold Axes, Fractures, trends of intrusions of basic bodies (dykes), long axes of basins, etc.

2.5 Seismic Activity

The north-eastern region of India is a high intensity seismically active zone. Many earthquakes from mild to high and also very high intensities occurred in this region. Mention may be made of the Shillong earthquake (1897) and the Assam earthquake (1950).

Earthquakes of minor to mild intensities were recorded during the study period. These varied from ranges of 2.4 to 5.2 in the Richter scale.

2.6 Tectonic characteristics of the study area

The Pre Cambrian Gneissic Complex is the northeastern extension of the peninsular shield. This segment forms the core part of the Shillong massif. It is the basement for the subsequent events taking place. The central part of the complex covering Khasi and Jaintia Hills developed a linear and narrow NE-SW trending basin during the late Proterozoic period. This basin was the repository for the detritus, which later on formed the Shillong Group of rocks. These sedimentary rocks experienced low grade metamorphism and gentle warping. The Khasi greenstone and Porphyritic Granitoids subsequently intruded these rocks.

The Pre Cambrian terrain remained more or less a positive mass till the early Carboniferous period and was subjected to degradation. However, Permo-Carboniferous period saw development of a minor intrakratonic basin where the Gondwana sediments were deposited as evidenced from the western tip of Garo Hills- Hallidayganj. The terrain remained more or less dormant till the beginning of Jurassic when Sylhet traps were erupted towards the southern margin of the massif through E-W trending fissures i.e. Raibah fault system along which the southern block subsided and the northern block upheaved. The end of Jurassic saw deposition of thick sedimentary pile (Cretaceous Tertiary) along the southern boundary. Sedimentation continued till Miocene along the southern and western fringe of Garo Hills and the southern part of the Khasi Hills. But the Jaintia Hills were uplifted as a block and formed a positive area. However, the principal block upliftment of the massif commenced at the end of Miocene. As a result all along the Khasi and Garo Hills, shallow lacustrine basins were formed. In these basins the Dupitila sediments (Mio-Pliocene) were deposited. Over these the sub-recent to recent (Quarternary) deposits were laid along the various fluvio-lacustrine regimes. Due to differential and continuing post Jurassic uplift the Cretaceous-Tertiary sedimentary pile occurs at varying levels. In general the pile occurs at lower levels in Garo Hills than in Khasi and Jaintia Hills.

The Shillong Massif can be divided into three domains tectono-stratigraphically each of them having a distinct evolutionary history:

i) The Peninsular Shield Extension comprising the Gneissic Complex

ii) Intra-kratonic sedimentary basin represented by the Shillong Group.

iii) The Mesozoic-Tertiary sedimentary sequence along with the Sylhet traps occupying the southern tip of the plateau.

2.7 Lineaments

The important Lineaments of the study area are given below:

a) Pre-Cambrian Gneissic Complex

NE-SW dominant	: fold axes and fractures
E-W dominant	: fold axes and fractures
N-S minor	: fold axes and fractures
NW-SE minor	: mainly fractures

b) Proterozoic Shillong Group

NE-SW dominant	: fold axes, long axes of basin, fractures, trends of intrusive bodies
E-W minor	: fractures

c) Proterozoic Porphyritic granitoids

NE-SW dominant	: granitoids spread on both sides of the NE Trend
NW-SE dominant	: granitoid distribution controlled to some extent about this trend
N-S minor	: fractures

d) Mesozoic Sylhet trap (Jurassic?)

E-W most dominant	: line of effusion, dykes and flexures
NW-SE minor	: dykes in the northern parts of the upland
NE-SW minor	: as above

e) Jurassic-Cretaceous sedimentary pile

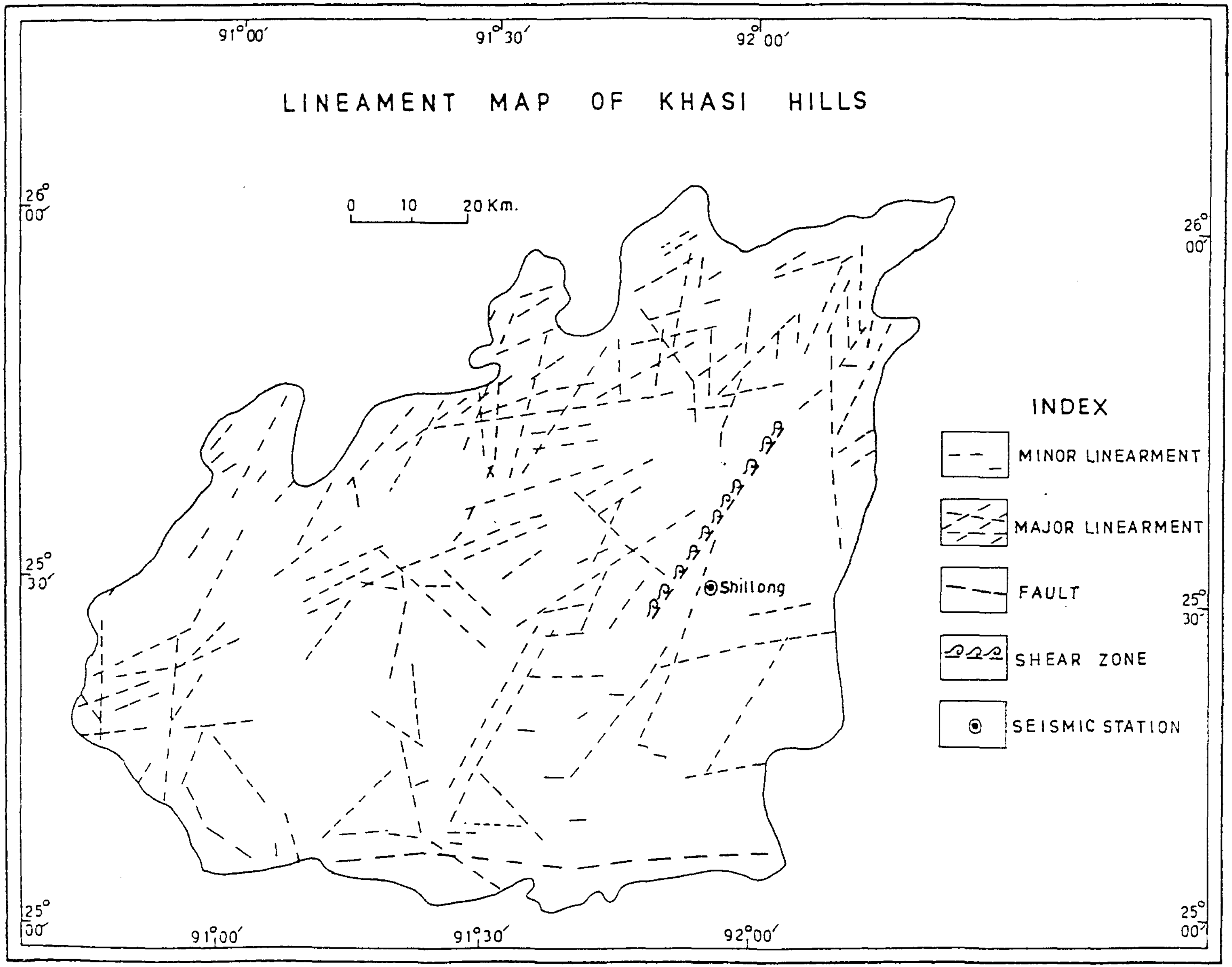
E-W dominant	: Raibah lineament

f) Tertiary sedimentary pile

E-W dominant	: facies contact, Dawki fault zone
NW-SE minor	: Kopili fault

Majority of these Lineaments are intraformational, hence if there are (map 4) any slip components associated, they are not distinguishable readily. As a result it is rarely possible to differentiate the Lineaments into faults and other mega sutures in the massif. At places where the Lineaments are seen to couple with scarps or bluffs, they can be recognized as the manifestations of particular fault systems. The alignment of the trunk streams dissecting down to Pre Cambrian can be assigned as the imprints of Quarternary fluvial cycles over the Pre-Tertiary exhumed surfaces of the Shillong Massif. Such features has progressed along the Lineaments reflecting their antiquity, deep seated nature and repeated reactivation. The massif in the southern fringe has the Pre-Tertiary topography, which is concealed below the cover sediments. The drainage networks have cut through deep gorges along the Lineaments initiating exhuming process. In contrast the northern tip has exhumed topography with embayments advancing towards the south into the massif along the Lineaments.

At the outset the Lineament trends were E-W and later during the Pre Cambrian period this trend was cut by NE-SW trend (map 4) that probably continued through during the intrusion of the Porphyritic granitoids. Thus Pre Cambrian is dominant with the E-W trending Lineaments while the Porphyritic granitoids seems to have been emplaced along NE-SW trend. The Khasi Greenstones too are emplaced along this trend. The NE-SW Lineament appears to be a deep suture along which major tectonic activity might have occurred and played a prominent role in shaping the evolution of the massif. The boundary between the Pre Cambrian and the Jurassic Sylhet traps is an important E-W Lineament. This Lineament is the famous Raibah fault that has a dip towards the south, and this fault had been active till the Cretaceous. The Dawki fault (E-W trending) further south is known to have


LINEAMENT MAP OF KHASI HILLS
91°00′
91°30′
92°00′
26° 00′
25° 30′
25° 00′
0 10 20 Km.
Shillong
INDEX
MINOR LINEAMENT
MAJOR LINEAMENT
FAULT
SHEAR ZONE
SEISMIC STATION

MAP NO. 4

been active till Tertiary period and which has been responsible for the upliftment of the Shillong Massif.

Even today many of the Lineaments are said to be active as evidenced from high micro seismic activities in an around the massif. The Lineaments that trace towards north into the Brahmaputra plains as well as towards south to the Surma plains display evidences of neotectonic movements. Release of built up stress mainly through vertical movements coupled with negligible or no lateral displacement maybe causing these modifications to this day.

2.8 A Brief Metamorphic History of the Study Area.

As metamorphism involves the interaction of temperature, pressure and several other variable factors, precise determination of metamorphic history of any area is often not possible. It is obvious that the metamorphic history of the Shillong Group is closely related to the tectonic and igneous activities of the area, which also governs the principles and nature of metamorphism. From the observable fields relations and by assembling different factors of metamorphism, the following metamorphic history can be suggested:

The deposition of the sediments of the Shillong Group took place in a depression or basin during the Pre-Cambrian times. A load pressure was exerted on the rocks or sediments as a result of prolonged sedimentation. As a consequence of this the sediments were subjected to burial metamorphism due to progressive rise in temperature and pressure with depth. This brought about the consolidation of the sediments accompanied by partial recrystallisation. In the arenaceous sediments, quartz does not show signs of appreciable degree of crystallization but the clayey matrix have recrystallised into scaly aggregates of Sericite. The Argillaceous sediments have emerged as Phyllite with the mineral assemblage Sericite-Chlorite-Albite-Quartz. The undulations or folding of the rocks, development of longitudinal or cross joints in the rocks took place during the initial tilting of the sediments concomitant to the regional metamorphism. .

Basic igneous rocks of Doleritic composition have intruded into the consolidated sediments both as concordant and discordant bodies. This suggests that by that time the sediments were sufficiently compacted, so that the intrusive bodies could follow the bedding planes in them. The basic igneous rocks have also imparted thermal effects on the country rocks, but this was very local in extent. Within the thermal zone, Quartz in the Quartzite has developed at places, marginal outgrowths of Silica in the same optical continuity with the parent grain. Effects of shearing are indicated by undulose extinction and pressure lamellae in Quartz.

Thermal effects in the Peletic rocks are exhibited very locally in narrow bands at the contact of small intrusive like Quartz veins. Here, the Sericite acquire a talcose appearance with a greasy feel i.e. Mergarodite.

The basic igneous rocks also suffered Regional metamorphism along with the Shillong Group of rocks and were subsequently altered to Metadolerites or the Khasi Greenstone. The original augite or Labrodorite transformed to Actinolite and Albite respectively.

The regionally metamorphosed Shillong Group and the Khasi Greenstone were intruded by the Mylliem Granite, which caused thermal metamorphism of both the group of rocks.

The Quartzites of the Shillong Group were thermally metamorphosed after the intrusion of the Granite Batholiths. At the proximity of the Granite, the Sericite of the Quartzite has been gradually converted into Muscovite. The recrystallised Quartz usually becomes free of inclusions, which are drawn towards the margins of the grains and acquire polygonal crystal outline with fairly straight margins meeting at triple point showing Granoblastic Polygonal texture. Most of the Quartz grains show strain shadows and pressure lamellae.

The emplacements of the Granite Plutons have superimposed thermal effects upon the Metapeletic rocks of the Shillong Group. Within the Thermal Aureole, the Sericite have been dehydrated and recrystallised as Muscovite. Quartz grains show perfect mosaic appearance. The rock become Schistose and the incipient crystals of Andalusite developed, which is thought to be formed at the partial expense of Muscovite and Quartz ($\pm$ Chlorite).

After the intrusion of the Granite Plutons the regionally metamorphosed Khasi Greenstones have been remetamorphosed.

2.9 Geological and Structural History of the Study Area.

The rock types found in the Khasi Hills can broadly be classified under two subdivisions namely the metasediments and the igneous rocks. The metasediments include Quartzites and Peletic rocks belonging to the Shillong Group. The igneous rocks intruding into the Metasediments include both basic and acidic types. The basic type is represented by Metadolerites (Khasi Greenstone) and the acidic type is represented by Porphyritic Granites. The metasediments of the Shillong Group were first intruded by the Khasi Greenstone (Rahman 1981) and then by Porphyritic Granites, for example the Mylliem Granite (765$\pm$ 10 million years; Crawford 1969).

The Metasediments of the Shillong Group form the country rocks of the area, which are undoubtedly of sedimentary derivation. This is indicated by the sequence of Lithologic Layering, Repetition of Strata, Current

Beddings, Ripple Marks, Graded Bedding, etc. Petrographic studies have shown that the Quartzites are highly Arenaceous rocks with more than 70 % Quartz, embedded in a matrix of Sericite. The Peletic rocks are highly Sericitic with little amount of Quartz. The Shillong Group of rocks have undergone low grade regional metamorphism prior to any igneous activity in the area. The earliest intrusives into the consolidated sediments of the Shillong Group are the Khasi Greenstones, which have also suffered metamorphic effects along with the rocks of the Shillong Group. Later these Metamorphites were intruded by the Granitic Plutons and imparted thermal effects at the proximity of the Porphyritic Granite. A narrow Thermal Aureole (nearly 400m.) could be traced along the Granite margin. Within this Thermal Aureole, the Sericitic matrix of the Quartzites has recrystallised to Muscovite and the rock shows a compact Granoblastic texture. Again the low grade Phyllites have transformed into Mica-Schist and high grade Hornfelses, which bear porphyroblasts of Andalusite.

The Granite, which is the last intrusive into the Metasediments and the Metadolerites (Khasi Greenstones) are rich in Potash Feldspar Phenocrysts. It is a normal Biotite-Granite. The Granite shows cross-cutting relationship with the country rocks and contain xenoliths of both the Quartzites and the Metadolerites.

Structurally, although the rocks of the whole Shillong Plateau have been affected by six phases of deformation, the Upper Shillong Group of rocks have been affected only by three phases of deformation.

In the study area, the first phase of deformation produced large open folds (Laitlyngkot and Umthli). The primary Foliation (Bedding Planes) in the rocks was folded by these folds. The folded layers retain equal thickness all throughout. The folds are more frequent near the contact of the granitic bodies. Metamorphism with recrystallisation produced a Foliation in the Argillaceous members of the area. The Foliation is axial planar to the first phase folds. Hence the metamorphism leading to the development of the Foliation was syntectonic with the deformation leading to the formation of the folds in the rocks.

The second phase of deformation took place after the emplacement of the Porphyritic Granites in the study area. Clear evidences in the field can be traced at outcrops in Laitlyngkot and Umthli (along highway) landslide prone areas. This deformation s confined to the development of discrete zone in the area and is expressed well in the small crush belt in the area east of Umthli. The shear planes are parallel to each other, which render the rocks into closely foliated Pyllonites, folds are developed and these are associated with the development of Strain-Slip Cleavage.

2.10 Age and Correlation

Age: In the Khasi Hills the Gneissic Complex is the oldest rock type. Krishnan (1968), by correlating the rocks of Shillong Group with that of the Iron ore Group of Chotanagpur plateau, assigned it to a Middle Dharwar age.

Though Khasi Greenstone is younger than Shillong Group, yet they have been folded up in some places along with the Shillong Group and suffered the same Regional Metamorphism. Hence, they are considered to belong to the same age as the Shillong Group.

Dasgupta (1934), has assigned Mylliem Granite to the post Archaean age as it does not show any sign of foliation due to any crustal movement.

Rahman (1969) concluded that the Mylliem granite, whose longer dimension along E-W direction follows more or less parallel to the trend of the country rocks does not show any sign of Foliation due to the tectonic movement unlike the crystalline Gneisses and Schists forming the basement in the Shillong Plateau. Based on this consideration, Mylliem Granite may be placed some where between Pre-Cambrian and Cretaceous age. But the down warping of the Shillong Group of rocks is regarded as contemporaneous to Iron ore orogeny of Sarkar and Saha (1962). Thus the Mylliem Granite can be correlated with the Singhbhum Granite of Bihar (Pre-Cambrian).

The present study area forms a part of the metamorphic terrain dominated by the Shillong group of rocks and the Archaean Gneissic complex. The Shillong Group is exposed in the central and southern parts of Khasi Hills while the Gneissic complex is exposed in the northern and western parts. The Shillong Group in the study area is represented by Quartzites, Phyllites and Conglomerates. These rocks are of sedimentary derivation as evident from their sedimentary features and structures.

Correlation: Correlation of the rocks present in the Khasi Hills with similar rocks of other parts in India has been determined on the basis of structural and mineralogical similarities amongst them. The present area forms a part of the Pre-Cambrians of Shillong Plateau. Geologically Shillong Plateau is regarded as the NE continuation of the Indian Peninsular Shield separated from the Chotanagpur Plateau by the Ganges –Brahmaputra valley. The ENE-WSW Satpura trend, which is seen in the Chotanagpur Plateau, can also be traced in the Shillong Plateau. Similarly, the ENE-WSW Eastern Ghat strike is also prevalent in the eastern part of the Shillong Plateau.

The Pre-Cambrian sedimentary formations (now metamorphosed) with igneous intrusions that are encountered in the area appear to be similar with that of the Dharwarian Formations of Mysore.

Medlicott (1869) assigned the rocks of the Shillong Group to the lower portion of the "Transition System" of sub-metamorphic and metamorphic rocks, which were comparable to those of Bihar and equivalent to the Bijawars and Champaner beds that were deposited on some Gneissic, Granitoid and Schistose basement.

The distinctly foliated formations like the Dharwars, the Champaner and the similar Schistose and Semi-Schistose rocks of Bihar and Shillong plateau together with the unfolded Gwalior were included within the "Transition".

The idea has been supported that the rocks of the Shillong Group are similar to the "Transition" of Bihar in composition and in order of succession.

Fox (1939), regarded the Shillong Group as equivalent to Bijawar Group of Bundelkhand, which, Heron has shown as equivalent to Aravalli system of Rajasthan and which Dun has compared again with the Iron ore Series of Bihar.

Pascoe (1950), stated that the Shillong Plateau is a disconnected portion of the Peninsular India, separated by a strip of alluvium from the nearest Archaean rocks of Chotanagpur. He derived his conclusions from the fact that the Quartzites of Shillong Plateau are equivalent to the Dharwar Quartzites.

Krishnan (1950), has shown the resemblance of the Iron ore Group of Bihar, Shillong Group of Meghalaya, Sausar and Sakoli Group of Madhya Pradesh, Silpi Ghat Group of Sikkim and Darjeeling.

In the Dharwars of South India (Mysore) the Conglomerate beds, marked the bottom of the Upper Chloritic division of the Dharwars. The thick Conglomerate beds occurring below the Graphitic Quartzites of

Shillong Group can be roughly correlated with the Chloritic division of Smith and at the bottom of the middle division of Rama Rao of the Dharwar rocks of South India. Chowdhury and Rahman (1959), found xenoliths of Quartzites in the Khasi Greenstones at Umtyngar and xenoliths of Khasi Greenstone in Mylliem Granite near Mylliem Town. This suggests that the Shillong Group of rocks are the oldest, followed by the Khasi Greenstones and then by the Granite. Correlation of the different rock types of the present study area (Khasi Hills) under investigation with their counterparts in other stratigraphic horizons of India as given by Krishnan (1968) is as shown in table 10.

Table 10 : Stratigraphic Correlation

Age	Mysore	Chotanagpur	Central Provinces	Shillong Plateau	Khasi Hills
Jurassic	-	-	-	Sylhet Trap	-
	Closepet Granite	Singhbhum Granite	Amla Granite	Mylliem Granite	Mylliem Granite
	Charnockite	-	-	-	-
	Peninsular Gneiss				Khasi
	Upper Dharwar	Kolhan			
	Middle Dharwar	Iron ore	Sakoli	Shillong	Shillong
	Lower Dharwar	Gangpur			

2.11 Geochronology: S.N. Sarkar (1964), published a paper "Geochronology of the Pre-Cambrian of Peninsular India", in which he writes "in Assam the Pre-Cambrian Sillimanite Schist, Gneiss and Granites have a general NE-SW trend with local variation to E-W. The Gneiss is unconformably overlain by the Shillong Group of metasediments. K-Ar age of coarse Muscovite (472 m.y.) from Mica-Schist of Shillong Group with E-W strike is comparable with that of Hornblende (1529 m.y.) from Amphibolite in Granite Gneiss near Guwahati. It is clear that the Pre-Cambrian here are affected by Indian Ocean cycle closely at 450 m.y."

Rb-Sr analysis of the Durgapur Granite (West Bengal) and Mylliem Granite (Shillong Plateau) gives an age of 795±10 and 765±10 m.y. respectively. (Crawford 1969).

Now the age of the Shillong Group as determined from the coarse Muscovite is 472 m.y. Again, the age of Mylliem Granite, as determined by Crawford, is 765±10 m.y. But the rocks of the Shillong Group are older than the Mylliem Granite as shown by Krishnan and later confirmed by Rahman, Chowdhury and others. There fore the Shillong Group of rocks cannot be only 472 m.y. old. The Muscovite, from which this age was determined, might have developed at a much later age, probably syntectonically with the Strain-Slip Cleavage Foliation. Again the age of Iron ore Group, with which the previous workers have compared the Shillong Group, has been determined at more than 2038 m.y. (Sarkar and Saha 1962). Hence the age of the Shillong Group cannot be 472 m.y.

Based on the data obtained by radiometric age determination of rock samples collected from different localities of India, Sarkar (1964) revised the Pre-Cambrian of India, (excluding the igneous activities) and put forward a generalized succession of the orogenic metamorphic cycle and phases of the different regions. The ages are given in millions of years (m.y.) indicating the closing of events and these with time of sedimentation.

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Chapter 3

Weathering, Mass Wasting and Soils

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Weathering, Mass Wasting and Soils

The three processes-weathering, mass wasting and soil act in nature sequentially and is a part of the cycle of "Circulation of Matter". Weathering is the initial stage in the history of denudation of a landscape, (King, 1953). The harder parts of the earth's surface must be weathered away before the denuded particles can be transported to another place. Much of the rocks on land must pass through the soil stage before being ultimately removed insitu, (Bloom, 1978). The movement of these materials is controlled by a number of processes, some of which act at a slower pace while the others are taking place all of a sudden.

3.1 Weathering

The definition of weathering can be given as the disintegration or decomposition of various rocks in place at or near the ground surface. It is primarily concerned with the reduction of a rock mass to a form and size, which is susceptible to erosion and accompanied by agencies like mass movement, running water, etc.

Four stages of weathering have been recognized universally by scientists all over the world.

First Stage: Initiation of physical weathering when the parent rocks change to coarse and fine grained detritus. Present day weathering activity is sometimes terminated under severe environmental conditions and active denudation.

Second Stage: The second stage involves the alkaline reactions in the zone of weathering due to leaching of bases from the primary minerals. Secondary minerals are produced during this stage by oxidation, hydration, hydrolysis and carbonization of primary minerals. The dominant secondary minerals produced belong to Montmorillonite and Nontronite groups. All the recent scree and surfacial materials on the slopes of mountainous terrain reflects the second stage of weathering.

Third Stage: The third stage is characterized by the further removal of Alkaline and Alkaline Earth elements from the products of weathering. Consequently, acidity is activated in the zone of weathering. Under these conditions, Halloysite and Kaolinite groups of secondary minerals are produced dominantly. This stage of weathering is predominant under conditions of slow or retarded denudation and also relatively high rainfall or wetting.

Fourth Stage: This stage involves the formation of a residual allitic weathering crust enriched in Iron and Aluminoxides. Attainment of this stage is conditioned by the presence of intensive chemical decomposition of primary minerals in rocks coupled with very slow denudation under hot and humid conditions. The red earths of the humid subtropical areas best represent the allite type of weathering. The red colouration is due to the accumulation of Ferric Hydroxides in the residuum.

In the study area the process of weathering is very much active, specially in the Guwahati- Shillong highway (NH-40), where almost all the rock types have been altered to soils and rendered it susceptible to heavy landsliding.

Weathering as may be expected, starts at two planes : Foliation and Joint Planes. Both the vertical and horizontal joint planes are present in the Quartzites (near Barapani) and as a result of weathering along those planes rectangular blocks and slabs are produced and which ultimately under the action of gravity rolls down along the slope. These blocks near Barapani form masses of talus below vertical cliffs. Because of the hardness and compactness and particularly the vertical Joints in Quartzites the surface water flows over the rock in the form of rapids and falls e.g. Fuller falls near Umsning. The isolated harder Gneissic hills on the north and north-west are formed as a result of weathering. The soft and brittle Mica-Schist, Phyllites and other clay rocks, which are very susceptible to weathering, has been eroded away and hence are found to expose on the lower elevations. Spheroidal weathering is a noticeable feature in the rocks, which is due to the presence of irregular Joints developed in the rocks and subsequently shapeless blocks are produced (plate 12).

In Cherrapunji area, during extensive field observations, the researcher came across some evidences of physical weathering (plate 13) where limestone beds are showing pothole like structures. Especially it shows the action of water in the Joints indicating the initial stage of weathering. The development of cracks along the joints can be clearly noticed. There are usually vegetative growths along these cracks.

The process of weathering results in weakening, fragmentation or decomposition of bedrock at and near the surface of the earth (table 11). It is very difficult to ascertain as to what depth the effects of weathering extend, but records have shown that it can be active upto a depth of 100m. below the earth's surface. The position of the water table and the length of time that weathering has been in operation have an important influence upon the depth to which the weathering processes may extend. A given set of climate and geological conditions causes the development of certain complex weathering and erosional processes. Almost all landforms are to a greater or lesser extent the result of weathering, (Ollier, 1969).

Plate 11 Slickensided surface - indicative of a palaeoslide in Sericite-Schist.

Plate 12 Spheroidal weathering - due to the presence of irregular Joints in the rocks.

Plate 13 Limestone beds showing Pot Hole like structures.

Table 11: Physical Characteristics of the landslide prone zones

Landslide Spot	Weathering	Infilling Material	Water Movement
Jorabat	Unweathered	No Infill	Moderate
Umling	Highly Weathered	No Infill	Great
Barapani	Highly Weathered	Thick Infill	Great
Umtyngar	Moderate	Thin Infill	Moderate
Mawphlang	Moderate	Thin Infill	Moderate
Tyrssad	Moderate	No Infill	Moderate
Weiloi	Moderate	No Infill	Moderate
Laitlyngkot	Moderate	Thin Infill	Moderate
Umthli	Moderate	Thin Infill	Moderate
Lumshoshur	Moderate	Thin Infill	Moderate
Lingkerdem	Moderate	Thin Infill	Moderate
Pynursla	Moderate	Thick Infill	Moderate
Sohiong	Moderate	Thick Infill	Great

Among the main rock forming minerals Quartz is the only one that can show high resistivity to chemical weathering. Moreover the mafic minerals are highly prone to chemical weathering. A very long Geological time period is required for the total completion of chemical weathering. As a result, huge quantities of unstable primary rock detritus and secondary clay minerals are very often transported to the base level of erosion before they are reduced to free oxides. Hence the presence of rock fragments and their degree of weathering in the sedimentary rocks is an important indicator of the weathering history of a particular terrain. It is noticed that higher the incidence of rock fragments, closer is the provenance of the detritus and lesser the time to which the parent rock suffered weathering processes. Likewise, the degree of alterations suffered by these fragments indicates the relative time-space significance. In the extreme cases of weathering and low denudation, wastelands are produced where anthropogenic activities degrade the landscape beyond its resilient capacities.

3.1.1 Factors controlling weathering

The various factors that influence weathering in an area are temperature, rainfall, humidity, Geology, etc. The above mentioned factors each have a role to play both individually and also as a group. The geologic factors more or less remain constant in an area over a long period of time, whereas the other factors are time dependent. Thus, the climatic factor (temperature, humidity and rainfall) exerts greater influence in the weathering processes in an area.

Weathering has mostly been influenced/activated by the following factors in the study area(in their order of intensity):

i) rainfall

ii) temperature

iii) humidity

iv) lithology

The above mentioned factors (i-iii) each have a role to play both individually and also as a group that can be assigned under climatic factors, but it is rather difficult to estimate the rate at which it is affecting the areas. The lithology is a long term factor which cannot be determined quite easily and changes caused by it may not be prominent.

3.1.1.1 Climate

Tropical monsoon climate prevails in Meghalaya. There is a huge altitudinal difference in Meghalaya (50m. to 1961m. above m.s.l.), which accounts for large variations in the climatic parameters. The rains spread over with maximum precipitation during the months- June to September. The state has two distinct seasons:

i) May to Mid October (Rainy season)

ii) Mid October to February (Winter season)

The high rainfall (table 12) and the plateau nature of the state of Meghalaya is a boon to the occurrence of deep-seated chemical weathering. Due to climate and altitude the state has large patches of thick forest cover. The litter of the forest turns the soil acidic, which in turn increases leaching i.e. chemical weathering. High relief and dissection of the state have helped in flushing out the water soluble ions produced by chemical leaching along the flanks of the upland. This process is responsible for the formation of large quantities of lateritic soils.

The state experiences high rainfall. The rainfall over the acidic soils yields large amount of acidic waters, which increases removal of huge quantities of leached ions and precipitate part of them when changed Eh-pH conditions are encountered. Similarly, higher rainfall in the state increases runoff along slopes causing sheet and gully erosion in the interfluve areas, (Singh, 1979). Consequently large quantities of materials are constantly removed downslope thereby frequently exposing new bedrock to physical and chemical weathering.

Similarly the state shows wide variations in temperature. The high variation in temperature increases mechanical disintegration of rocks.

Humidity is related to rainfall and temperature. Because of high rainfall in the state, the humidity normally remains moderate to high. As a result evaporation is slow. This indirectly helps in retaining the soil moisture for longer periods. The overall effect is faster and prolonged chemical weathering.

Table 12: Average annual rainfall of selected towns in Meghalaya

Years	Mawsynram	Cherrapunji	Shillong	Barapani
1990	11,152.3	10,217.2	158.68	2370
1991	16,112	13,505.9	210.45	1967
1992	13,109	8,533.4	156.2	2204
1993	13,848	12,801.3	175.19	2498
1994	10,840.6	11,205.1	131.18	2160
1995	13,802	14,192.6	192.48	2259
1996	12,952.9	12,896.8	151.16	1888.5
1997	9,647.6	8,993.1	178.13	2409
1998	15,972.2	14,536.9	167.43	2019
1999	13,452.4	12,502.8	191.75	2348
2000	13,382.8	12,260.6	191.38	2405

A very important factor in weathering is the alternate wetting and drying of rocks, a process known as slaking. The researcher has observed the disintegration of fine grained sandstones into a number of large pieces of about equal size in between Umtyngar and Cherrapunji. A large variation in diurnal and monthly rainfall in this region helps the process of slaking.

3.1.2 Weathering Characteristics

Meghalaya can broadly be grouped under the following lithological categories viz. i) Gneissic complex, ii) Shillong Group, iii) Granitoid Pluton, iv) Khasi Greenstone and v) Terrace deposits. These five litho units exhibit different weathering characteristics, due to the intrinsic variation in mineralogy and structural attributes. The difference in physical weathering is more pronounced than the differences in chemical weathering.

i) Gneissic complex: The gneisses, by and large are the most competent rocks in Meghalaya. These rocks tend to break down into two stages; firstly, the rocks break into blocks along joints and gneissosity surfaces and detach from the main mass. Under the influence of gravity these blocks move down as per the profile of the slope. These dislodged invariably show spheroidal weathering. The hummocky topography in the gneissic terrains is due to accumulation of such boulders or remnants of it.

Reduction in size and opening of joints along with other surfaces of fissility like gneissosity and schistosity causes the rocks to be attacked faster chemically. It alters into granular debris, comprising kaolinised feldspar, clay minerals and quartz depending upon the maturity stage of the weathering. Much of the Fe and Mg ions have leached out of the weathered rock. The chemical weathering advances along joints and other fissile surfaces, from the outer surface to the inner surface. As a result, the slope profiles show at many places "Core Boulders", which is an unaltered gneiss core with an envelope of weathered mass of sand like gritty material.

ii) The Shillong Group: The rocks of the Shillong Group are very well bedded and show differential weathering due to the alternations of quartzites, phyllites and siltstones. The quartzites and phyllitic quartzites are more resistant to weathering that stands out in relief, while the siltstones and phyllites form subdued topography like 'benches' and 'valley flats'.

In areas where the beds have horizontal to sub-horizontal disposition the physical weathering of rock is much impeded except where the slopes have been destabilized by excavations (table 12). However, in areas where the rocks have steeper or vertical dips, the physical weathering is more pronounced, particularly in the viscinity of Tyrssad-Barapani shear zone and other reactivated lineaments. Such areas show large accumulation of rubble due to rock disintegration along bedding, foliation and joint surfaces. The rocks are pulverized along "shears" and weathers out faster as slides of different scales and modes.

Chemically, the rock is not as receptive as the Khasi Greenstone, but being well bedded and foliated are more permeable. The permeability is further enhanced due to the presence of joints and fractures. The permeability induced subsurface water circulation is conspicuously evident by numerous fresh water springs in an around Shillong, Mawlai and Barapani ICAR research farm. Water seepage is a very common phenomenon visible along sharp cuttings or topographic breaks in the Shillong Group of rocks.

This subsurface water circulation network has altered the Shillong Group of rocks extensively. The intergranular cementing material has been leached out at many places. As a result the Quartzite, Phyllitic-Quartzites have lost their intergranular bonding strength and have become like "sands" and "silts". These altered rocks are being used as building materials as a substitute for river sands and silts.

Another conspicuous feature of the subsurface water circulation is the movement of Fe-Mg ions and their precipitation along fractures and open space cavities. A very common feature seen in the Shillong Group of rocks is the presence of thin encrustations of goethite as laminae and dripstones. This is due to the precipitation Fe ions as a result of evaporation. These goethite encrustations are commonly seen where the rock cuttings remain unmodified for prolonged periods. Such feature is commonly seen in Mawlai, Barapani and Nongbir areas. Where the rock cutting is modified frequently, the Shillong group of rock show variegated colouration (brown-maroon-orange).

iii) Granitoid Pluton: These rocks display spheroidal weathering and bouldery- hummocky landforms. The boulders detach along the joints and fracture plains and develop exfoliation surfaces. These weak planes have provided access to the chemically active fluids through which the weathering front advances below the ground surface. Moreover, the coarse texture and predominance of potash feldspar make these plutons highly prone to chemical alteration. Conspicuously, the physical weathering aids the chemical weathering and vice-versa resulting in production of coarse sandy-gritty detritus in vicinity of these plutons. Similar granitoids in central and southern India have bald and barren domal features. However, these plutons though they have analogous domal expression they lack the baldness and instead have thick weathered mantle supporting luxuriant vegetative cover. This contrast is mainly due to the difference in climatic regimes.

iv) Khasi Greenstone: These rocks occur as minor linear impersistent lenses. In contrast to the Gneisses, the Khasi Greenstone produces bouldery outcrops due to its massive nature. The size of boulders varies mostly between 10cm. to 30 cm., rarely upto 1-2m. across. The boulders are detached mostly along the orthogonal fractures and have suffered rounding of corners due to chemical weathering. Such features are very commonly seen in areas around Mawiong.

The Khasi Greenstone due to its basic/ultrabasic nature is more prone to chemical alterations, which has weathered out fast producing a reddish brown regolith and soil mantle of laterite variety. Due to steeper slopes and extensive deforestation, the red soil mantle has moved outwardly and mushroomed over the underlying rocks. As a result the lateritic mantle is spread over disproportionately to the aerial distribution of the parent rock. At places the pine growths makes the rock residuum acidic in nature and due to high precipitation the leaching of Fe-Mg is fast in the acidic medium. As a result, the ferric staining and pigmentation of adjoining rocks along joints and fractures has become pronounced. Where the rock is sheared it has suffered brittle failure occurring as a pulverized mass. Due to this phenomenon the Khasi Greenstone has become more permeable to the chemical solutions or more prone to chemical attack. In such areas the rock has completely altered into an undifferentiated soil profile (Rahman 1981).

v) Terrace Deposits: These are the Quarternary sediments comprising secondary minerals like Kaolinite, Montmorillonite with abundant refractory detritus produced from weathering of the rocks forming the uplands. Mineralogically these detritus and the secondary minerals are relatively stable in the present physico-chemical environment. Therefore, their future breakdown is a very slow process; consequently they persist unchanged in the zone of weathering. The terraces and colluvium of the upland have so far not attained the "fourth stage " of weathering process discussed above. As a result the relict bases, alkaline and alkaline earths are constantly being leached out.

The above five lithological categories have been identified by Geologists and Geomorphologists working in this area.

3.2 Mass wasting

Mass Wasting involves the bulk transfer of masses of rock debris down slopes under the direct influence of gravity. Mass wasting is usually aided by the presence of water, but is not present in such an amount as to be considered a transporting medium.

There are four major classes of mass wasting which are designated as slow flowage, rapid flowage, landslides and subsidence. Among them landslides are by far the most important mass wasting phenomenon.

Mass wasting is an important gravity controlled movement of materials over the earth's surface. It is a slow to sudden downward and outward movement of materials and perhaps it is the most important agency to remove the surface loose material.

Mass wasting is an important process, which is a part of weathering. The weathered material, which rests on the sloping ground, comes down under the influence of gravity. The process of mass wasting is more effective on steep slopes as well as on the slopes, which have loose bare rock surfaces. The effectiveness of mass wasting depends on such factors like lithology, stratigraphy, structure, relief, climate and vegetation cover. Different factors become dominant in different parts of the study region. The dominating type of mass wasting observed in the study area (landslide areas) is:

i) Soil Slide

ii) Debris Slide

iii) Rock Slide

3.2.1 Soil Slide: Heavy soil slides have been noticed along the Guwahati-Shillong road (NH-40) in the study area. These soil slides ranges from small dimensions of about 4-5m. to very large dimensions of around 30 m. (Mawiong, NH-40).

3.2.2 Debris Slide: Debris slide is nearly the free fall of earth debris from the vertical or overhanging face, (Blackwelder, 1942). Debris fall is noticed in Barapani area constituted by the phyllites, (NH-40). Tremendous leaching activity caused by heavy rainfall over the highway

3.2.3 Rock Slide: Rock slide is the process of sliding or falling of individual rock masses down usually along bedding joints of fault surfaces. It appears that due to the action of physical and biological weathering along joints and fracture planes in the rocks, (rectangular to irregular) different shapes of rock blocks and slabs move under the influence of gravity and roll down along the slopes. It has been noticed that landslides are more frequent where the developmental activities have modified slope profiles, particularly making the profile segments steeper in sections. This makes the slope unstable with a tendency to fall as and when the equilibrium is disturbed, (Selby, 1982).

The field observations of landslides in the study area reveal two important contributory anthropogenic factors leading to the instability of slopes. They are deforestation and steep cut slopes for stone quarrying along the roadside. Deforestation is mainly due to the illegal practice of jhum cultivation by the local population.

3.3 Soils

Soils are the product of chemical, biochemical and physical processes acting upon the earth materials under various topographic and climatic conditions, hence they reflect as much as landforms do the climatic and geomorphic history of a region in which they evolved, (Keller, 1957). So important is knowledge of soils that no earth scientist today is adequately trained who lacks an appreciation of the soil-forming processes and a basic understanding of soil characteristics.

The state of Meghalaya shows little variation in respect of climatic-factors (rainfall, temperature and humidity). Geologically, the different rock types show gross homogenous characters and more or less similar uniform weathering phenomenon. Consequently the resultant soil profiles are the products of local relief differences and high degree of deforestation by "Jhum" and lumbering activities.

The soils of Meghalaya has broadly been divided into four categories:

1) Red loamy soil
2) Laterite Soil
3) Red and Yellow Soils and

4) Alluvial Soil

The red loamy soils occupy the central part of Garo Hills district and the upland zone in central and eastern Meghalaya. Generally, the soil is loamy but sometimes clayey or sandy loam. The laterite soils occur in abroad belt extending from west to east in northern part of the state. Another belt of red and yellow soils occur in the southern part of the state, which extends from west to east. They vary in colour from yellow, reddish yellow and yellowish brown to red. The soils are usually fine textured and vary from loam to silty loam. The alluvial soils occur all along the northern, western and southern fringes of the state. The alluvial soils are sandy to clayey loam.

The soils of Meghalaya are acidic in reaction. They are strongly acidic (pH-3.0), in areas adjoining the coal mines and not so acidic in other areas. Generally, the soils at higher altitudes receiving high rainfall are more acidic (pH about 5). The acidic nature of soils in Meghalaya is attributed to the leaching of substantial amount of cations, such as potassium, calcium and magnesium ions from the exchange complex due to high rainfall and undulating topography of the state. The soils of Meghalaya are generally rich in nitrogen content. It is about 0.15 % in the degraded sites (Cherrapunji) and about 0.94 % in undisturbed forest soil (Mawphlang). Scientists made surveys on the soil nutrient levels of Meghalaya, which includes both macronutrients and micronutrients and analysed over 3000 soil samples collected from different parts of the state. According to them, the soils of entire Meghalaya (except in Pynursla and Mawkyrwat blocks) are deficient in available phosphorus. In most of the regions the content of soil organic carbon is high (more than 0.75 %). The soils contain 125 kg. to 250 kg. ha^{-1} of potassium, which is considered to be a medium quantity. The total

Zinc, Copper and Manganese contents in different altitudes of Khasi Hills (100m. to 1900m. above m.s.l.) vary from 10.0 ppm to 47.25 ppm. However, the extractable Zinc, Copper and Manganese are very low and range from 0.72 to 3.289 ppm.

By and large the insitu soil profile is thick with argillic horizon and a thick weathered mantle below. The salient pedologic characteristics are given below.

3.3.1 Soils over Shillong Group

Soils derived from rocks of the Shillong Group are medium to fine textured. The depth of soil horizon varies between 18cm. to 200cm. with a local gravelly horizon. Due to continuous leaching the bases are leached out. In general the soil is homogenous, granular, sandy, loamy to clayey, non-sticky and non-plastic but the predominant type is sandy. The colour of the soil varies from very dark grayish brown to yellow through brownish yellow and red. In some areas Jhuming activity has eroded much of top soil to lower levels and at such areas the fertility of the soil has been reduced. The soils show differentiated profile on gentler slopes only.

3.3.2 Soils over Gneissic Complex

The soils derived from the gneisses are mostly medium to fine textured. The soil profile is mostly thick and the colour varies from dark tan to dark orange brown. Texturally it is loamy to clayey, non-sticky and non-plastic. The depth of soil horizon varies from 10cm. to 300 cm. This soil is gravelly at places due to the presence of fragmental quartz grains. The soil is rich in humus but on areas of Jhum cultivation the top soil has relatively lesser humus. It is constantly being eroded and deposited at lower levels and valley flats. As a result the soil profile does not show well differentiated horizons.

3.3.3 Soils over Granitoid Pluton

The soils derived from these plutons are in general medium to coarse textured. It is dark brown to grey in colour with high percentage of Quartz. The soil is highly rich and has clay pockets locally, which is the weathering product of Feldspars of the Granitoids. In general, the soils show textural variation with altitudes. The soils over the Mylliem Granitoid are loamy while the soils occurring at Kyrdem and Nongpoh Pluton are clayey in nature.

3.3.4 Soils over Khasi Greenstone

Soils derived from Khasi Greenstones are typically lateritic giving a reddish brown colour. Due to the basic nature of the rock it is more, it is more susceptible to alteration and has produced extensive soil horizon. The soil is clayey to loamy, moderately fine and granular. It is non-plastic and non-sticky. The colour varies from yellowish red to red. The insitu soil profile varies in depth from 22 cm. to 185 cm. and shows homogenous nature.

3.3.5 Soil over Terrace Deposits

In general, these are transported alluvial soils deposited by running as well as stagnant waters (bils, lakes and swamps). The thickness varies from 1m. towards the uplands and exceeds 10m. towards the lowlands. The terraces having their proximity to base of hills and pediments constitute thin aprons and fans of washed of soils from the uplands. These terraces conspicuously have primary layering due to alternations of fine and coarse detritus. The upper part of the soil has lost its primary layering due to high incidence of anthropogenic activities (agricultural, settlements, tea plantations, etc.). The soil aprons flanking the pediments and hill slopes are by and large structureless and heterogeneous.

Steep slopes accelerate removal of soil separates, exchangeable cations through the various agencies like high rainfall, movement of animals and human beings. There has been significant removal of organic carbon, exchangeable calcium, magnesium and sodium from sloping lands and these have been accumulated in the valleys. Clay content in the valleys is low; this is mainly because the runoff with fine sediments gets less time for settling due to heavy flow. This feature is noticed throughout the entire Shillong Massif. It is abundantly clear that chemical weathering in the state of Meghalaya has altered all litho types thereby enhancing the erodibility. The competent rocks like Gneisses, Granitoids and Quartzites (Shillong Group) have become highly vulnerable to erosion due to leaching.

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Chapter 4

Morphometric Analysis of Landforms

Chapter 4
Morphometric Analysis of Landforms

Morphometric analysis forms the scientific basis for a rational and optional utilization of land resources. This technique helps to understand the nature of land degradation along with the factors responsible for it. This is a method that provides spatial information produced in the form of thematic maps and statistical data by quantitative geomorphic characterization, (King, 1962). Morphometric analysis also helps in locating Geo-Hazards, if there are any. These analytical products are helpful for planners to choose favourable locations for taking up developmental schemes for agriculture, forests, hydro-potential utilization, industrialization, pasture, urbanization and settlements.

Although the Geo-Hazards and geomorphic risks cannot be avoided altogether, still then their recognition in the initial stages of planning and constant regular monitoring helps to adopt suitable precautionary measures within the framework of benefit or cost analysis.

The methodology of preparation of the morphometric parameters should be systematic, practicable and simplest as possible so that the users including engineers, geographers, geologists, environmentalists and planners have no difficulty in understanding and putting them into practice efficiently.

From the realm of descriptive approach to quantitative approach, geomorphology has come a long way. Numerous geomorphic or morphometric attributes such as Absolute Relief, Relative Relief, Dissection Index, Drainage Frequency, Drainage Density, Slope, etc. are being used for the terrain characterization, that is termed as a parametric approach of terrain evaluation. Recognition of the quantitative techniques in geomorphology had been slow, but the need to communicate with user agencies for benefit-cost analysis in utilization of land resources gradually emphasized on to these techniques.

The following geomorphic attributes have been considered in the present study:

i) Relative Relief
ii) Drainage Density
iii) Drainage Frequency and
iv) Slope Analysis

A significant development has been observed in the field of quantification and its applicability in physical geography nowadays has expanded. Geomorphologists are very keen regarding the utilization of morphometric techniques in the context of increased quantification of different geomorphic attributes. Although there are drawbacks related to the use of these techniques especially for more consumption of time, these techniques are preferred to the more advanced ones considering the locational limitation. Parameters of slope and drainage assume great significance. At times a combination of several results have been utilized to obtain a better understanding of the geomorphic attributes of the area.

4.1 Relief Analysis

To study the geomorphological features of any area, the first step is the analysis of its relief features. Relief and other geomorphic elements are based on differences in elevation. The important geomorphic elements are Absolute Relief, Relative Relief, Altitudinal Distribution etc.

The process of evolution of the relief of an area depends upon geological structures, lithology, climatology and the nature of the original topographic surfaces of the area. Only relative relief as an element has been considered in the present research work.

Relative Relief in general, denotes the actual variation of height in an unit area with respect to its local base level. According to Glock (1932), relative relief is not strictly a function of elevation above sea level. Importance of Relative Relief study in understanding landforms has been highlighted by Johnson (1933) and Smith (1935).

4.1.1 Method of Analysis

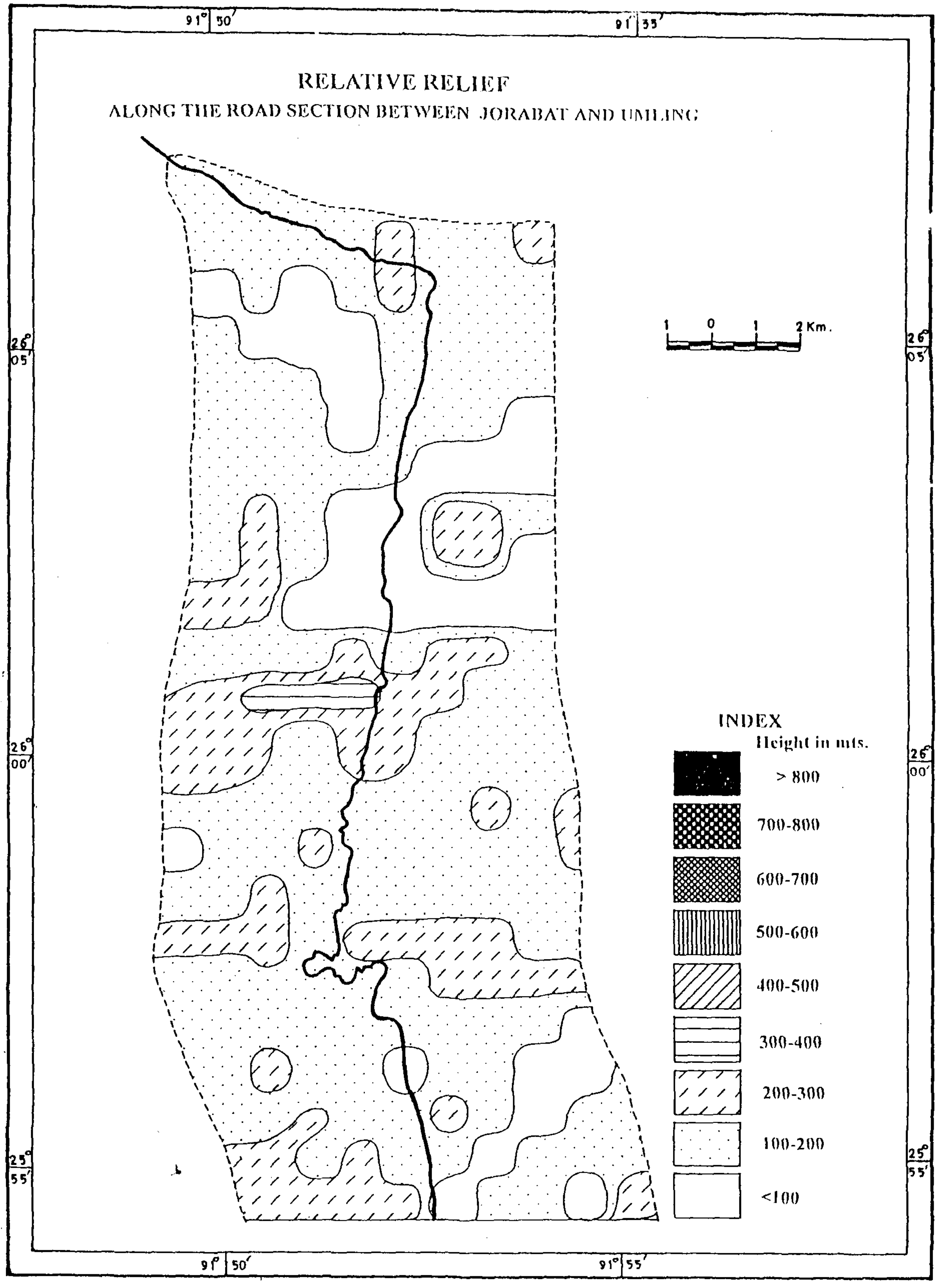
Relief analysis of the study area has been done along the highways to a stretch of 3-4 kms. away (from both sides of the highways). Relative Relief has been analysed for the study area, denoting the actual variation of height in a unit area with respect to its local base level. For the analysis of Relative Relief the area has been divided into one square kilometer grids. The difference between the highest and lowest elevation with each grid is computed and recorded and placed at the centre of each grid. The area has been grouped into 100m. interval. The relief analysis reveals nine categories of Relative Relief ranging from less than 100m. to above 800 m (table 13, map 5a – 5g).

4.1.2 Distribution Pattern of Relative Relief

From the above table it can be seen that the study area comprises mainly of low category relief while the higher categories are minimal, the maximum area being covered by the 100-200m. category with an area of 457.10 sq. kms. which is 33.82% of the total area.

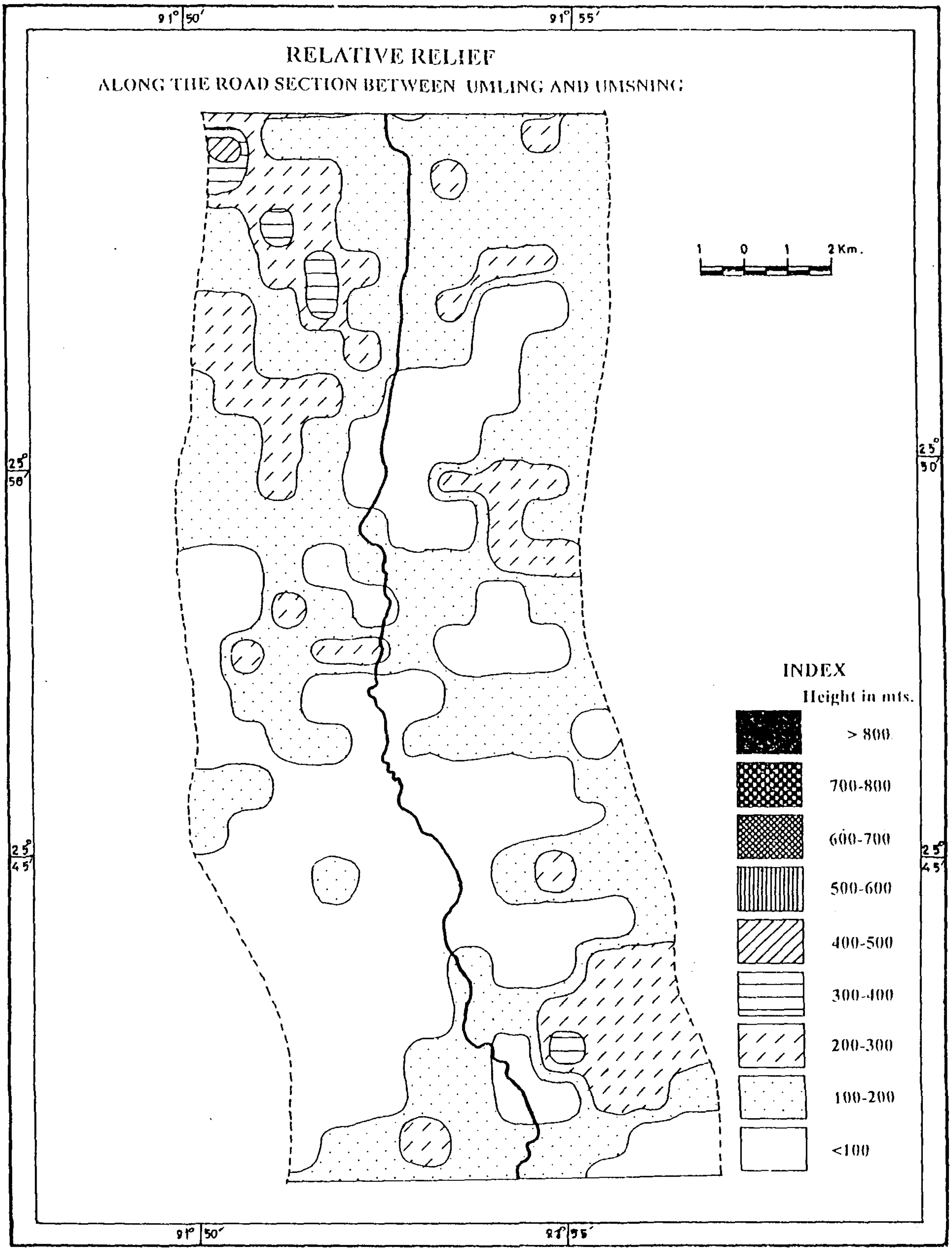
Very High Relative Relief category (above 700 m.)

This category covers a negligible area (0.41%) in the study area along the roadside, which is confined as isolated patches over the terrain (map 5a-



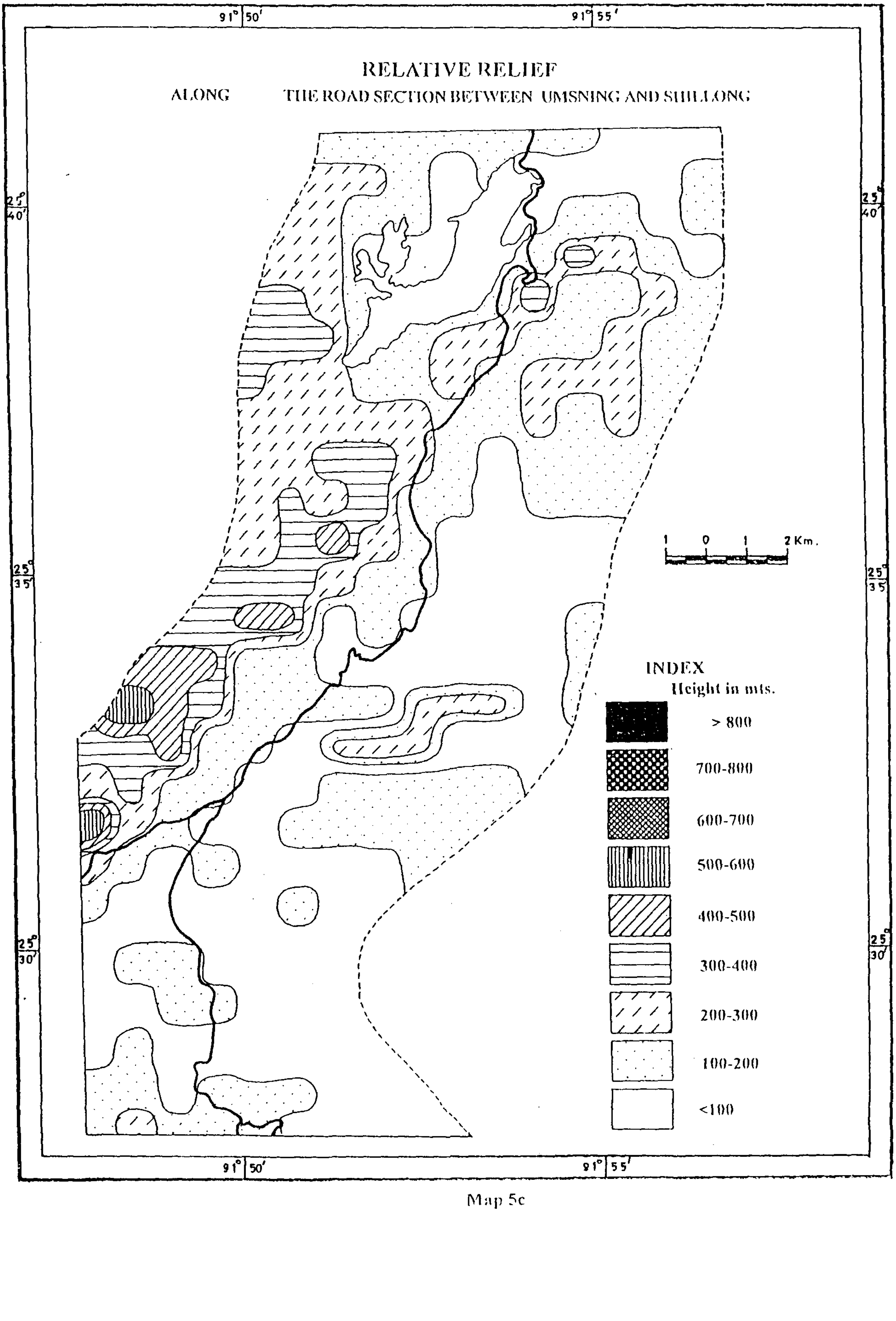
Map 5a

* **Full index has been given for Relief, Slope, Drainage Density and Drainage Frequency Maps**

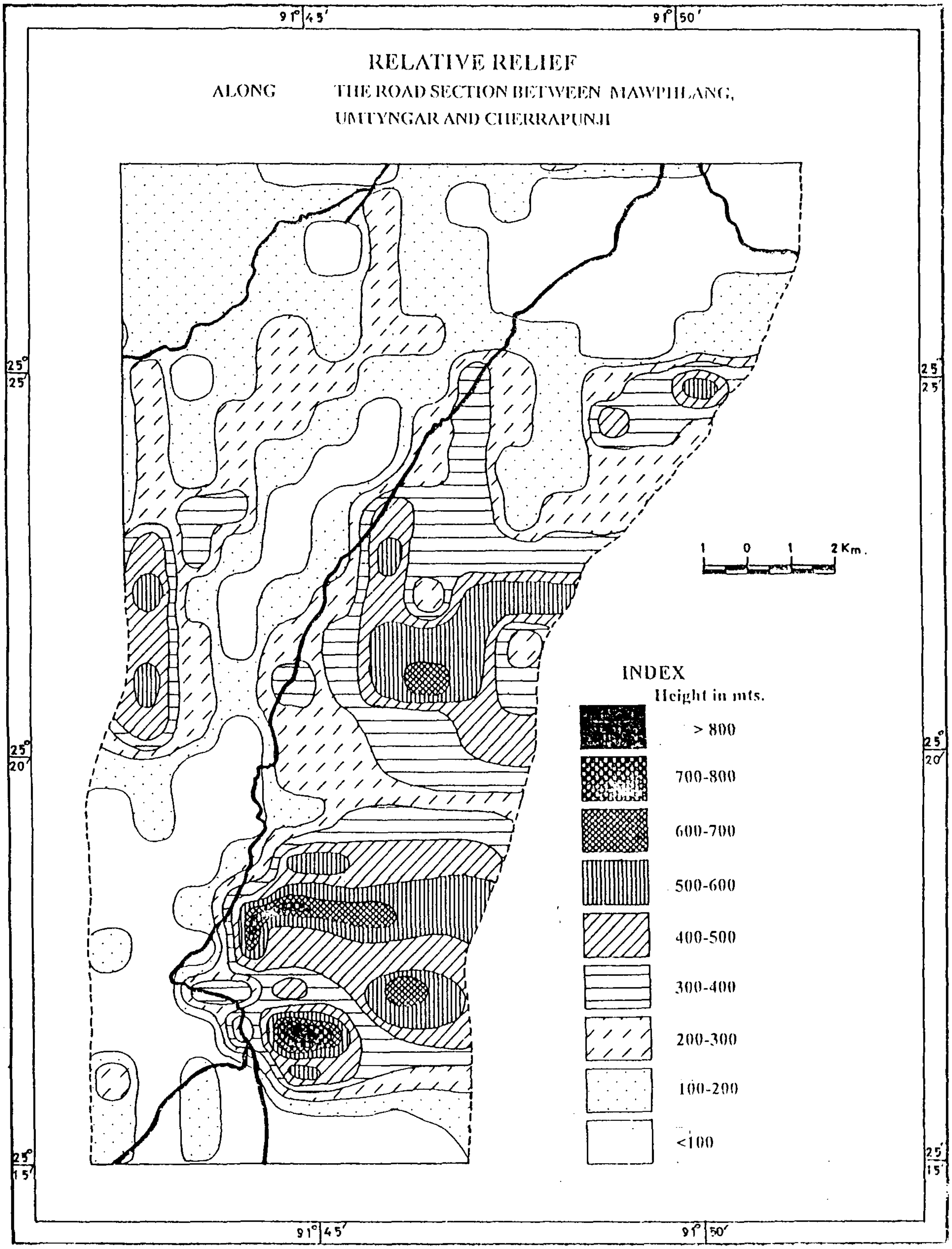


91° 50′
91° 55′
RELATIVE RELIEF
ALONG THE ROAD SECTION BETWEEN UMLING AND UMSNING
1 0 1 2 Km.
25° 50′
25° 45′
INDEX
Height in mts.
> 800
700-800
600-700
500-600
400-500
300-400
200-300
100-200
<100

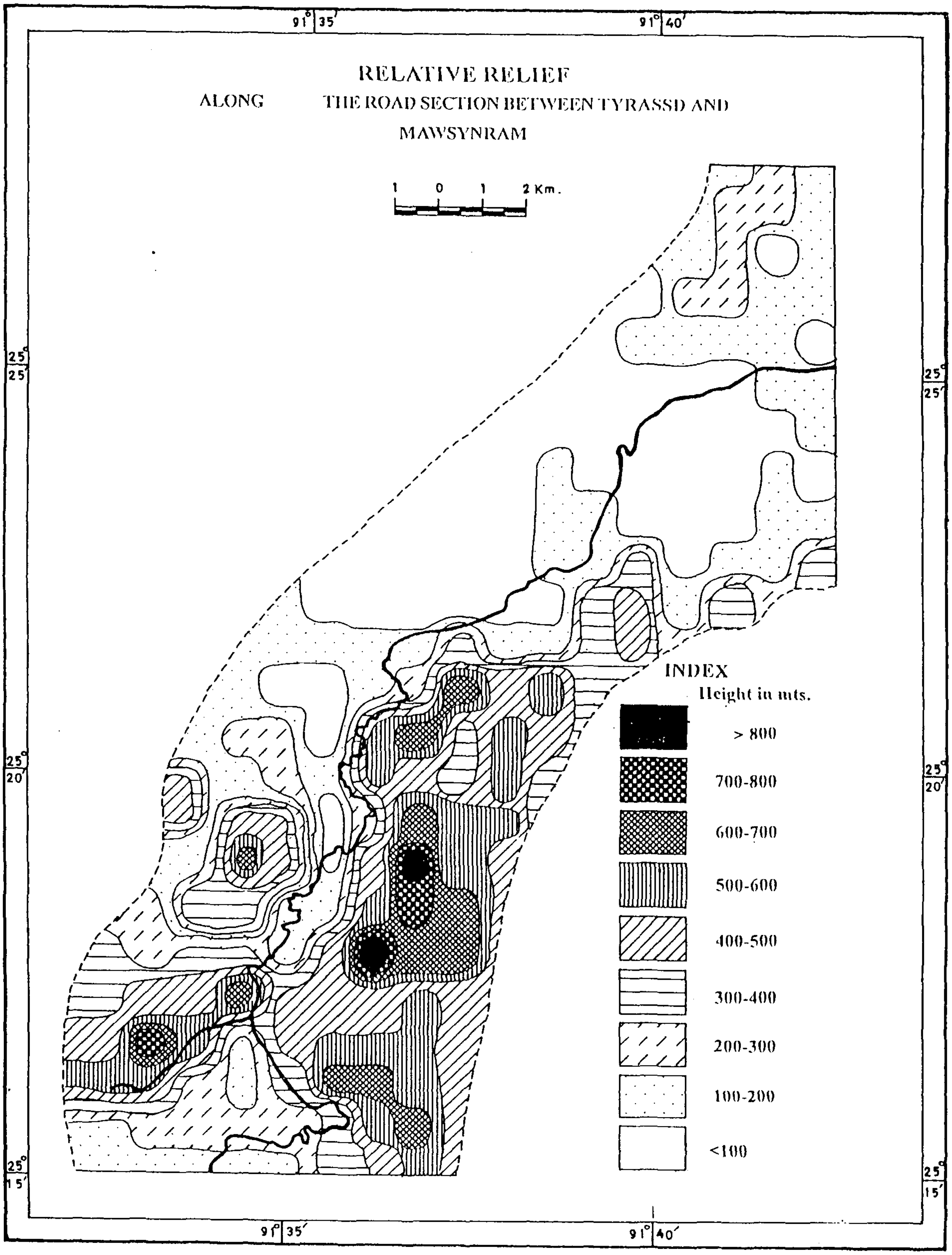
Map 5b


91° 50′
91° 55′
RELATIVE RELIEF
ALONG THE ROAD SECTION BETWEEN UMSNING AND SHILLONG
25° 40′
25° 35′
25° 30′
1 0 1 2 Km.
INDEX
Height in mts.
> 800
700-800
600-700
500-600
400-500
300-400
200-300
100-200
<100

Map 5c

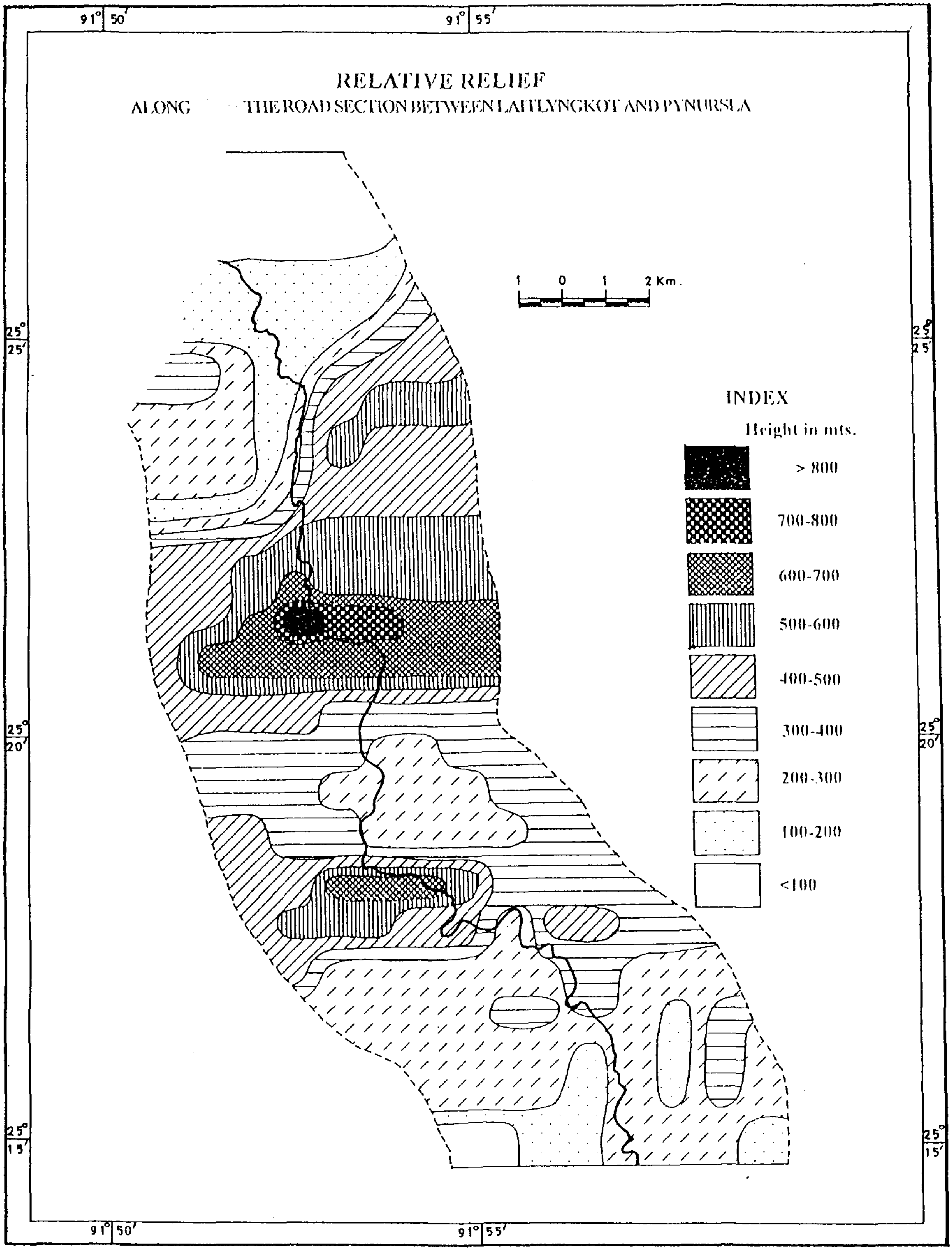

91° 45'
91° 50'
RELATIVE RELIEF
ALONG THE ROAD SECTION BETWEEN MAWPHLANG, UMTYNGAR AND CHERRAPUNJI
25° 25'
25° 20'
25° 15'
1 0 1 2 Km.
INDEX
Height in mts.
> 800
700-800
600-700
500-600
400-500
300-400
200-300
100-200
<100

Map 5d



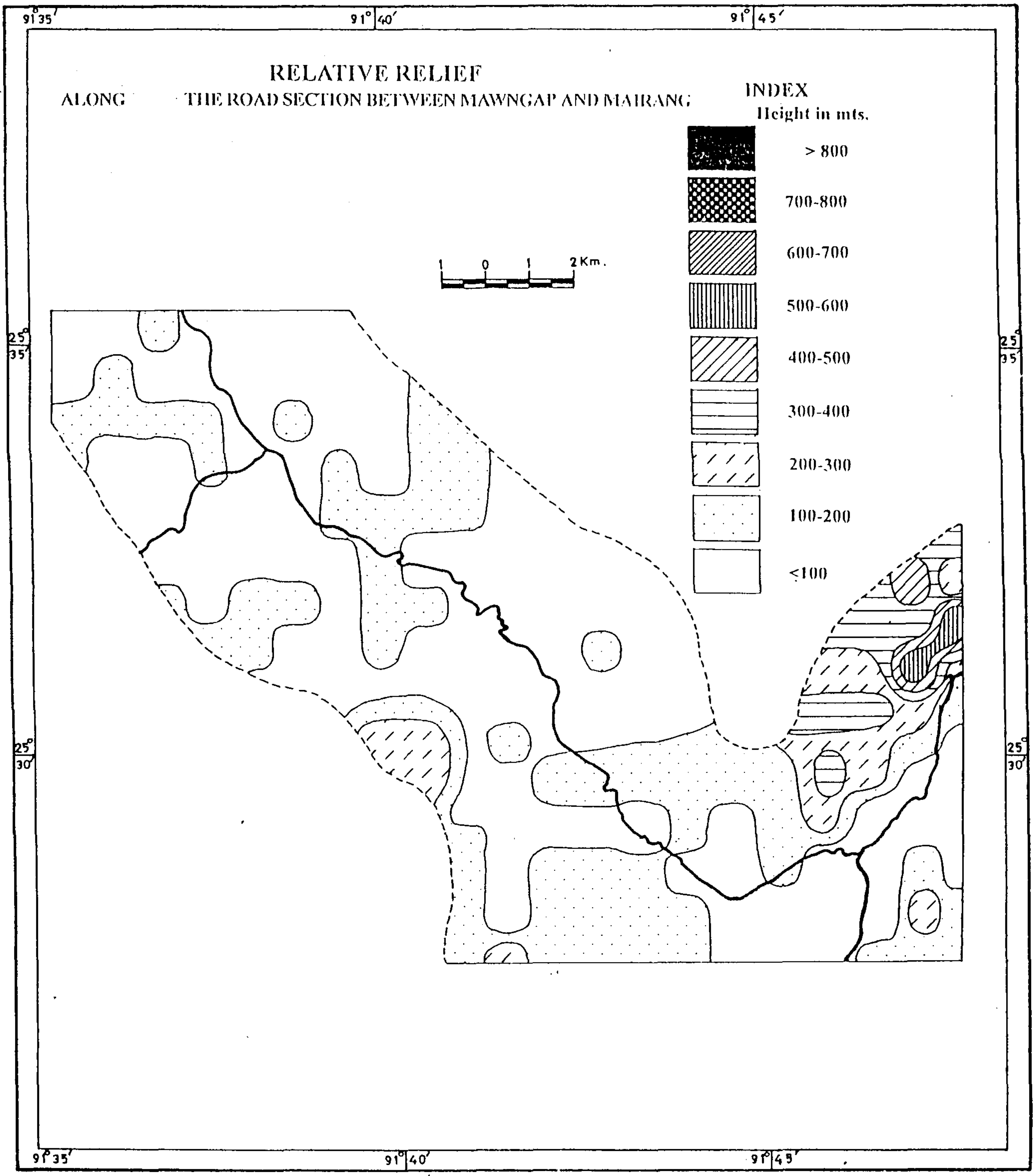
91° 35′
91° 40′
RELATIVE RELIEF
ALONG THE ROAD SECTION BETWEEN TYRASSD AND MAWSYNRAM
1 0 1 2 Km.
25° 25′
25° 20′
25° 15′
INDEX
Height in mts.
> 800
700-800
600-700
500-600
400-500
300-400
200-300
100-200
<100

Map 5e



91° 50′
91° 55′
RELATIVE RELIEF
ALONG THE ROAD SECTION BETWEEN LAITLYNGKOT AND PYNURSLA
1 0 1 2 Km.
25° 25′
25° 20′
25° 15′
INDEX
Height in mts.
> 800
700-800
600-700
500-600
400-500
300-400
200-300
100-200
<100

Map 5f


RELATIVE RELIEF
ALONG THE ROAD SECTION BETWEEN MAWNGAP AND MAIRANG
INDEX
Height in mts.
> 800
700-800
600-700
500-600
400-500
300-400
200-300
100-200
<100
1 0 1 2 Km.
91°35′
91°40′
91°45′
25° 35′
25° 30′

Map 5g

g). Such patches indicate localized vigorous downcutting, perhaps in response to pulses of rejuvenation.

Table 13: Relative Relief of the study area

Relative Relief (Km^2)	Area Km^2	Covered %	Category
< 100	398.75	29.50	Very low
100-200	457.10	33.82	Low
200-300	229.58	16.99	Low
300-400	111.63	8.26	Moderate
400-500	76.57	5.67	Moderate
500-600	50.42	3.73	Moderately High
600-700	21.87	1.62	High
700-800	4.22	0.31	Very High
>800	1.39	0.10	Very High
Total Area	1351.53	100	

High Relative Relief category (600-700 m.)

This category covers an insignificant area (1.62%) and is spread in clusters over the terrain. This preferred distribution is because of deep incision by renewed erosion into the plutons due to rise of local base level associated with magmatic intrusion and repeated rejuvenation.

Moderate to Moderately High Relief category (300-600 m.)

This group covers 17.66% of the area. It is scattered throughout the area; the moderate variety being 13.93% and moderately high relief variety is covered by 3.73% along the roadside area. The low incision is because, the erosion in the plutons could commence only after the Shillong Group envelope and possible supracrustals were stripped off from the Plutons by the successive fluvial cycles.

Low to Very Low Relief Category (<100- 300 m.)

This category covers 80.31% of the surveyed area along the roadside and occurs as large patches throughout the area on all lithotypes. The patches of this group over hard rocks indicate remnants of older peneplains or erosional surfaces under dissection by the ongoing Quarternary Fluvial Cycles.

4.2 Drainage Morphometry

The significance of drainage in the evolution of landscape has always fascinated Geomorphologists, Hydrologists and Geologists. Thus an understanding of the drainage characteristics is very important and basic to understand the evolution of landscape in the area which receives the highest rainfall in the world.

Runoff rainwater in the form of sheet wash or in concentrated channels forming streams, is the dominant geomorphic agent in sculpturing the landscape of an area. The analysis of drainage characteristics is by far the most important in analysis of landforms. The adjustments of streamlines to the underlying rocks are rather an index of the sculpturing agency. The activities of streams or running water could be either erosional or depositional. Progressive dissection and degradation of higher lands is caused by the various drainage patterns. The aim of the present study is to analyze the various aspects of drainage characteristics i.e. Drainage Frequency and Drainage Density.

The computations are based on 1:50,000 scale Toposheets of the area where all perennial and non-perennial streams have been considered and the conclusions are based on topographical maps in conjunction with field checks.

Drainage Analysis helps to understand the evolution of landforms. More and more elaborate methods are being studied and applied to the analysis of drainage pattern. As a result these increasing accurate methods are generating huge amounts of quantitative data. It is generally seen that the lithology and structure of the area primarily control a drainage system.

The first attempt to analyze the landforms was made by Davis (1903) in a systematic manner. Prior to Horton drainage analysis was treated in a qualitative manner by the geomorphologists. Horton (1945) was the first to introduce quantitative analysis of hydrological data.

The Drainage Analysis has been applied to the area along a stretch of 3-4 km from both sides of the highways. The channel networks were sampled and measured from toposheets and field checks were also carried out. Drainage Density and Drainage Frequency are the morphometric parameters that were taken for computation.

4.2.1 Drainage Density: One of the most common quantitative measures of drainage of a particular area is the density measurement. Drainage Density of the area considered is the length of streams per unit area. It is denoted mathematically as:

4.2.1.1 Method of Analysis

The area has been divided into one square kilometer grids. The total length of streams crossing a single grid were counted and subsequently calculated for all the grids.

Drainage Density = Total length of Streams/ Unit area

(The unit taken for the present analysis is 1 km^2)

Table 14: Drainage Density of the Study area

Drainage Density Km/km^2	Area Km^2	Covered %	Category
<3	134.04	9.92	Very Low
3-6	757.28	56.03	Low
6-9	428.09	31.67	Moderate
9-12	31.69	2.34	High
>12	0.43	0.03	Very high
Total Area	1351.53	99.99	

4.2.1.2 Distribution Pattern of Drainage Density

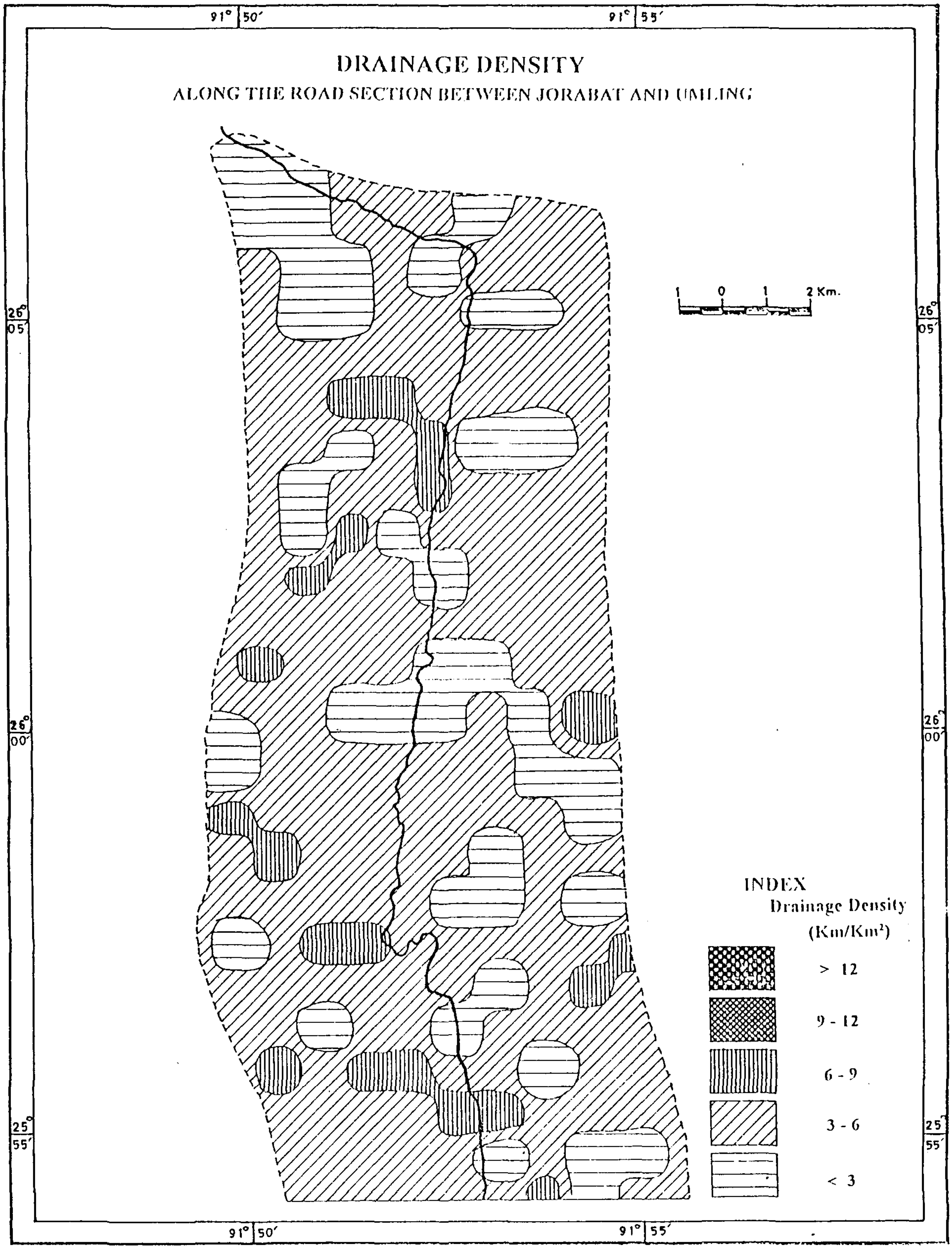
It may be inferred from the above table that the dominant drainage is 3-6 category with 56.03% coverage of the total area (table 14). The basin is divided into five categories on the basis of density (map 6a- 6g).

High to Very High Drainage Density (above 9km/km^2)

It occurs over Shillong Group as an insignificant patch (2.37%). This isolated patch of very high Drainage Density reflects presence of very localized resistant lithology within the Shillong Group.

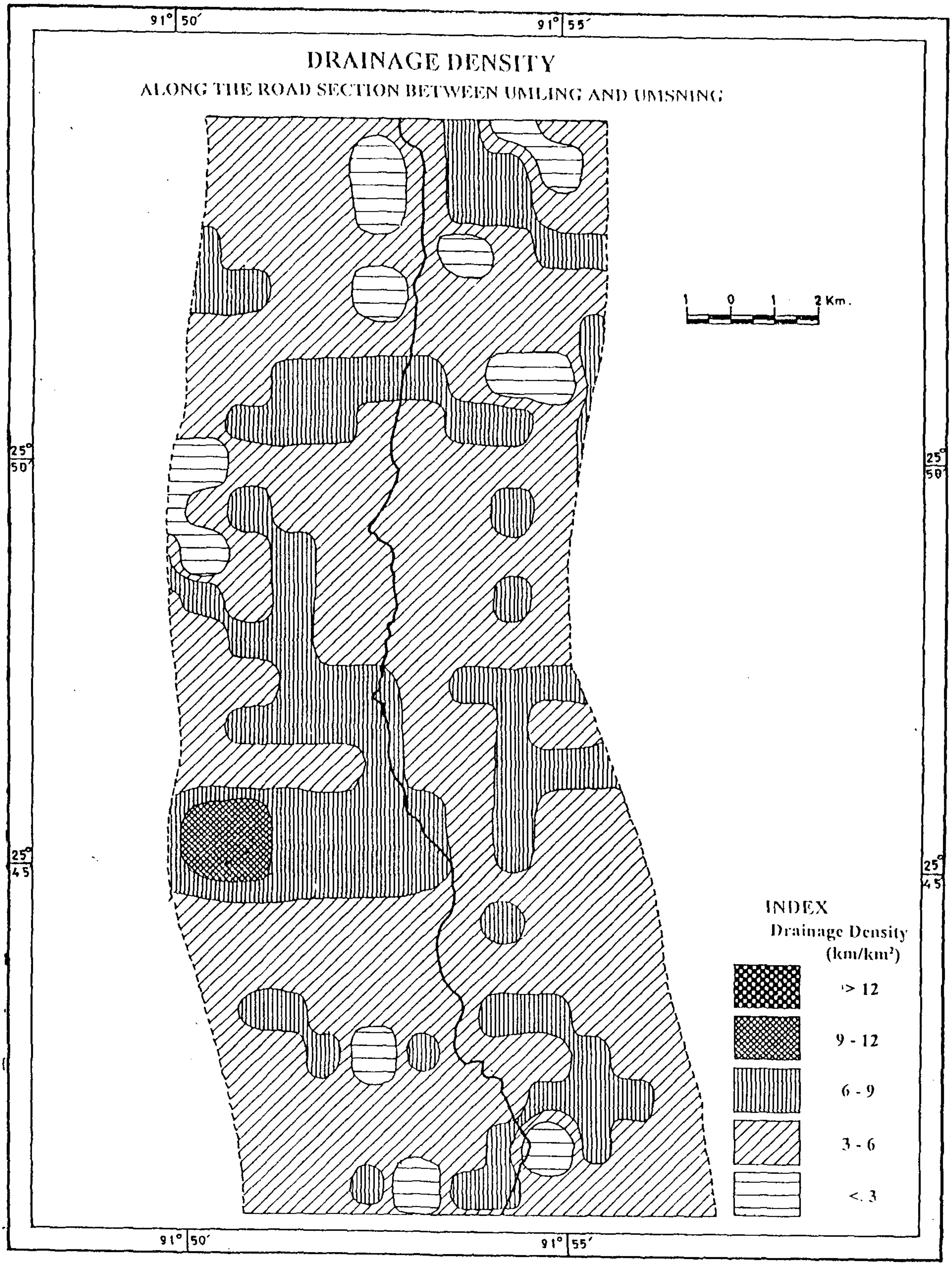
Low to Moderate Drainage Density (3-9 km/km^2)

It is the major group occupying 87.70% of the study area along roadside evenly distributed over the Shillong Group as well as the Granitoid Pluton. Its patches locally depict NW-SE alignments indicating influence of oblique structural elements (lineaments) on the evolution of drainage lines. Conspicuously the narrow part of the area which characteristically has terraced plateau landforms with relatively lesser development of this group than the Nongpoh Pluton. This mild contrast indicates that the upper reaches of the study area has relatively high permeability than the lower reaches.



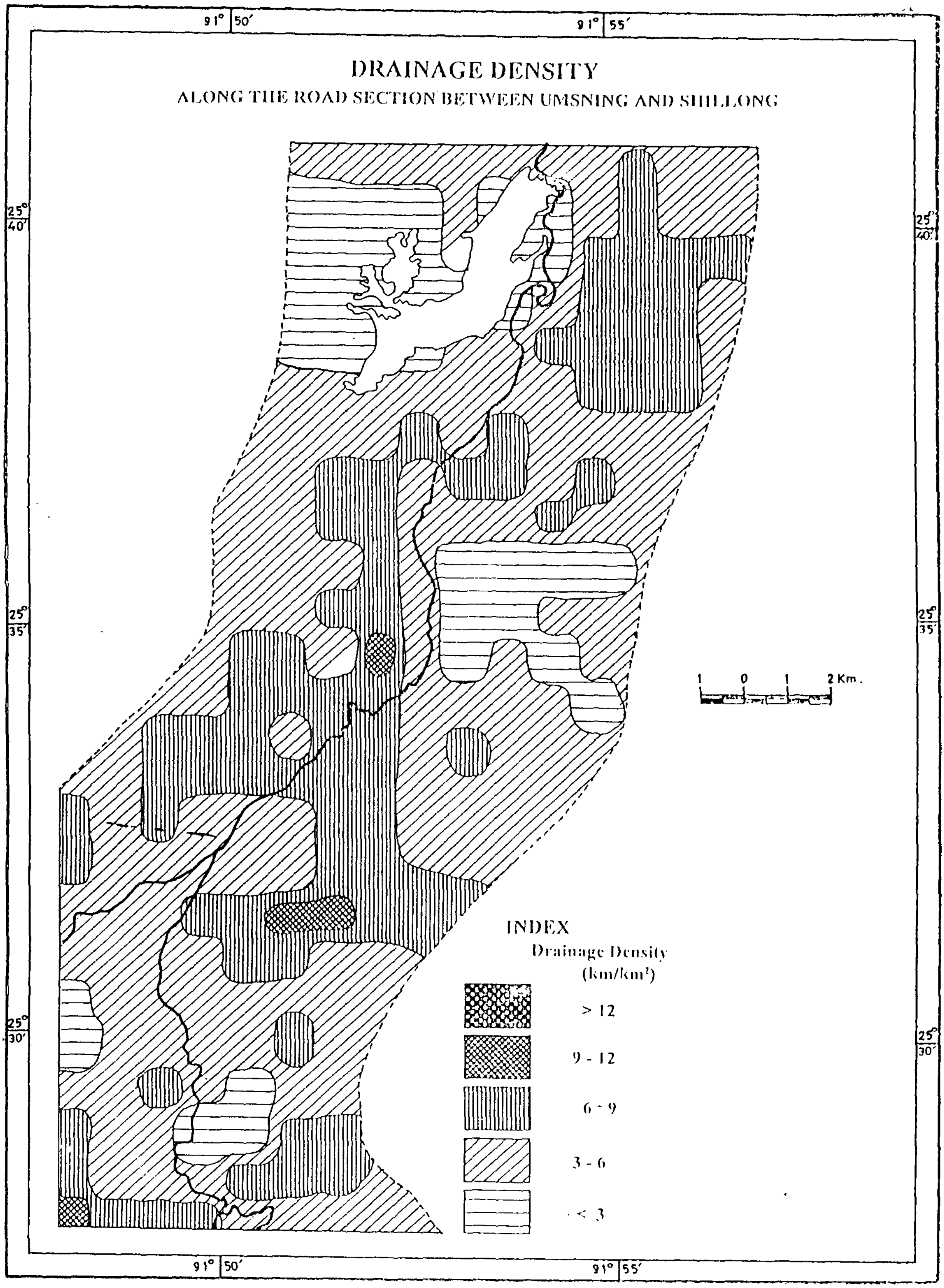
91° 50′
91° 55′
DRAINAGE DENSITY
ALONG THE ROAD SECTION BETWEEN JORABAT AND UMLING
1 0 1 2 Km.
26° 05′
26° 00′
25° 55′
INDEX
Drainage Density
(Km/Km²)
> 12
9 - 12
6 - 9
3 - 6
< 3

Map 6a



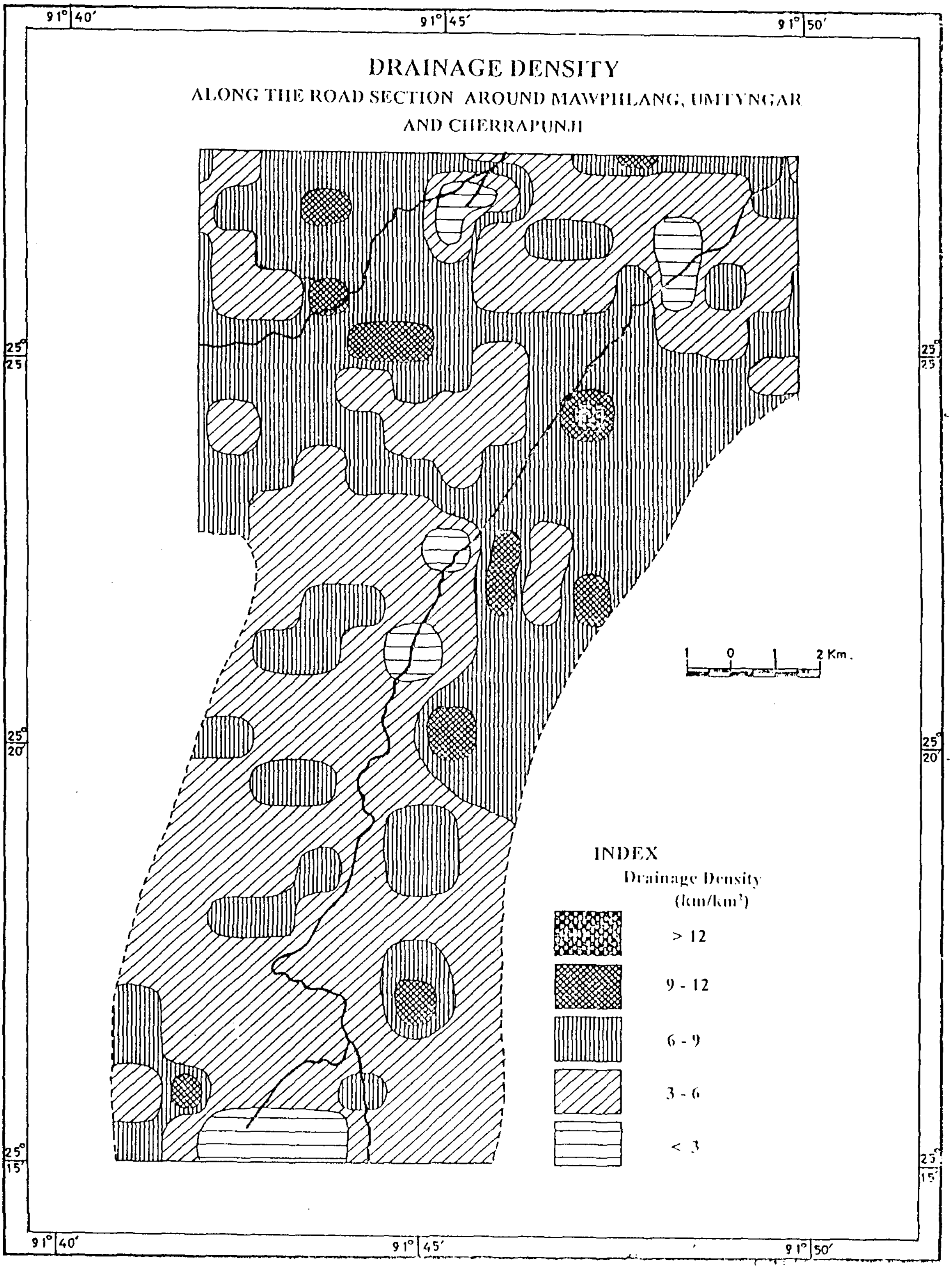
91° 50′
91° 55′
DRAINAGE DENSITY
ALONG THE ROAD SECTION BETWEEN UMLING AND UMSNING
1 0 1 2 Km.
25° 50′
25° 45′
INDEX
Drainage Density
(km/km²)
> 12
9 - 12
6 - 9
3 - 6
< 3

Map 6b

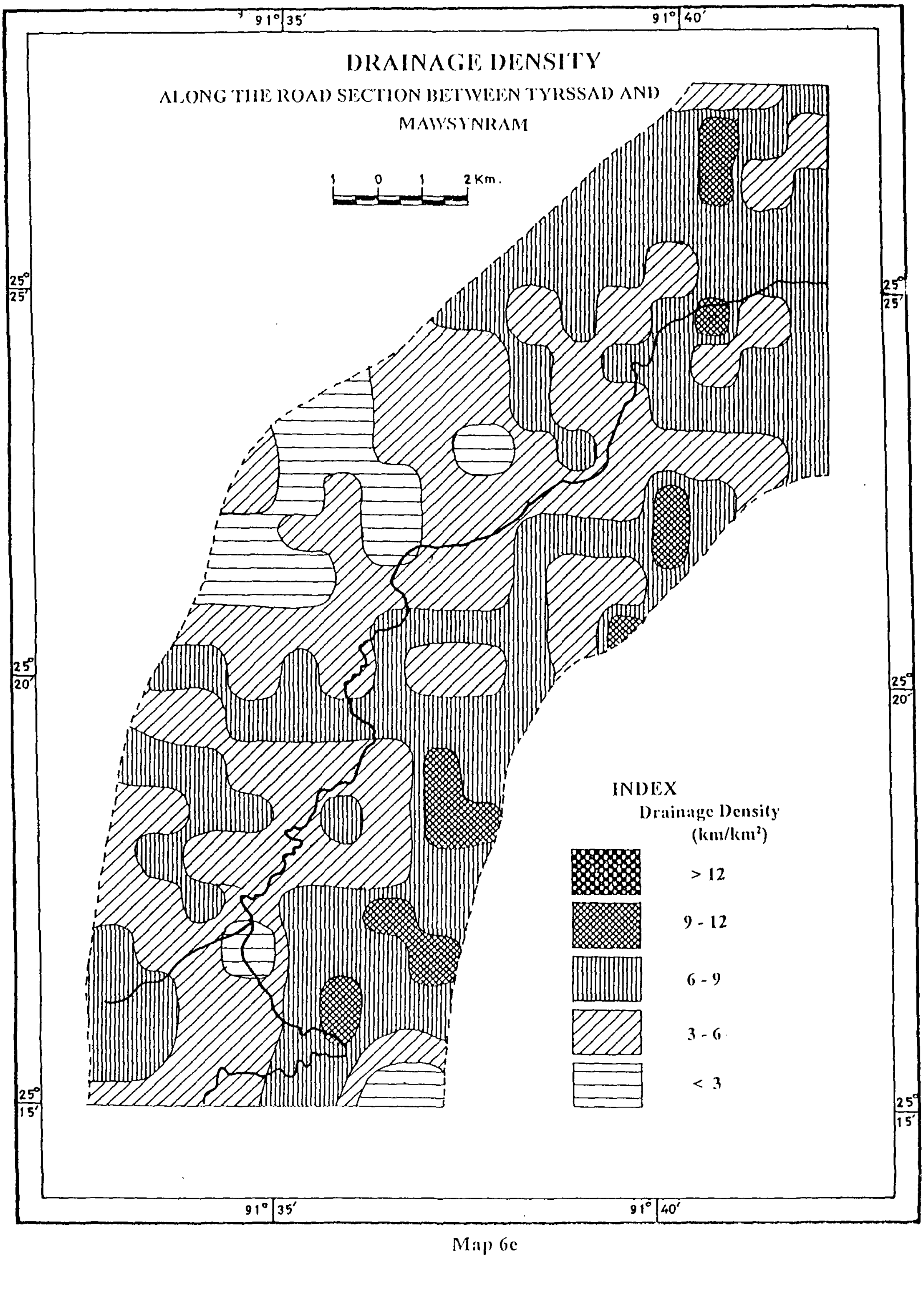


91° 50′
91° 55′
DRAINAGE DENSITY
ALONG THE ROAD SECTION BETWEEN UMSNING AND SHILLONG
25° 40′
25° 35′
25° 30′
1 0 1 2 Km.
INDEX
Drainage Density
(km/km²)
> 12
9 - 12
6 - 9
3 - 6
< 3

Map 6c

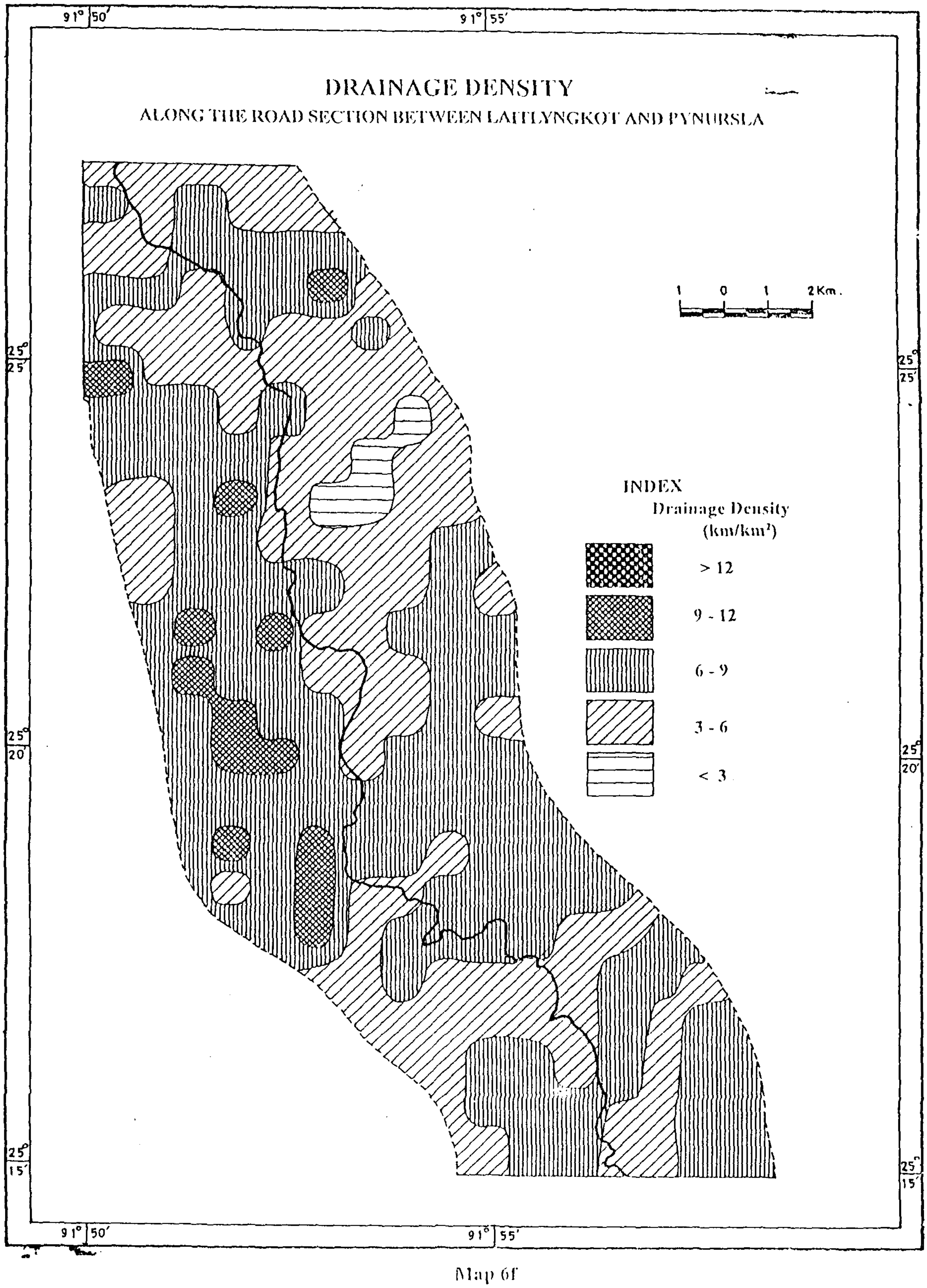

91° 40′
91° 45′
91° 50′
DRAINAGE DENSITY
ALONG THE ROAD SECTION AROUND MAWPHLANG, UMTYNGAR AND CHERRAPUNJI
25° 25′
25° 20′
25° 15′
1 0 1 2 Km.
INDEX
Drainage Density
(km/km²)
> 12
9 - 12
6 - 9
3 - 6
< 3

Map 6d

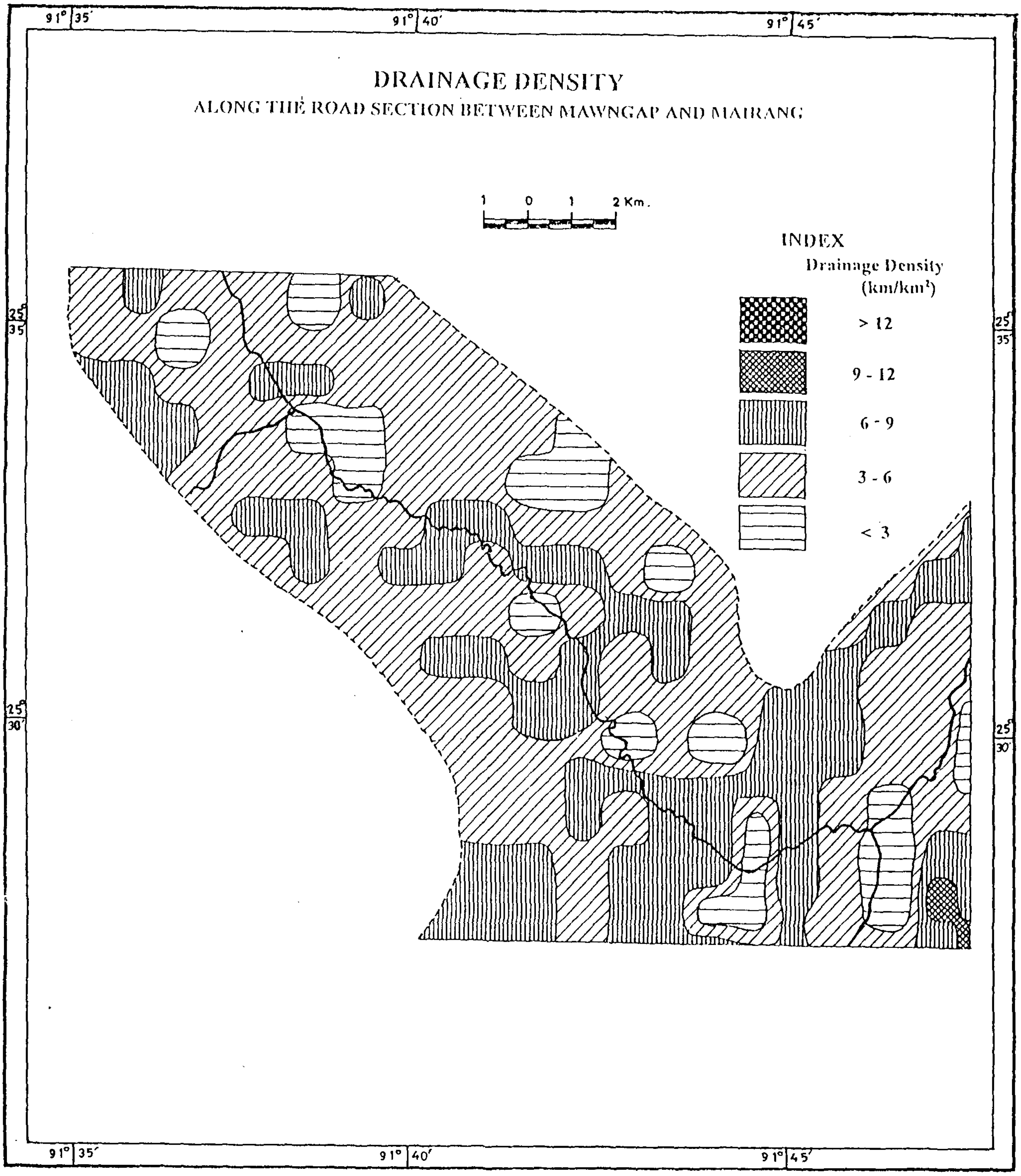


91° 35′
91° 40′
DRAINAGE DENSITY
ALONG THE ROAD SECTION BETWEEN TYRSSAD AND MAWSYNRAM
1 0 1 2 Km.
25° 25′
25° 20′
25° 15′
INDEX
Drainage Density
(km/km²)
> 12
9 - 12
6 - 9
3 - 6
< 3

Map 6c


DRAINAGE DENSITY
ALONG THE ROAD SECTION BETWEEN LAITLYNGKOT AND PYNURSLA
91° 50′
91° 55′
25° 25′
25° 20′
25° 15′
1 0 1 2 Km.
INDEX
Drainage Density
(km/km²)
> 12
9 - 12
6 - 9
3 - 6
< 3

Map 6f


DRAINAGE DENSITY
ALONG THE ROAD SECTION BETWEEN MAWNGAP AND MAIRANG
1 0 1 2 Km.
INDEX
Drainage Density
(km/km²)
> 12
9 - 12
6 - 9
3 - 6
< 3
91° 35′
91° 40′
91° 45′
25° 35′
25° 30′

Map 6g

Very Low Drainage Density (< 3km./km^2)

This group has the second largest distribution occupying 9.92% of the study area. It does not have any preferred distribution with lithology. However, its large patches show NE-SW and NW-SE alignments, parallel to formational trends and Lineaments respectively.

4.2.2 Drainage Frequency

Another measure of drainage network is the frequency of streams in a unit area. It is defined as the number of occurrence of streams per unit area (1 km^2).

This measure of the frequency of streams gives an idea where streams are well knitted. It gives information whether the area is properly drained or not. The following table gives a ready reference about the distribution of streams per sq. km. in the area.

4.2.2.1 Method of Analysis

The area has been divided into one square kilometer grids. The total number of streams crossing a single grid were counted and subsequently calculated for all the grids.

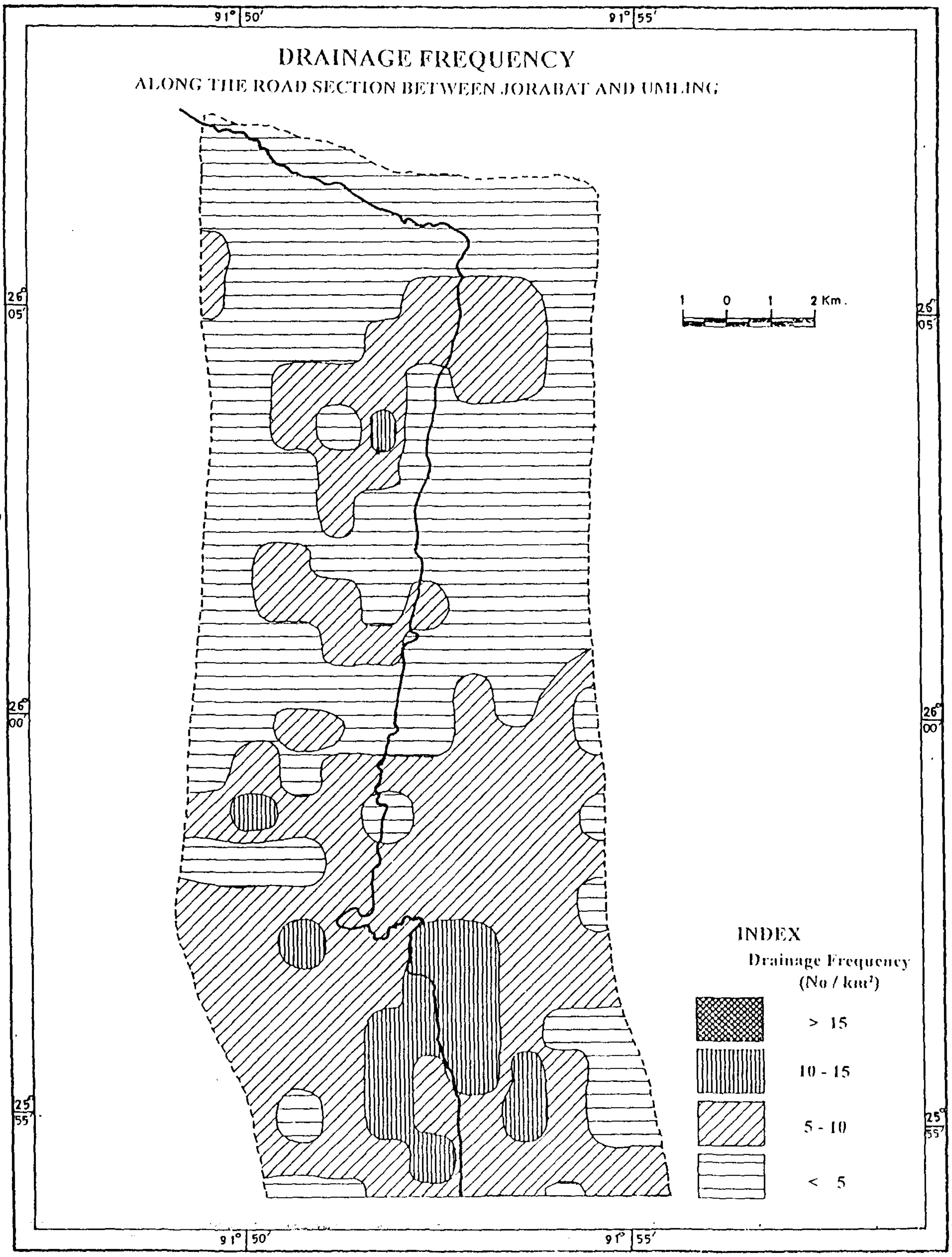
Drainage Frequency = Total number of Streams/ Unit area

(The unit taken for the present analysis is 1 km^2)

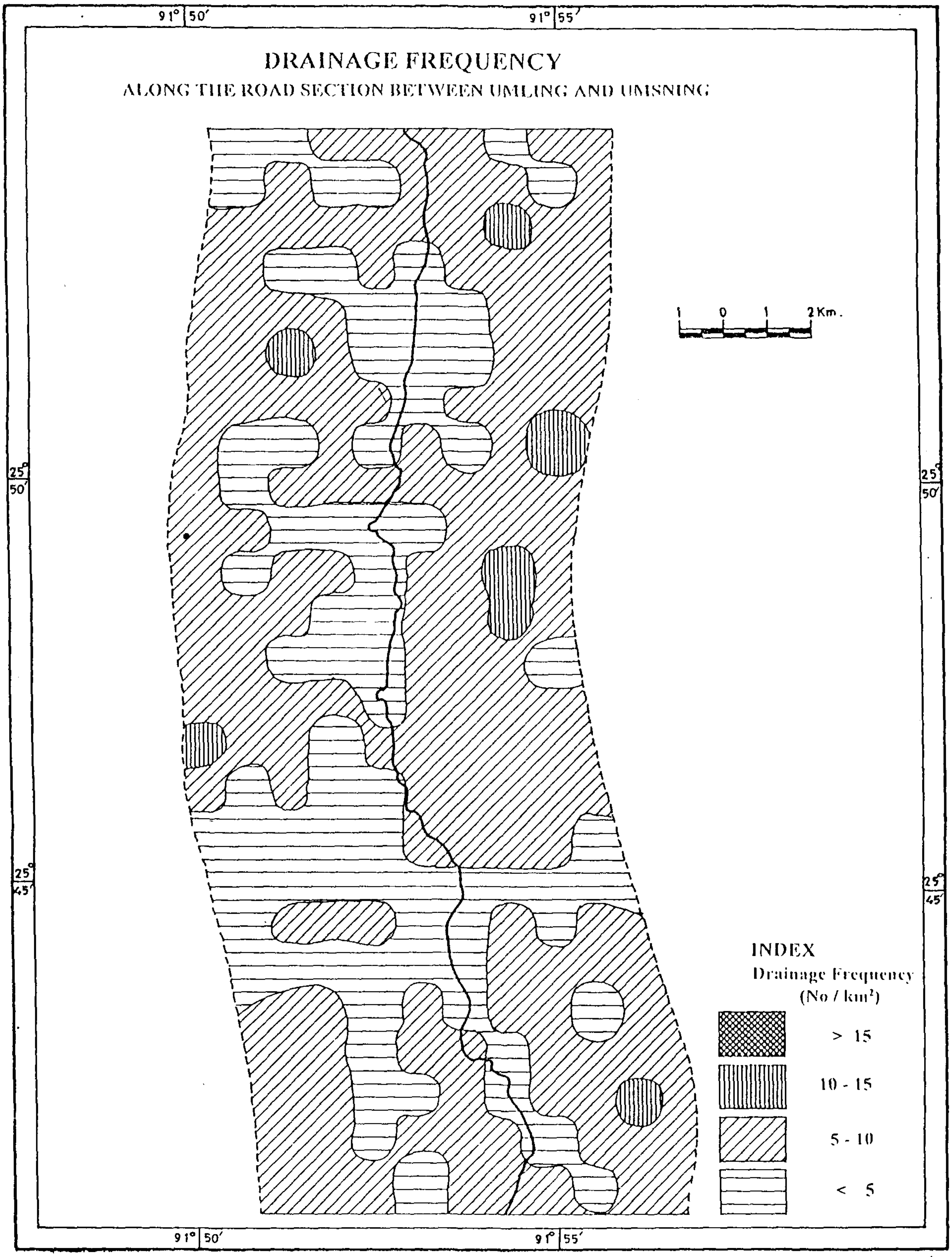
4.2.2.2 Distribution Pattern of Drainage Frequency

The above measure of Stream Frequency indicates that the drainage in the basin is generally of moderate frequency (5-10 category) covering 61.35 % of the total area (table 15, map 7a –7g).

The different Drainage Frequency categories reveal a peaked grid frequency distribution between 5 numbers per square kilometer and 10 numbers per square kilometer Drainage Frequencies {map 7 (a-g)}. The distribution of these groups are discussed below.

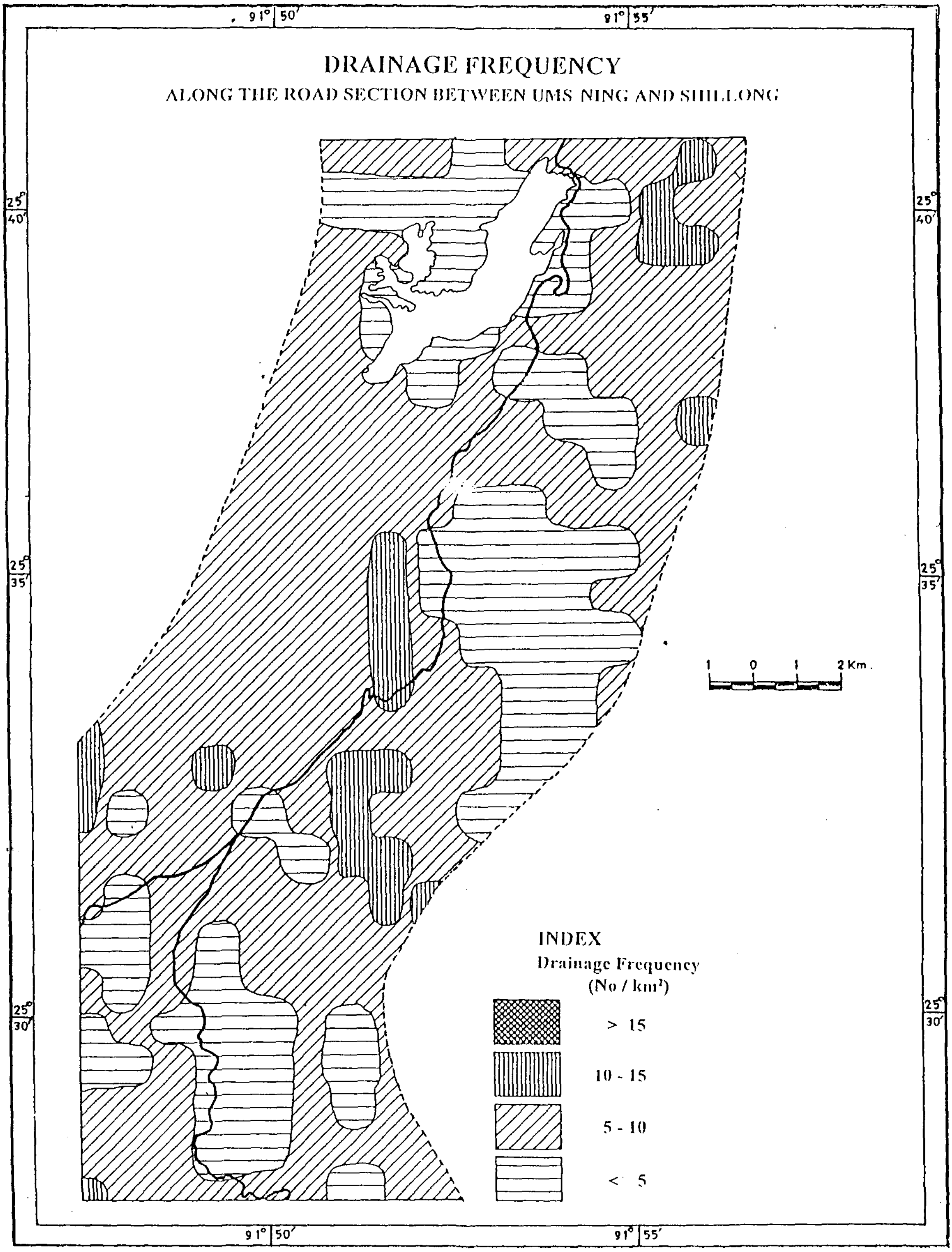

DRAINAGE FREQUENCY
ALONG THE ROAD SECTION BETWEEN JORABAT AND UMLING
91° 50'
91° 55'
26° 05'
26° 00'
25° 55'
1 0 1 2 Km.
INDEX
Drainage Frequency
(No / km²)
> 15
10 - 15
5 - 10
< 5

Map 7a

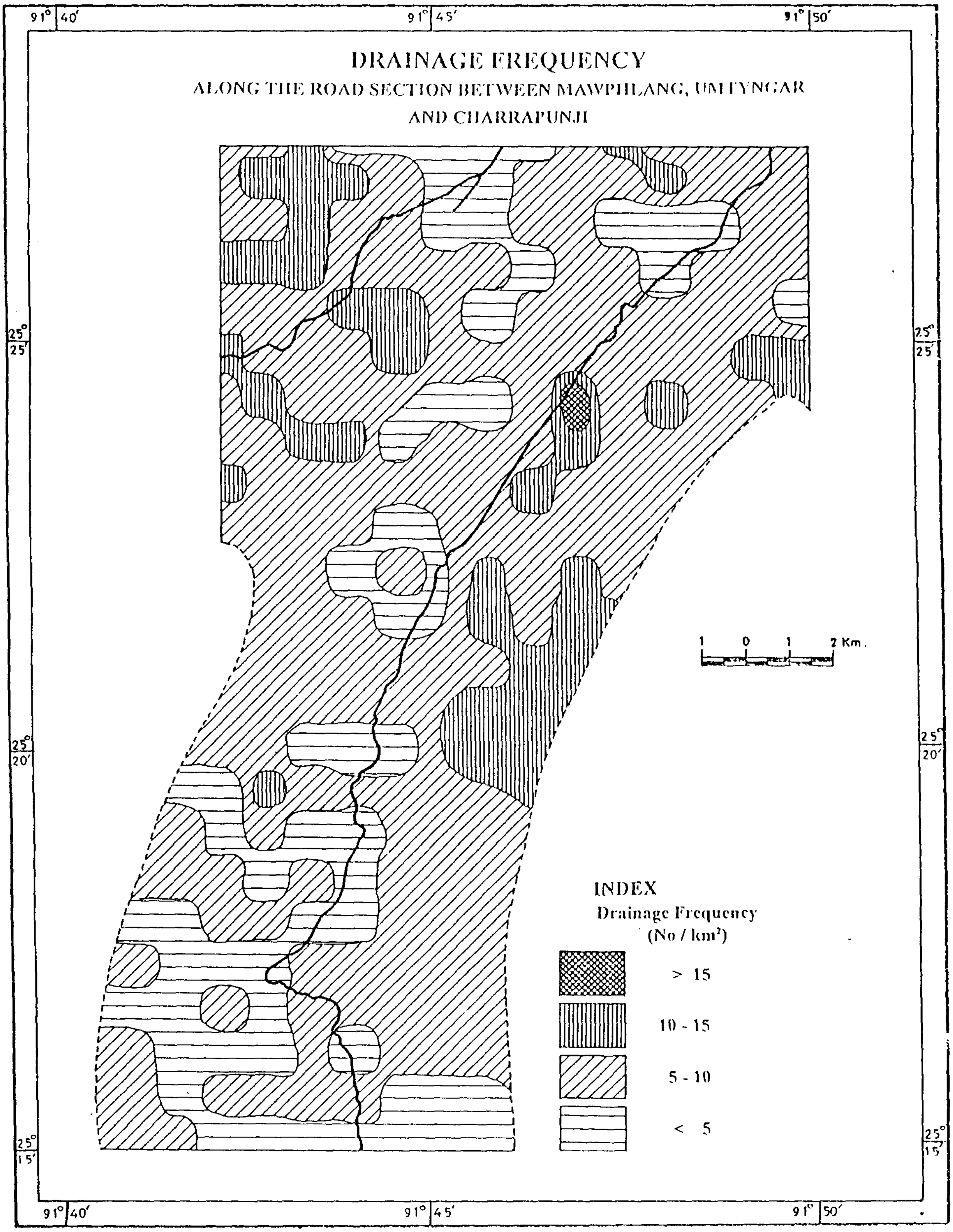


91° 50′
91° 55′
DRAINAGE FREQUENCY
ALONG THE ROAD SECTION BETWEEN UMLING AND UMSNING
1 0 1 2 Km.
25° 50′
25° 45′
INDEX
Drainage Frequency
(No / km²)
> 15
10 - 15
5 - 10
< 5

Map 7b

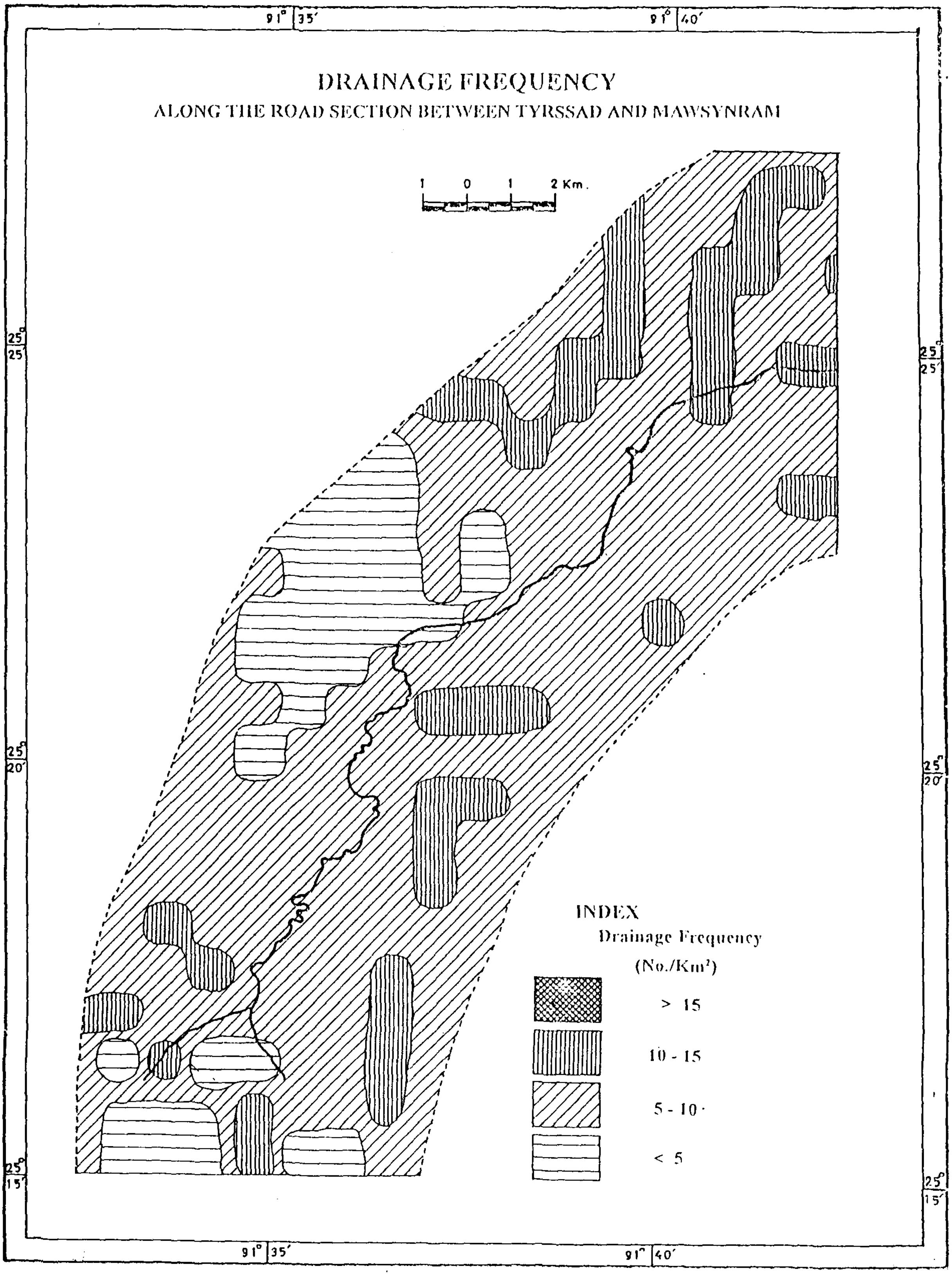

91° 50′
91° 55′
DRAINAGE FREQUENCY
ALONG THE ROAD SECTION BETWEEN UMS NING AND SHILLONG
25° 40′
25° 35′
25° 30′
1 0 1 2 Km.
INDEX
Drainage Frequency
(No / km²)
> 15
10 - 15
5 - 10
< 5

Map 7c



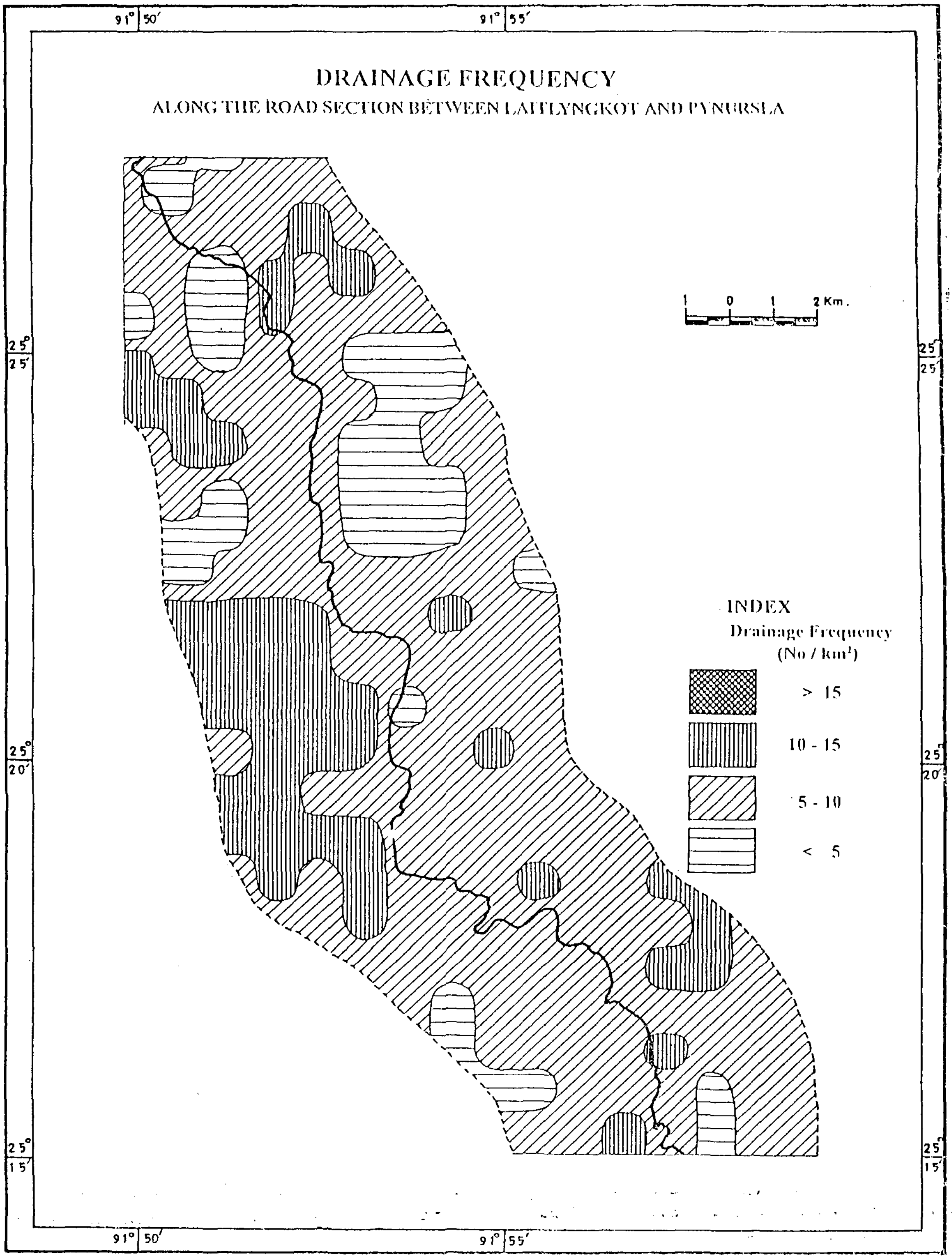
DRAINAGE FREQUENCY
ALONG THE ROAD SECTION BETWEEN MAWPHLANG, UMTYNGAR
AND CHARRAPUNJI
91° 40′
91° 45′
91° 50′
25° 25′
25° 20′
25° 15′
1 0 1 2 Km.
INDEX
Drainage Frequency
(No / km²)
> 15
10 - 15
5 - 10
< 5

Map 7d



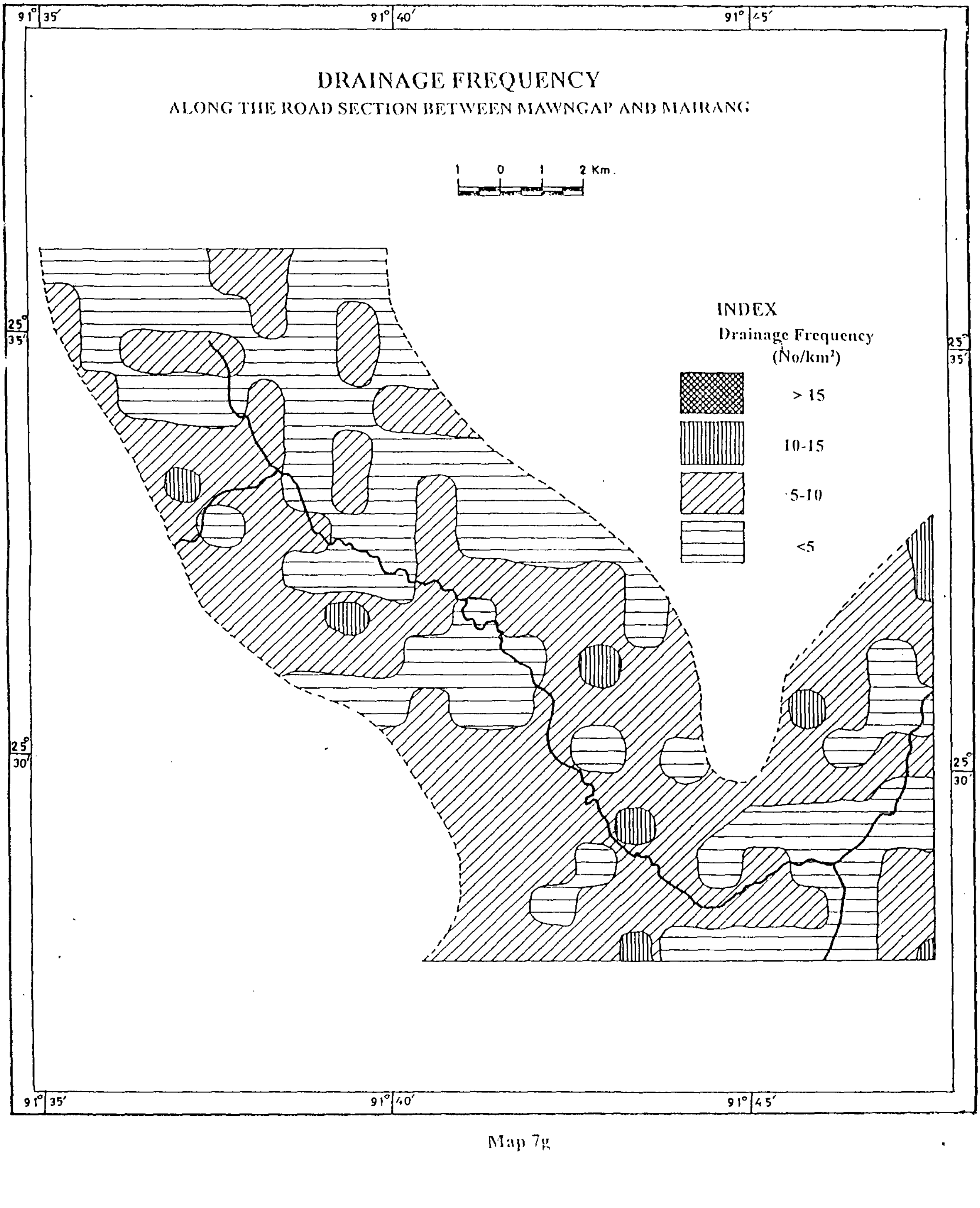
91° 35′
91° 40′
DRAINAGE FREQUENCY
ALONG THE ROAD SECTION BETWEEN TYRSSAD AND MAWSYNRAM
1 0 1 2 Km.
25° 25′
25° 20′
25° 15′
INDEX
Drainage Frequency
(No./Km²)
> 15
10 - 15
5 - 10
< 5

Map 7e



91° 50′
91° 55′
DRAINAGE FREQUENCY
ALONG THE ROAD SECTION BETWEEN LAITLYNGKOT AND PYNURSLA
1 0 1 2 Km.
25° 25′
25° 20′
25° 15′
INDEX
Drainage Frequency
(No / km²)
> 15
10 - 15
5 - 10
< 5

Map 7f



91° 35′
91° 40′
91° 45′
DRAINAGE FREQUENCY
ALONG THE ROAD SECTION BETWEEN MAWNGAP AND MAIRANG
1 0 1 2 Km.
INDEX
Drainage Frequency
(No/km²)
> 15
10-15
5-10
<5
25° 35′
25° 30′

Map 7g

Table 15: Drainage Frequency of the study area

No. of Streams Per km^2	Area Km^2	%	Category
<5	406.09	30.05	Low
5-10	829.17	61.35	Moderate
10-15	115.72	8.56	High
>15	0.55	0.04	Very high
Total Area	1351.53	100	

Very High Drainage Frequency (> 15nos/km^2)

This category covers a negligible (0.04%) of the surveyed area along roadside. Inspite of being a very high rainfall region, very low aerial distribution of this group suggests presence of higher secondary permeability and lower concentrated flow or lower channelization in the hard rocks.

Moderate to High Drainage Frequency (5-15 nos./km^2)

This group 69.91% of the study area and occurs as large patches all over the lithologies except the undifferentiated Alluvium. The special distribution of this group does not show any influence of lithology or structure.

Low Drainage Frequency (<5 nos./ km^2)

It occurs as patches throughout the roadside covering 30.05% of the total area surveyed. The low drainage frequency over the area signifies high infiltration, low runoff that is low channelizaton consequently lesser development stream networks.

The Drainage Frequency in the Meghalaya Plateau is overall very high and the streams are in full flow during the rainy season. These streams cut across the country rocks and make the top soil vulnerable to weathering.

4.3 Slope Analysis

Slopes are regarded the fundamental elements of any landscape (King, 1962). It is an element of the interface between Lithosphere and Hydrosphere or Atmosphere. The slope elements of a particular area reflect the evolutionary history of the existing landscape.

Slopes are often used to refer to the angle which any element of the landscape makes with the horizontal, i.e. slope is a function of relief inclination shown in degrees. Thus, slopes are upward or downward inclination of the surfaces of landscape measured in degrees with respect to horizontal.

In the present research work, the slopes associated with fluvial denudation are taken into consideration. Such slopes comprise headwater of streams and are adjusted to the geometry of stream network systems.

4.3.1 Elements of Slope

Slopes are perceptible inclinations that are visible on mountain ranges, ridges, scarps, plateau section, flanks of valley, etc. Commonly, slopes are classified in terms of Slope Profiles, which is a slope belt of unit width extending from drainage divide at the upper extremity, down to a lower terminus which is commonly a stream channel or a natural discontinuity such as terrace, pediment or cliff. A Slope Profile is best drawn along the down gradient line orthogonal to topographic contours.

A Slope Profile may have a variety of forms. Geometrically, slopes may consist segments which are concave upward, convex upward, straight or rectilinear and complex. The inflexion points or the points where the Slope changes its profile is termed as "break-in-slope". King (1957) has given a different Slope Profile for stratified rocks depicting the different elements. King's profile is usually not applicable in areas with non-stratified rocks. However King's profile is useful in qualitative analysis of Slope Profiles. The four elements of King's profile are described below:

i) Crest (waxing slope): Crest slope or Waxing slope is the upper part of the Slope Profile. The profile is usually convex. Weathering and soil creep are the main processes forming this convexity.

ii) Scarp (Free face): The Scarp or Free Face is usually present immediately below the Crest slope. It is the most active element in back wearing caused by rillwash and landslides.

iii) Debris Slope (Constant Slope): This part of slope forms just below the Free Face. It is mostly developed on scree or talus fallen from the scarp above and hence, termed as Debris slope. The angle is determined by the angle of repose of the coarse material. Weathering reduces it to finer particles, which are then removed by wash, flowing as rills, or turbulent sheet flow.

iv) Pediment (Wanning Slope): Wanning slope is generally formed by the accumulation of debris from higher slopes. The pediment is a broad concavity extending from the base of the other elements to the streams or alluvial plains. It is produced by surface wash and its profile may approximate to a hydraulic curve.

Young (1972) has classified slopes into ten classes based on their inclination. As given below:

4.3.2 Method of Analysis

The Average Slope of the area has been calculated by the application of Wenthworth's method. This method even though tedious, is best suited to serve the interest of the research. The modified formula is as follows:

	Division	Category
i)	0°-2°	level to very gentle
ii)	2°-5°	gentle
iii)	5°-10°	moderate
iv)	10°-18°	moderately steep
v)	18°-30°	steep
vi)	30°-45°	very steep
vii)	45°-70°	precipitous
viii)	70°-90°	almost vertical
ix)	over 90°	over hanging

$$\text{Tan } 0 = N \times I / 636.6$$

Where, N = average number of contour crossings/km.

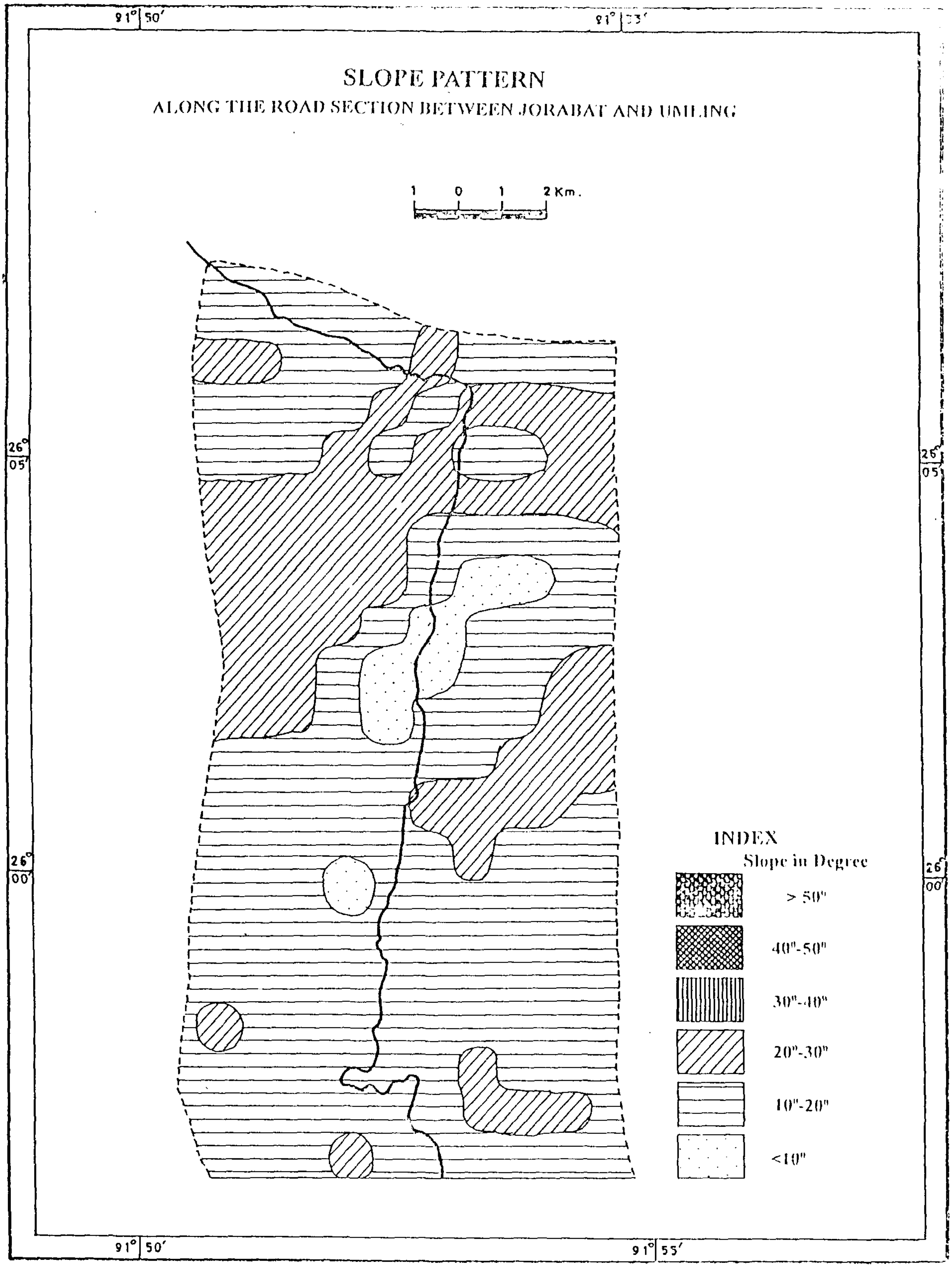
I = contour interval

636.6 = a constant

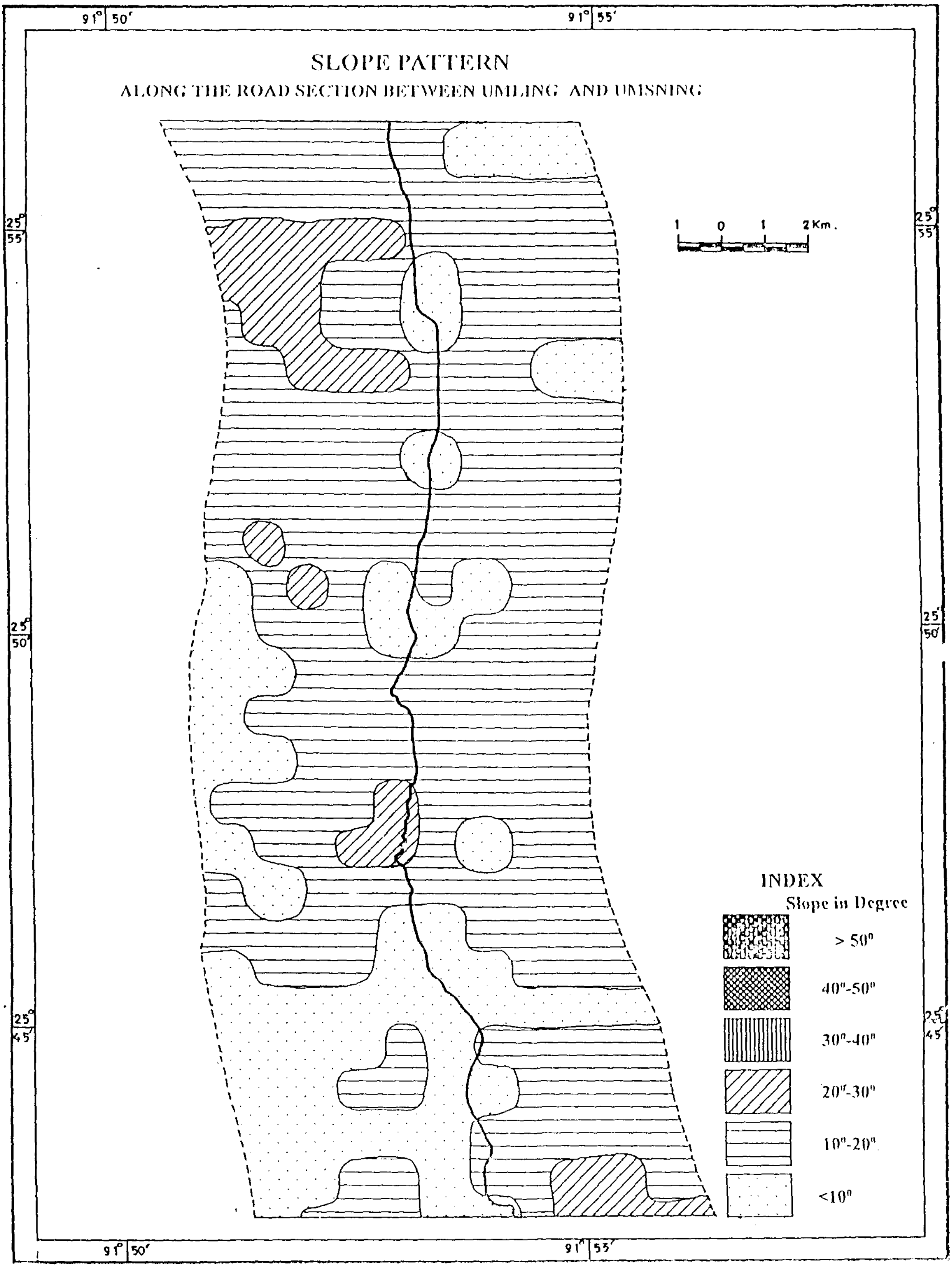
The area surveyed could be divided into six Average Slope categories. The maximum slope in the area is falling under 10°-20° category covering 641.91 sq. kms., while the minimum is under >50° category covering only 7.48 sq.km. indicating that the steep slopes are comparatively lesser in the area (table 16, map 8a –8g). The distribution of the different categories of slope are tabulated below:

4.3.3 Distribution Pattern of Slope

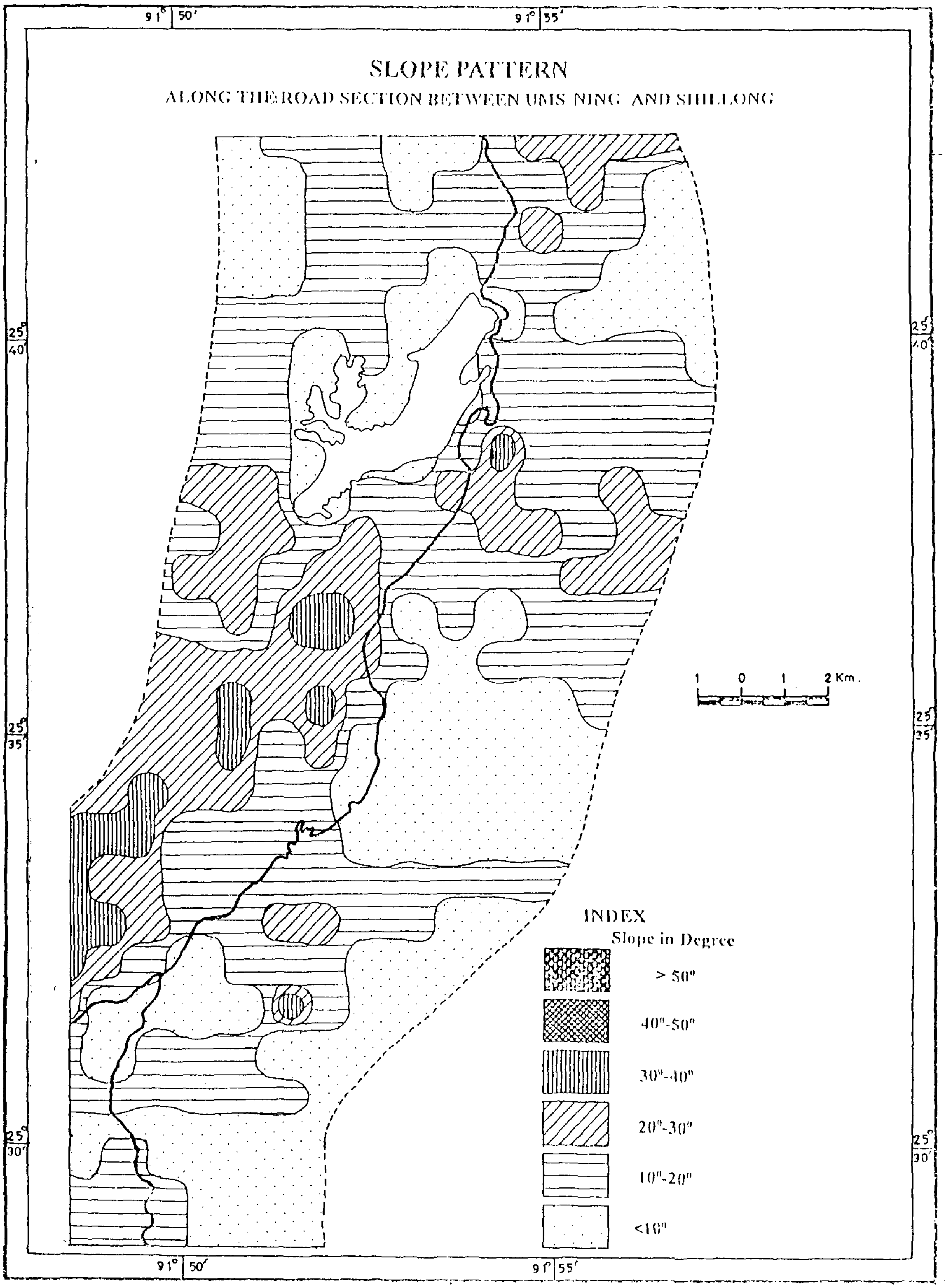
The different slope categories show a peak frequency distribution of slope between 10° and 30° categories {map 8 (a-g)}. The distribution of the various slope groups in the study area analysed are :


91° 50′
91° 55′
SLOPE PATTERN
ALONG THE ROAD SECTION BETWEEN JORABAT AND UMLING
1 0 1 2 Km.
26° 05′
26° 00′
INDEX
Slope in Degree
> 50°
40°-50°
30°-40°
20°-30°
10°-20°
<10°

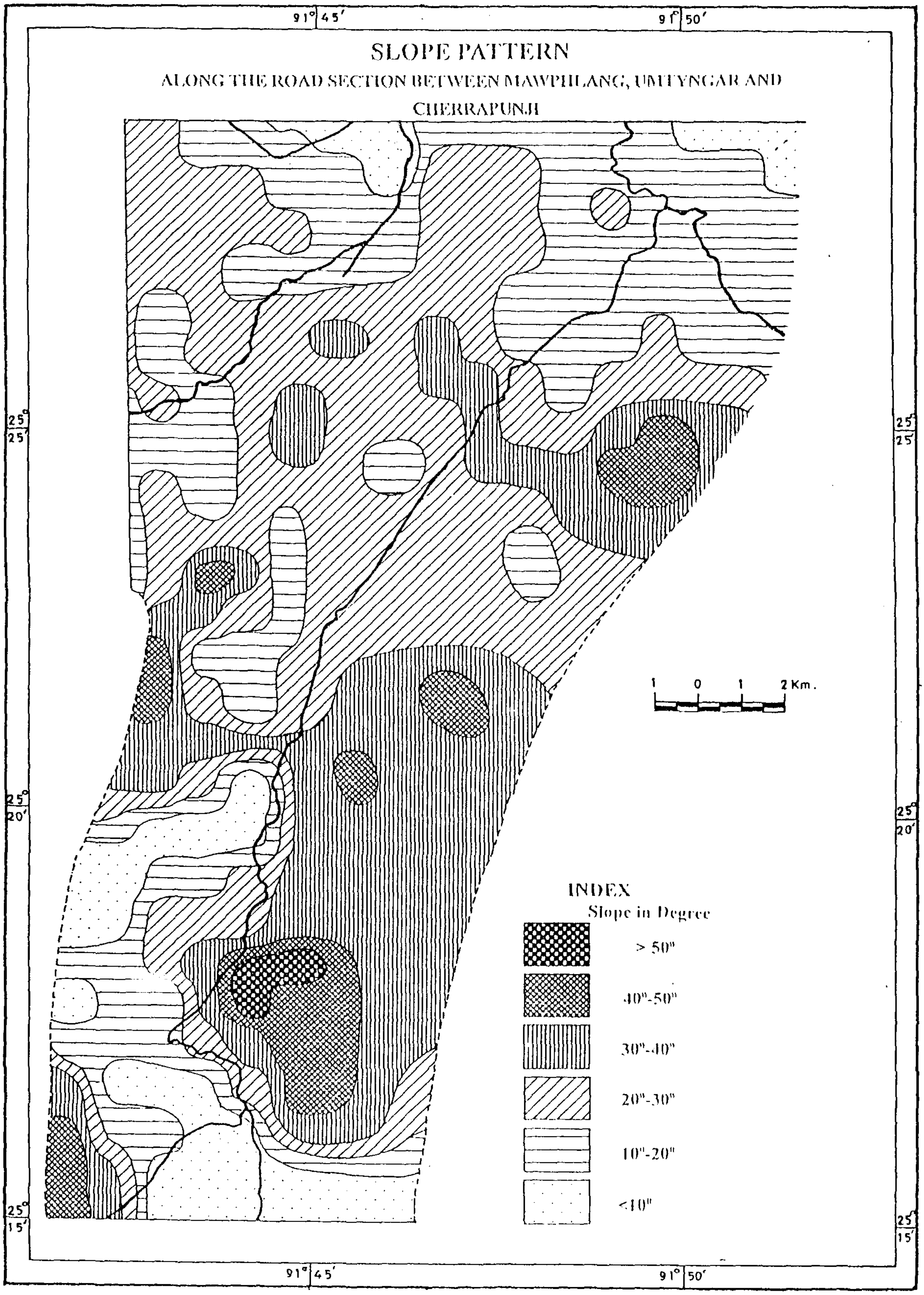
Map 8a


91° 50'
91° 55'
SLOPE PATTERN
ALONG THE ROAD SECTION BETWEEN UMLING AND UMSNING
1 0 1 2 Km.
25° 55'
25° 50'
25° 45'
INDEX
Slope in Degree
> 50°
40°-50°
30°-40°
20°-30°
10°-20°
<10°
91° 50'
91° 55'

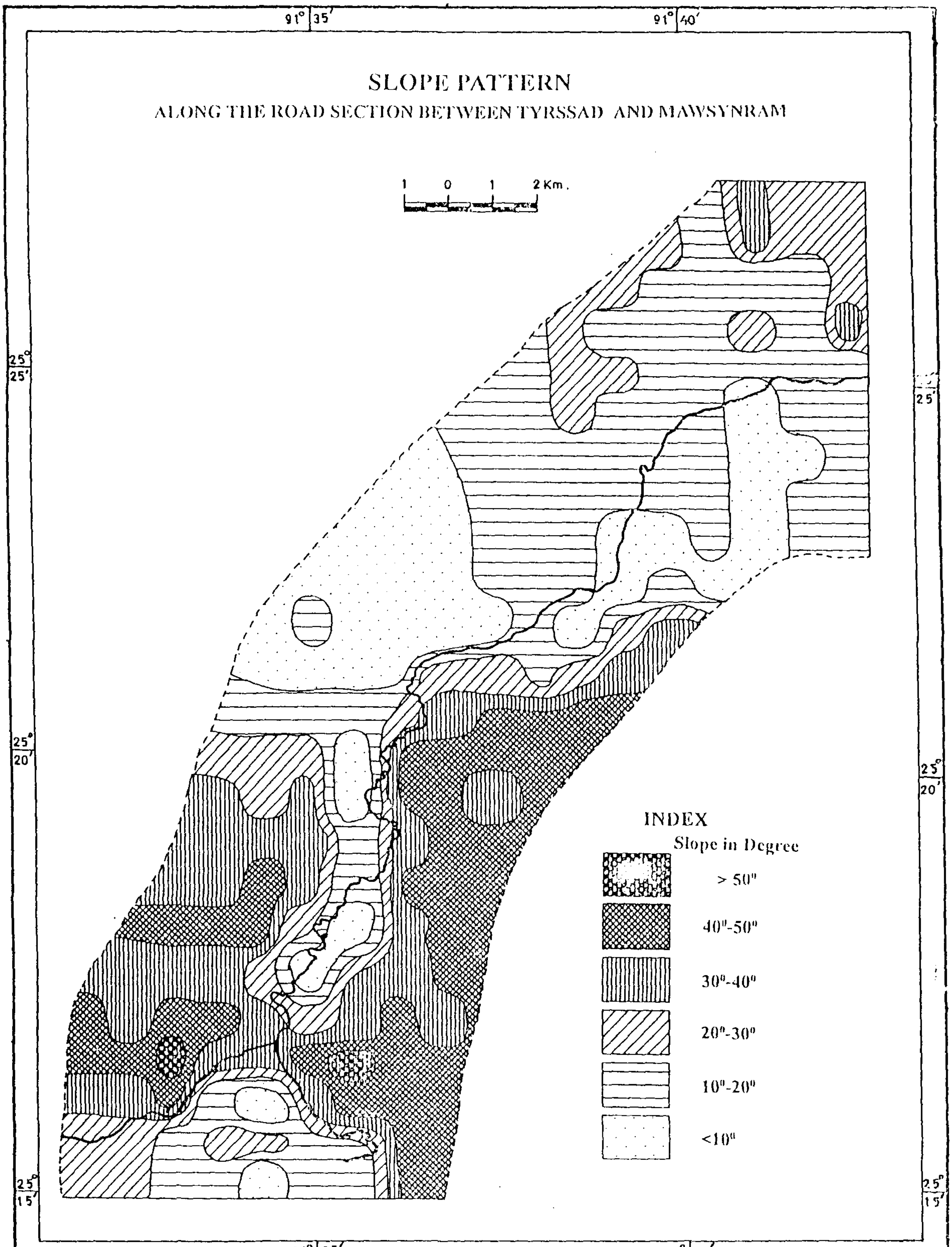
Map 8b


SLOPE PATTERN
ALONG THE ROAD SECTION BETWEEN UMS NING AND SHILLONG
91° 50′
91° 55′
25° 40′
25° 35′
25° 30′
1 0 1 2 Km.
INDEX
Slope in Degree
> 50°
40°-50°
30°-40°
20°-30°
10°-20°
<10°

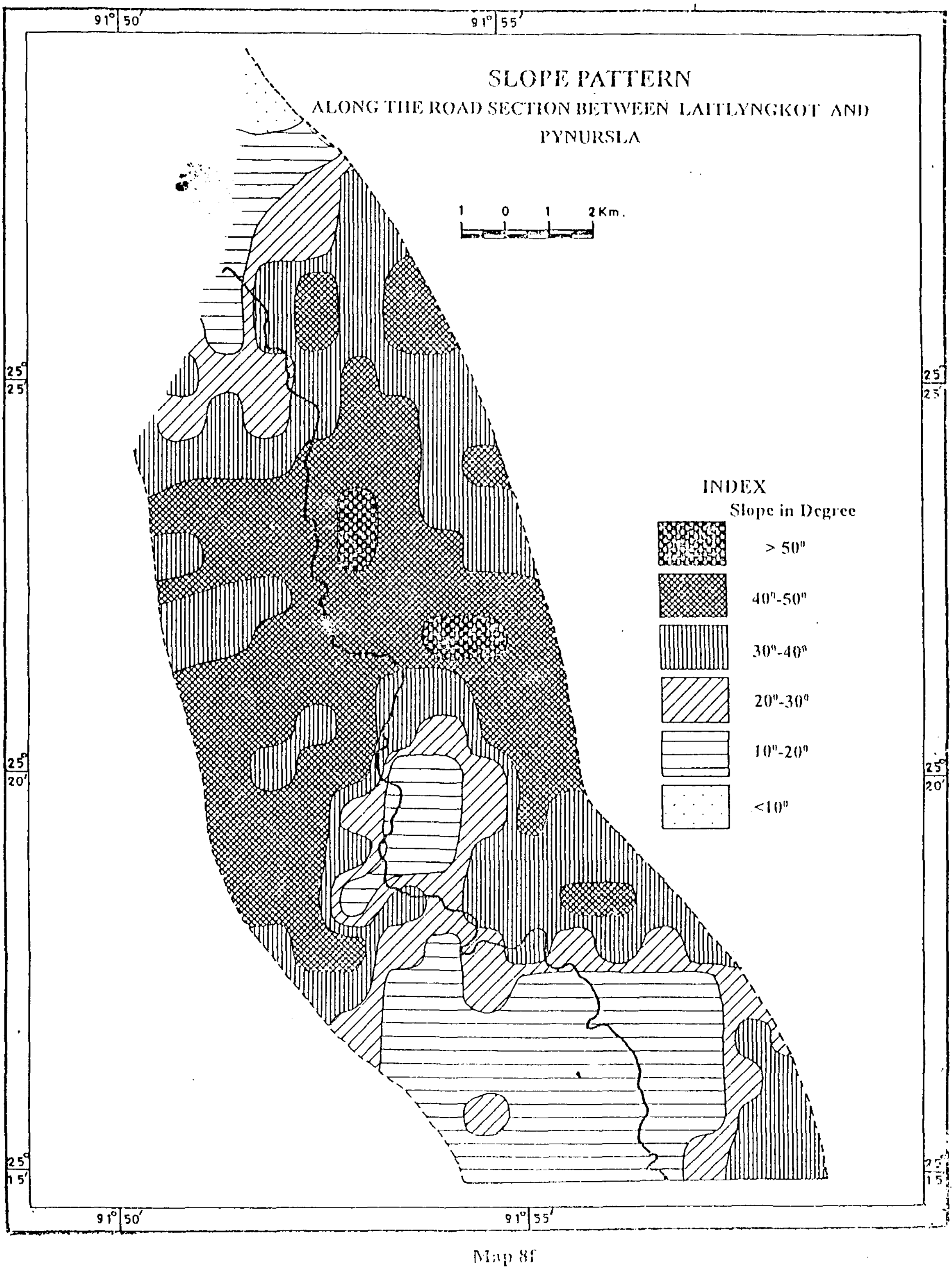
Map 8c


SLOPE PATTERN
ALONG THE ROAD SECTION BETWEEN MAWPHLANG, UMTYNGAR AND
CHERRAPUNJI
91°45'
91°50'
25°25'
25°20'
25°15'
1 0 1 2 Km.
INDEX
Slope in Degree
> 50°
40°-50°
30°-40°
20°-30°
10°-20°
<10°

Map 8d

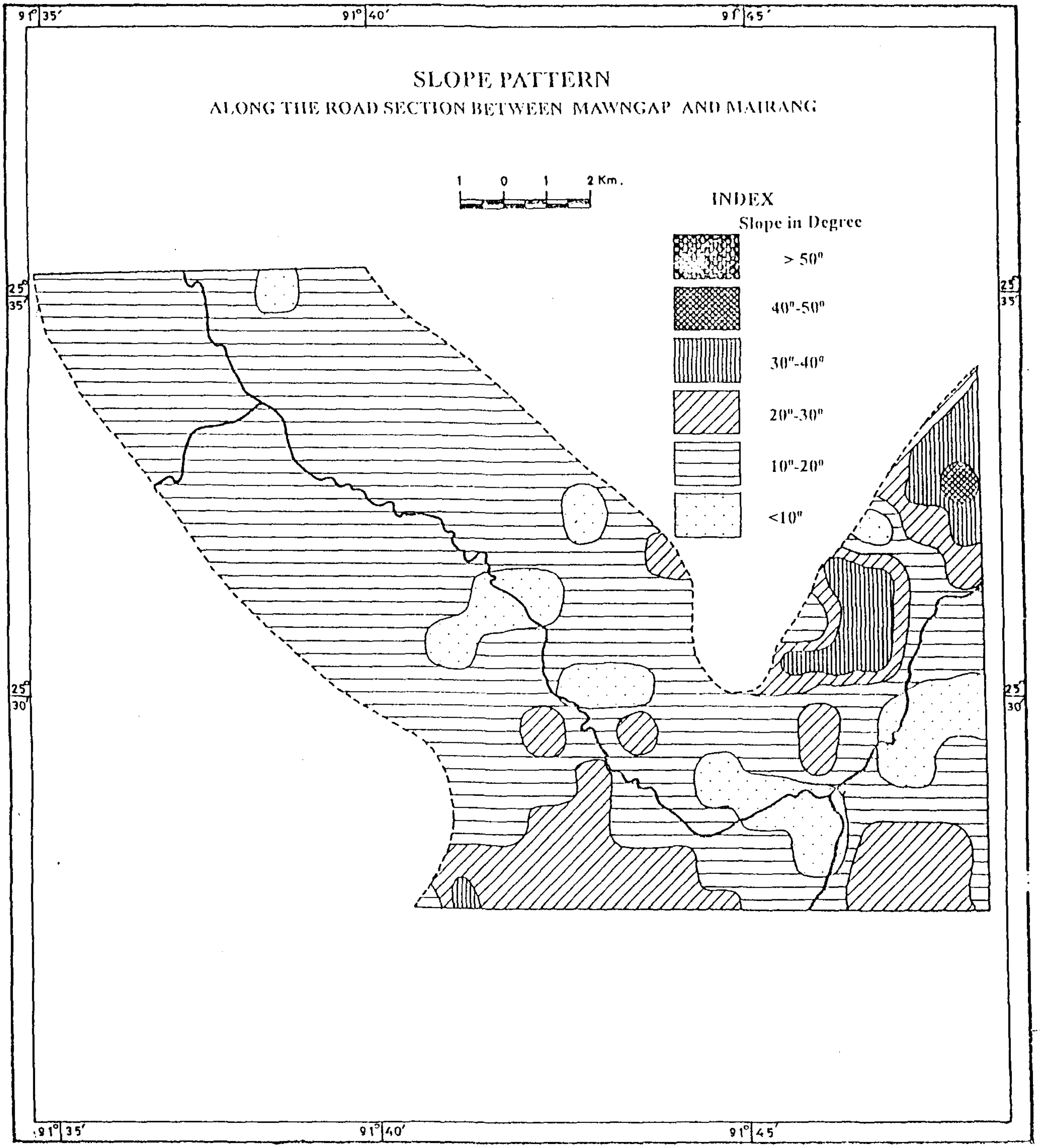

91° 35′
91° 40′
SLOPE PATTERN
ALONG THE ROAD SECTION BETWEEN TYRSSAD AND MAWSYNRAM
1 0 1 2 Km.
25° 25′
25° 20′
25° 15′
INDEX
Slope in Degree
> 50°
40°-50°
30°-40°
20°-30°
10°-20°
<10°

Map 8e



SLOPE PATTERN
ALONG THE ROAD SECTION BETWEEN LAITLYNGKOT AND PYNURSLA
1 0 1 2Km.
INDEX
Slope in Degree
> 50°
40°-50°
30°-40°
20°-30°
10°-20°
<10°
91° 50′
91° 55′
25° 25′
25° 20′
25° 15′

Map 8f



SLOPE PATTERN
ALONG THE ROAD SECTION BETWEEN MAWNGAP AND MAIRANG
1 0 1 2 Km.
INDEX
Slope in Degree
> 50°
40°-50°
30°-40°
20°-30°
10°-20°
<10°
91°35′
91°40′
91°45′
25°35′
25°30′

Map 8g

Table 16: Average Slope (Slope Pattern) of the study area

Slope (°)	Area (sq. km.)	Area (%)	Slope Class
<10	220.53	16.32	Level to Gentle
10-20	641.91	47.49	Moderately steep
20-30	249.97	18.49	Steep
30-40	135.56	10.03	Very steep
40-50	96.08	7.11	Precipitous
>50	7.48	0.55	Precipitous
Total Area	1351.53	99.99	

Precipitous (> 40°)

Precipitous slopes are present as small patches between Umtyngar and Mawphlang area and also between Umsning and Shillong. The total area covered by this category is 7.66 %.

Very Steep Slope (30°- 40°)

It occurs as isolated patches over Shillong Group of rocks and covers an area of 10.03 % of the area surveyed along the road. These isolated patches coincide with the traces of the Tyrssad –Barapani Shear Zone cutting through the area. Such discrete steep slope patches indicate accelerated erosion in vicinity of the shear zone, a consequence of minor reactivation.

Moderately Steep to Steep Slope (10°-30°)

This category of slope covers an area of 65.98 % the largest among the various categories. It occurs as large patches over the Shillong Group as well as on the Nongpoh Pluton. By far its maximum development is seen over the Pluton. Such localized steep slopes are suggestive of instabilities of slopes and attendant vigorous erosion.

Level to Gentle (<10°)

Over 16.32 % of the roadside area is occupied by the level to gentle slope group. Such slope differential is due to surviving terraced plateau landscape over the Shillong Group. The relatively steeper slopes over the Pluton landscape is the result of the overprinting of Quaternary Fluvial Cycles on the irregular Proterozoic Granitoid surface, after denudation of the Shillong Group over it.

4.3.4 Development of Slope Profiles

Slope of an area is a function of climate, lithology, tectonics, structural elements and biotic activities. A Slope Profile can have a concave, convex, straight or a complex morphology showing all the three forms.

The slopes in the study area depicts all the above mentioned forms or profiles separately as well as in combination. The tops of ridges usually have convex profiles whereas the flanks of ridges show combination of all the three forms. The convex and straight segments of the Slope Profiles in the areas are by and large erosional in nature while the concave slopes are depositional in nature. The natural Slope Profiles are seen at places modified due to the interference of man. The sections in the vicinity of developmental schemes show modified Slope Profiles particularly in the areas, which have been denuded of vegetation and where there are unsystematic slope cuttings. Such sites often become prone to landslides as the stability of slopes get jeopardized. The slopes frequently fail due to rapid change in equilibrium conditions. This is the common feature seen along NH-40 highway slope cuttings.

The Slope Profiles over gneissic lithology of the study area are mostly concavo-convex. Slopes over Shillong Group of rocks show all the three slope elements, however, the bottom slopes are remarkably concave with low curvature, merging with pediments.

It is evident from the correlation of different variables that the slopes in the area are by and large controlled by lithology, tectonics and structural characteristics in the area. The climate more or less can be taken uniform over the area.

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Chapter 5

Landslides

Chapter 5

Landslides

Population pressures and increasing urbanization, along with local zoning laws, have been forcing man from flat-lying areas and flood plains onto the adjacent hillslopes, (Leighton, 1976). The hillslope as an environmental setting can help us avoid the severe flooding of the low areas, but can be equally hazardous because of potentially unstable earth materials. Therefore, recognition of landslide –prone topography is becoming increasingly important in land use decisions, (Bailey, 1971).

Under the proper set of circumstances, landslides can affect most hillslopes. The three principal causes of landslides are excessive rainfall, human activities, and earthquakes.

Table 17: Location of major landslide prone zones in the study area

Landslide Prone Zones Along National Highway-40	
Latitudes	Longitudes
1. 25° 57.5'	91° 50.2'
2. 25° 51.5'	91° 52.5'
3. 25° 56'	91° 52.5'
Landslide Prone Zones along Shillong- Mawsynram Highway	
Latitudes	Longitudes
1. 25° 27'	91° 44.5'
2. 25° 16.3'	91° 34.8'
3. 25° 21.7'	91° 37.2'
Landslide Prone Zones Along Shillong -Cherrapunji Highway	
Latitudes	Longitudes
1. 25° 27'	91° 49.5'
Landslide Prone Zones along Shillong-Mairang Road	
Latitudes	Longitudes
1. 25° 30'	91° 42'

Table 18: Landslide prone zones in the study area

Sl. No.	Location	Movement Involved	Type of Material	Rock type	Causative Factors
1	Jorabat	Rock slide, Soil Slide	Big massive boulders	Granite Gneiss	Anthropogenic
2	Umling	Rock Slide	Big massive boulders	Granite	Natural
3	Nongpoh	Soil Slide	Non Plastic soil	Granite	Anthropogenic
4	Umsning	Soil Slide	Non Plastic soil	Gneiss	Anthropogenic
5	Barapani	Rock Slide	Highly Jointed	Phyllites	Natural
6	Mawiong	Soil Creep	Low Plasticity	Khasi Greensto ne	Natural
7	Umtyngar	Soil Slide	Non Plastic soil	Granite	Anthropogenic
8	Mawphlang	Debris Slide	Weathered boulders	Khasi Greenstone	Anthropogenic
9	Tyrssad	Rock Slide	Massive Boulders	Khasi Greenstone	Anthropogenic
10	Weiloi	Rock Slide	Massive Boulders	Quartzites	Anthropogenic
11	Laitlyngkot	Rock Slide	Debris	Quartzites	Anthropogenic
12	Umthli	Rock Slide	Debris	Quartzites	Anthropogenic
13	Lumshoshur	Rock Slide	Debris	Quartzites	Anthropogenic
14	Lingkerdem	Rock Slide	Debris	Quartzites	Anthropogenic
15	Pynursla	Rock Slide	Debris	Quartzites	Anthropogenic
16	Sohiong	Rock Slide	Massive Boulders	Quartzites	Natural
17	Ladmeri	Soil Slide	Non Plastic Soil	Quartzo-Feldspathic Gneiss	Natural
18	Manai	Soil Slide	Non Plastic Soil	Quartzo-Feldspathic Gneiss	Natural
19	Mairang	Soil Slide	Non Plastic Soil	Quartzo-Feldspathic Gneiss	Natural

The word 'Landslide' is being used as a group name for several types of mass movement of rock debris, (Coates, 1977). Landslides denote downward and outward movement of slope forming materials, primarily composed of natural rock, soil, artificial fills or a combination of all these materials. The moving mass might proceed by any of the three following types of movement or their combinations.

a) falling
b) sliding and
c) flowing

Various classifications of landslides are available, which helps an engineer for identification of the different phenomenon associated with the slides for proper and reliable remedial measures for their minimal occurrences, (Zaruba and Mencl, 1969). Earth scientists, Environmentalists or Engineers need a classification to interpret the past and present trends of topography as revealed by their observations.

5.1 Landslides in the Study area

The landslide prone zones are more frequent where the developmental (constructional) activities have modified slope profiles, particularly making the profile segments steeper in sections. This makes the slopes unstable with a tendency to fall as and when the equilibrium is lost, (Cleaves, 1961).

The occurrences of many landslides are noticed along the NH-40 (Guwahati-Shillong highway) as shown in table 17 and 18. Along steeper slope segments, during rains when the pore water pressure increases the weathered rocks easily fail along fissile surfaces like bedding, foliation or joints, under the load pressure of civil structures like residences or "load release" due to cutting of slopes, (Eckel, 1958). As such these landslides are one of the principal Geo-Hazards in the uplands. Conspicuously, the part of the area that falls within the Shillong Master Plan (between Mawlai and Sumer) where a number of educational institutions are likely to be established shows frequent incidences of landslides. All the active landslides of the area are encountered along the National Highway 40 itself. The landslides occurring along the study area can be grouped under two broad categories - rock slides and soil slides. Some landslides with their intensities and dimensions are discussed below:

5.1.1 Rock Slides

When huge blocks of rocks topple down slopes due to instability they are known as rockslides (Ladd, 1935). The term debris slide is used when fragments of such rocks slide down slope due to slope instability.

1) Rock Slide at Jorabat: The slide at Jorabat has occurred in Quartzo-Feldspathic –Gneiss which is massive in appearance and has a slope profile angle of 52° (fig 7). The crown height is 14m. and extent of slide is 11.5m. The width of slided portion is 30m. The free face is absent in the slide area. The calculated parameters under Geo-technical, Geological and Morphological heads have been analysed in laboratory.

2) Rock Slide at Umling: The Umling landslide has taken place in Granite, which is also massive in appearance. The rock has suffered extensive wearing and tearing due to great water movement within the area. The height of crown is 16m. and the lateral extent is 14m. while the width of the slided portion is 20m (fig 8). The slope profile angle was found to be 55°.

3) Rock slide at Barapani: The slide at Barapani has taken place in the Phyllites of the Shillong Group. The rocks are highly weathered and joints are closely spaced. The crown height is 10.8m. and lateral extent is 3.8m. The height of free face is only 1m. The width of the slided material is 11m (fig 9). The slide has a high slope profile angle of 82°. Due to the presence of thick vegetative cover, inspite of the presence of closely spaced joints, the occurrence of landslide is quite occasional.

4) Rock slide at Umtyngar: The slide at Umtyngar has taken place in Granites. This is a massive rock slide having a crown height of 25m. and lateral extent of the slide is 19m. (plate 14 a & b). The width of the slide at the toe is 125m. The slope profile angle when measured was found to be ranging between 55°-65° (fig 10). The slide has a free face of only 1m.

5) Debris slide at Mawphlang: The slide that has taken place at Mawphlang involves two rock types- the Khasi Greenstone and Schist (plate 15a & b). The slide has a crown height of 21m. an extension of 26.5m. and height of free face is 6.3m (fig 11). The width of the slided portion is 35m. The slope profile angle is 74°.

6) Rock slide at Tyrssad: Quartzite and Schist are the rock types, which are involved in the slide at Tyrssad. The quartzite here is of massive variety (plate 16) while the schist is highly weathered. The slide has a crown height of 20m. and its lateral extension is 18.3m. the free face here is totally absent. The slope profile angle is found to be 55° (fig 12). The width of the slided portion is 75m.

7) Rock slide at Weiloi: The rock slide at Weiloi has occurred in Quartzo-Feldspathic Gneiss. This is a massive variety of rock that has a slope profile angle of 53° (fig 13). The crown height is 17m. while the extent of slide is 14.4m. The width of the slided portion is 43m.

8) Rock Slide at Laitlyngkot: The rocks of this slide prone area are Quartzites. The joints are continuous and the rocks are moderately weathered. The slope profile angle here varies between 72° to 75°. The

SLOPE PROFILE OF LANDSLIDE AT JORABAT

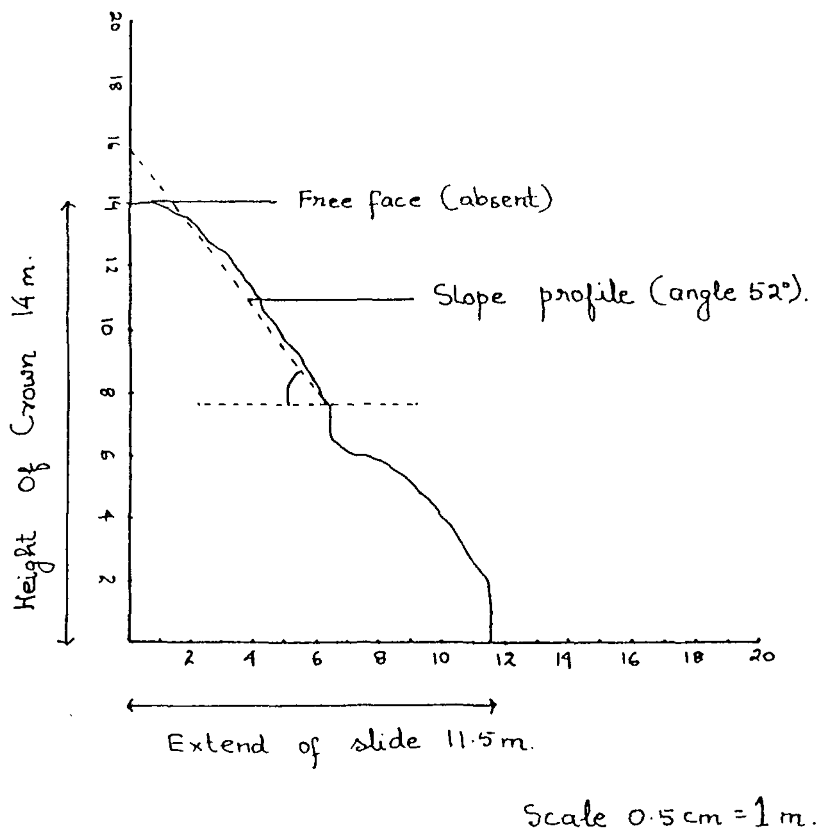


Fig. 7

SLOPE PROFILE OF LANDSLIDE AT UMLING

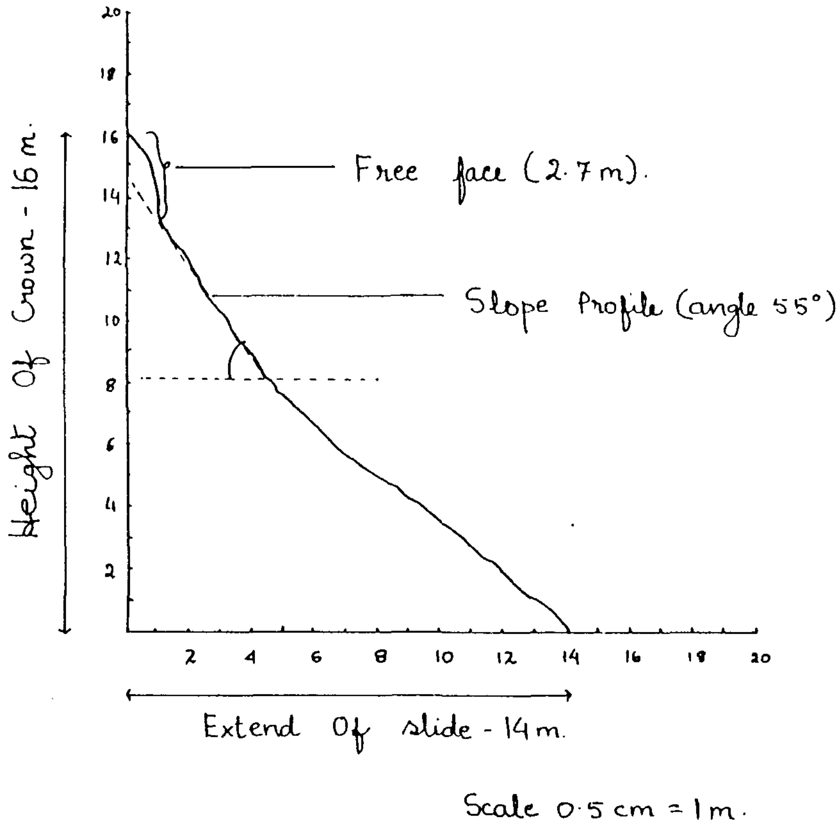


Fig. 8

SLOPE PROFILE OF LANDSLIDE AT BARAPANI

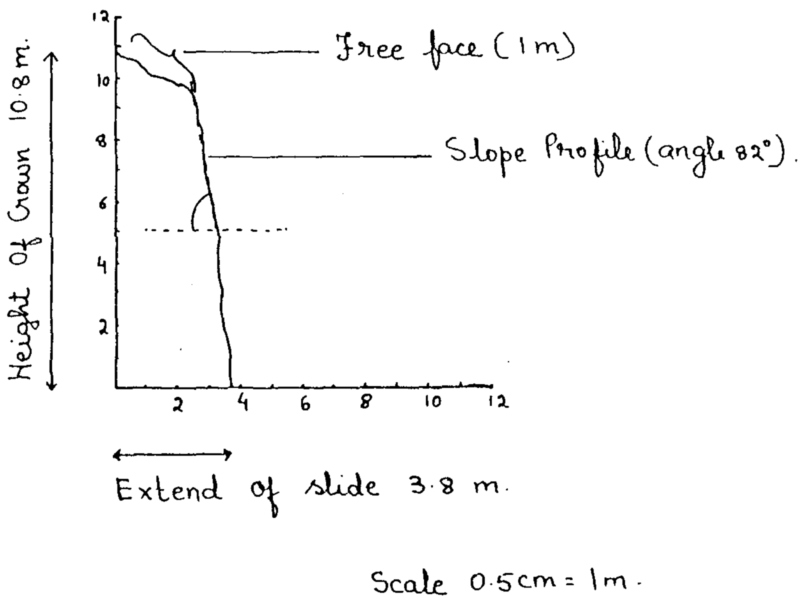


Fig. 9

SLOPE PROFILE OF LANDSLIDE ATUMTYNGAR

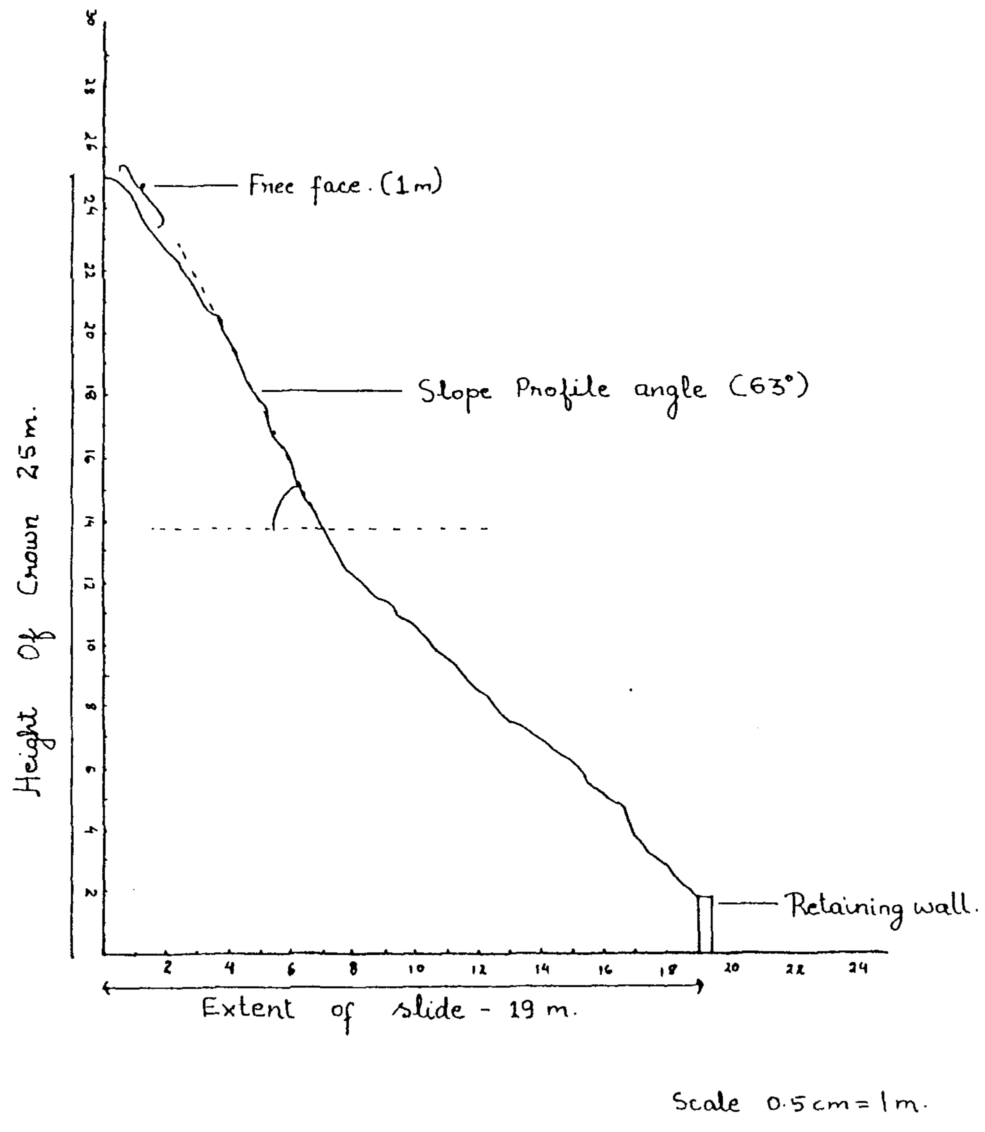


Fig. 10

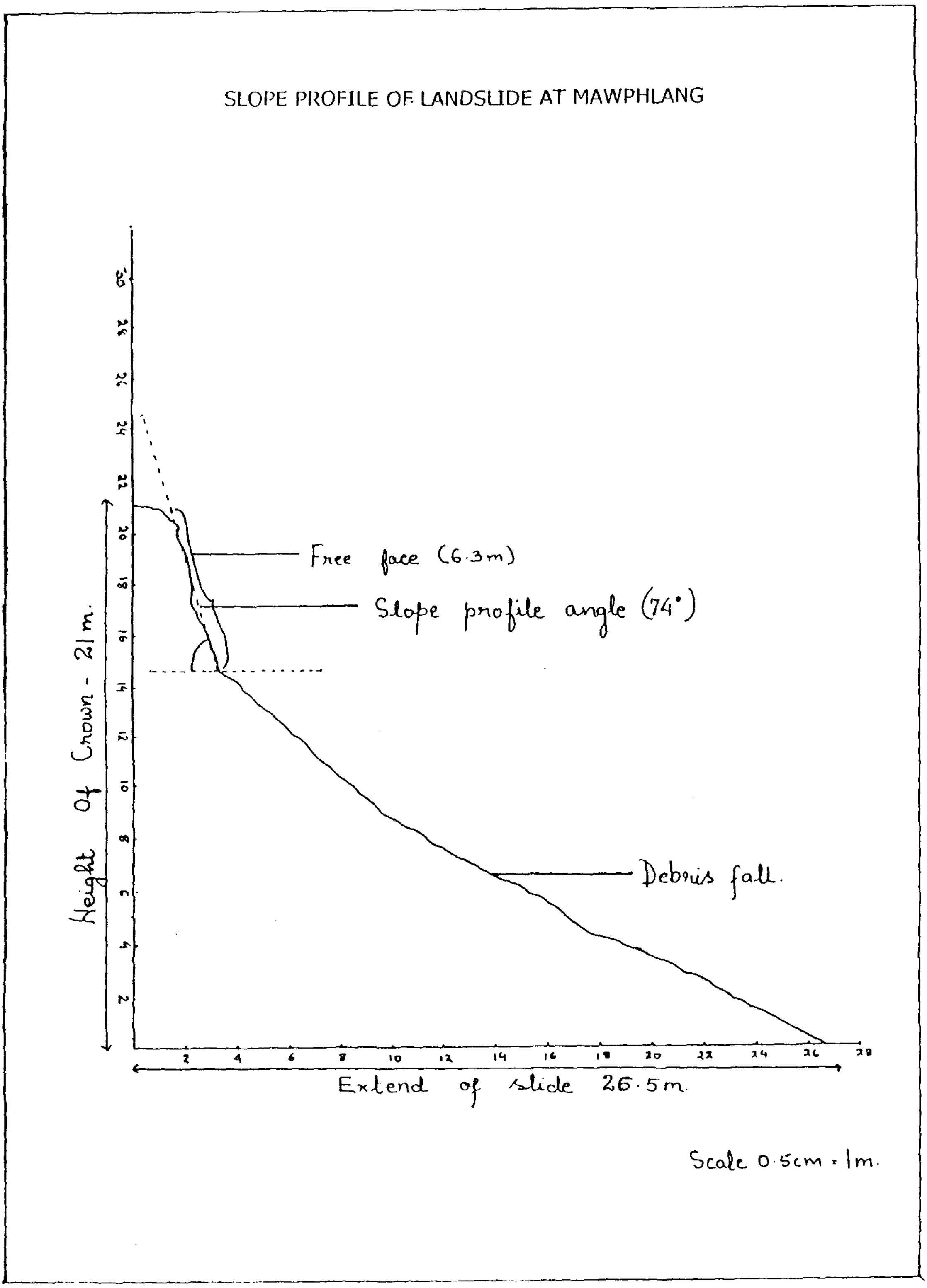
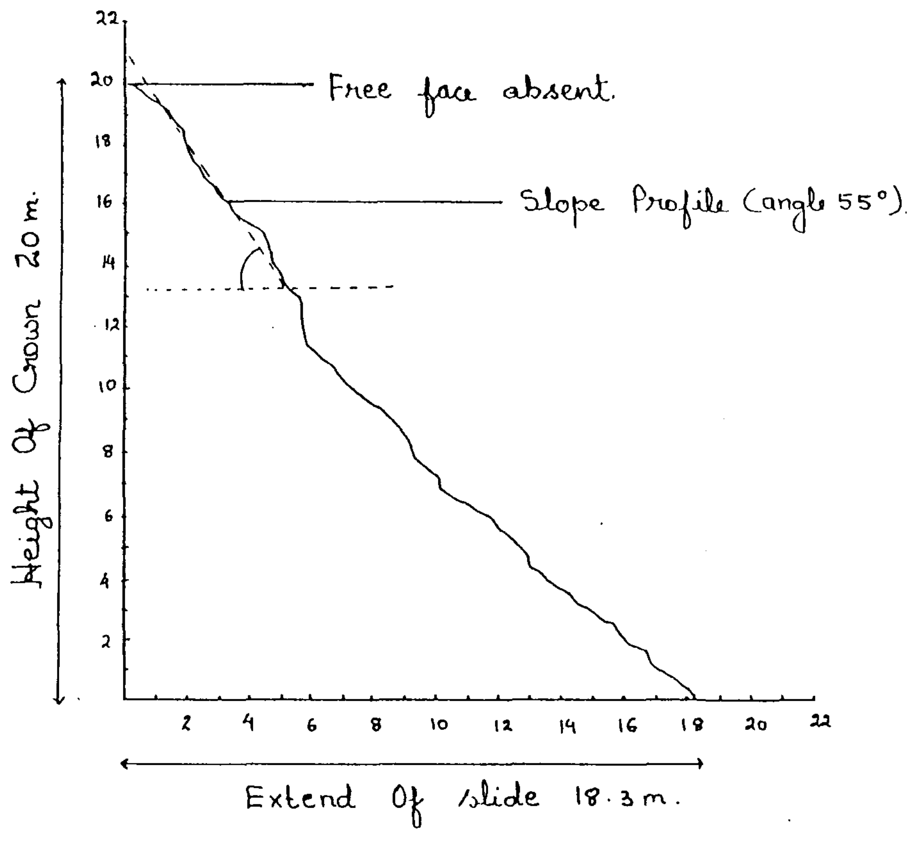

SLOPE PROFILE OF LANDSLIDE AT MAWPHLANG
Free face (6.3m)
Slope profile angle (74°)
Debris fall.
Height Of Crown - 21m.
Extend of slide 26.5m.
Scale 0.5cm = 1m.

Fig. 11

SLOPE PROFILE OF LANDSLIDE AT TYRSSAD



Scale 0.5 cm = 1 m.

Fig. 12

Slope profile of landslide at Weiloi

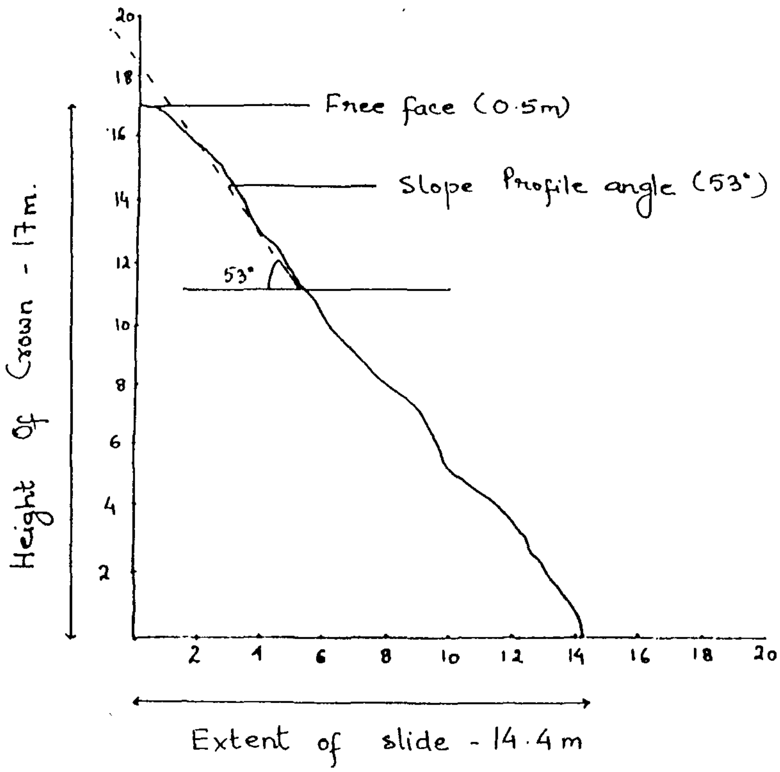


Figure 13

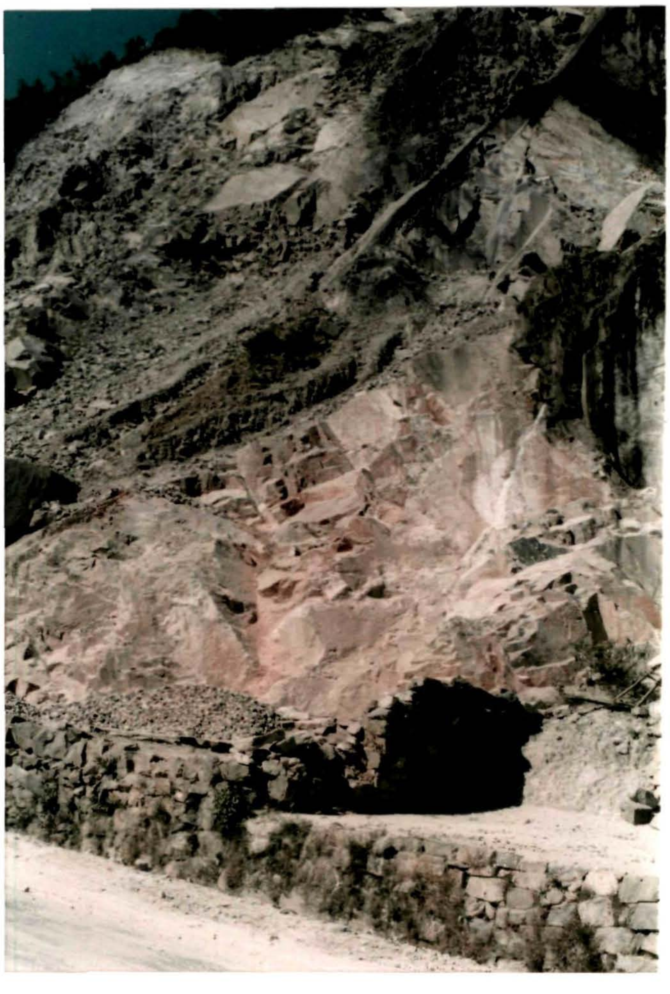


Plate 14a Rock slide at Umtyngar

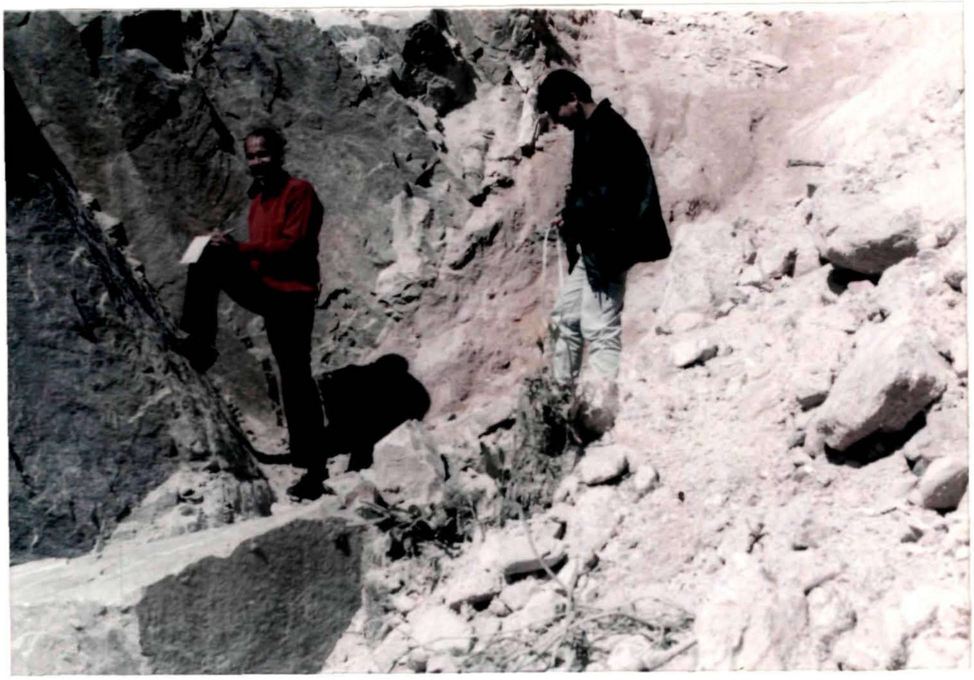


Plate 14b Rock slide at Umtyngar

Plate 15a Debris slide at Mawphlang

Plate 15b Debris slide at Mawphlang

Plate 16 Rock slide at Tyrssad

height of crown is 19 m. and the extent of slide is 15 m. The width of the slided portion is 30 m.

9) Rock Slide at Umthli: The Quartzites are affected in this slide prone area. The joints are continuous and almost vertical. The rocks are moderately weathered and the slope profile angle is very steep varying between 75° to 80°. The height of crown is 12 m. while the slide extends 35 m. The width of the slided portion is 12 m. from one end to the other.

10) Rock Slide at Lumshoshur: The rock types involved in this slide prone area are Quartzites. Here too the joints show continuity and the rocks are moderately weathered. The slope profile angle is varying between 65° to 70°. The height of crown is 12 m. and the extent of slide is 20 m. The width of slided portion is 8 m.

11) Rock Slide at Lingkerdem: Quartzites are affected in this slide prone area. The joints are continuous and water movement is moderate. The rocks are moderately weathered and the slope profile angle varies between 67° to 72°. The height of crown is 12 m. while the slide extends 18 m. The width of the slided portion is 12 m. from one end to the other.

12) Rock Slide at Pynursla: The rocks of this slide prone area are Quartzites. The joints are continuous and the rocks are moderately weathered. The slope profile angle here varies between 65° to 70°. The height of crown is 12 m. and the extent of slide is 18 m. The width of the slided portion is 13 m.

13) Rock Slide at Sohiong: The rock types involved in this slide prone area are Quartzites. Here the joints show few continuity and the rocks are moderately weathered. The slope profile angle is varying between 60° to 67°. The height of crown is 18 m. and the extent of slide is 14 m. The width of slided portion is 11 m.

5.1.2 Soil Slide

When sliding occurs only for soil then it is termed as soil slide. The prominent soil slides in the study area are listed below.

14) Soil Slide at Jorabat: The soil in Jorabat is medium sand variety as depicted from the grain size analysis. The Slope Profile angle is 47°. The height of crown of the slide is 12 m. The extent of slide is 18 m. The soil is homogenous without any differentiated Soil Profile. Mainly shrub variety vegetative cover is present at the crown of the slided portion.

15) Soil Slide at Byrnihat: The soil in Byrnihat is fine sand variety as depicted from the grain size analysis. The Slope Profile angle is 45°. The height of crown of the slide is 18 m. The extent of slide is 20 m. Here too the soil is homogenous without any differentiated Soil Profile. Mainly shrub variety vegetative cover along with a few large trees are present at the crown of the slided portion.

16) Soil Slide at Nongpoh: The soil slide at Nongpoh is of fine sand variety. Thick vegetative cover is present at the crown of the slided portion. They comprise mostly big trees. The Slope Profile angle is 52°. The height of crown of the slide is 11 m. The extent of slide is 13 m.

17) Soil Slide at Umsning: From Umsning we can see the transition in forest cover. Pine growths begin to appear. The soil type here is medium sand variety. The Slope Profile angle is 61°. Umsning recorded the highest value of liquid limit (43%) as per the analysis carried out among the soil slide areas. The height of crown of the slide is 16 m. The extent of slide is 17m.

18) Soil Slide at Barapani: This slide is located between 72-73 km. post on the left side of the road. The longitudinal profile of this slide is gently convex, about 50m. long running parallel to the highway. The slide has occurred on weathered Khasi Greenstones. The crown height is 14m. and the crown top has a slope of 55°. The crown portion is deforested with a few remnants of old pine trees, 37-42 years old. The slumped material has very steep slope (over 75°), which is prone to frequent failures. The trace of slip surface is intermittently visible. The soils at Barapani exhibits the lowest value in liquid limit (19.12%).

19) Soil Slide at Mawiong: The slide occurs near the Mawiong tollgate between 70-71 km. post, left side of the highway. This slide is also over highly weathered Khasi Greenstones and its Soil Profile exposes homogenous red coloured loamy to clayey soil. The width of the slide is m. with a crown height of m. The height of free face is about m. The top of the crown has a slope of about ° and show evidences of jhum cultivation. The top has now afforested pine trees of 15-19 years old. The slumped material has a steep slope of 75°.

20) Soil Slide at Ladmeri: The soil slide at Ladmeri is of very coarse sand variety. Very thin vegetative cover is present at the crown of the slided portion. The Slope Profile angle is 65°. The height of crown of the slide is 19 m. The extent of slide is 26 m.

21) Soil Slide at Manai: The soils of Manai comprises of fine sand. The soil is homogenous in nature without any differentiated soil profile. The Slope Profile angle is 57°. The height of crown of the slide is 16 m. The extent of slide is 27 m. Small trees are seen at the crown though the density is very less.

22) Soil Slide at Mairang: The soils in the slided portion of Mairang is of very coarse sand variety. The width of slide is 19 m., height of crown is 11m. and the height of free face is 3m. Vegetation is moderate in the slide area with few big trees. The Slope Profile angle here is 61°.

23) Soil Slide at Umtyngar: The soils of Umtyngar exhibits the very coarse sand variety. The width of slide is 25m., height of crown is 12m and the height of free face is 1m. Vegetation is practically absent in the slided portion rendering the slope vulnerable to instant failures. The Slope Profile angle here is 62°.

Apart from the above mentioned major slides in the study area, there are quite a few landslides of minor dimensions that have occurred along NH-40, some of which are discussed below.

Slump Slide: The slide is in weathered and altered Shillong Group of rocks between 73-74 km. post (Shillong-Guwahati) to the road's left. The rocks have been completely altered to soil of maroon to brown colour. The soil is homogenous in nature, coarse to medium grained, loamy without any differentiated soil profile. The slide has a width of 60m., height of crown is 10m. and the slumped material has a slope of 70°- 75°.

Slump Slide: This is a slide on an old stabilized slide (palaeoslide) between 73-74 km. post to the left of the highway. The slide has occurred in highly weathered Khasi Greenstone. In a red maroon matrix of loamy soil. The width of the slide is 50m. and height is 10m. the top of crown shows evidences of deforestation as revealed by the presence of only a few of 11-15 years old pine trees. The slumped material has a slope of 75°-80° which shows transverse tensional cracks and the trace of slip surface is visible.

Debris Slide: This slide occurs after Mawiong village between 71-72 km. post to the left of the highway. The rocks are sheared and highly weathered Khasi Greenstone with red soil on top. The slide is 45m. long with a crown height of 10m. the top of the crown has a slope of about 20°, which is deforested except a few pine trees of 15-19 years of age.

Slump Slide: The slide is positioned at 71 km. post, left to the road and has occurred on weathered Khasi Greenstone. The width of the slide is 90m. and crown height is 10m. The top of crown has a gentle slope of 15°-20° and is deforested consisting a few 11-15 years old pine trees. The slumped material has a steep slope of 75°-80°.

Slump Slide: The slide is on soil of weathered Khasi Greenstone between 70-71 km. post, left side of the highway. The width of slide is 40m., height of crown is 11m and the height of free face is 3m. At the crown an old stone line is seen indicating relict of a palaeoslide now exposed in the road cutting. The top of crown shows 11-15 years old pine afforestation and has 15°-20° slope. The slope of slumped material varies from vertical to 70°. The trace of slip surface is visible at intervals.

Slump Slide: This is a zone of four slides between 70-71 km. post to the left of the road. The cumulative length of these slides is 200m. the slides vary in width from 15m. to 20m., with crown heights varying from 10m. to 15m. The slides have likewise occurred in the weathered Khasi Greenstones. The soil is loamy to clayey and is reddish brown in colour. The top of crown has a slope of 15°-20° along with 11-15 years old pine afforestation. The angle of the slumped material varies between 70°-80°.

Slump Slide: This slide has taken place between 69-70 km. post, again to the left of the highway on weathered Khasi Greenstones. The colour of the soil is reddish brown. The slide has a width of 120m., crown height of 12m. and height of free face is 2m. the top of crown is deforested having only a few shrubs and its slope is about 20°. The slumped material has a steep slope ranging between 75°-80°.

Rock Fall and Rock Slide: The slide is in Phyllitic Quartzites and Phyllites of the Shillong Group between 67-68 km. post, left of highway. The beds have vertical dips with prominent joints parallel to bedding or foliation surface. The rock has been sheared with a zone of pulverized material at the central part of the slide. The width of the slide is about 12m. and height of free face is 20m. The top of free face has a slope of 35°-40°, which is, deforested rarely showing any growth of pine trees.

Rock Slide: The slide is on sheared Phyllitic Quartzites, Quartzites and Phyllites of Shillong Group between 67-68 km. post, right side of highway. The width of the slide is about 85m., crown height about 20m. and height of free face is 3m. The slide appears to be quite active all along its width but during different times. The top of crown has pine trees, which are about 27-32 years old while the dormant portion of the slide does not show pine trees older than 17-22 years indicating the dormancy period of the same order. The top of crown slope and the rocky material has the same slope, which is about 45°.

Slump Slide: This slide occurs about 30m. away from slide no. 11, towards Barapani, on right side of the road. This appears to be a frequent slide spot and the slide has been provided with a retaining wall. The slide is in soil after Shillong Group of rocks having a width of 12m. and crown height of 6m. the top of crown is afforested with pine trees of 15-19 years old. The trace of slip is not visible.

Slump Slide: The slide is on soil after Shillong Group of rocks between 67-68 km. post, right side of the highway. The slide is very much active which have broken the retaining wall. The width of the slide is 20m. and crown height is 3m. At the top of crown the slope is 20°-25° containing pine growths, 32-37 years old. However, the flanks of the slide have only 15-19 years old pine trees, indicating the dormancy period of flanks. The slumped material has a slope of 65°.

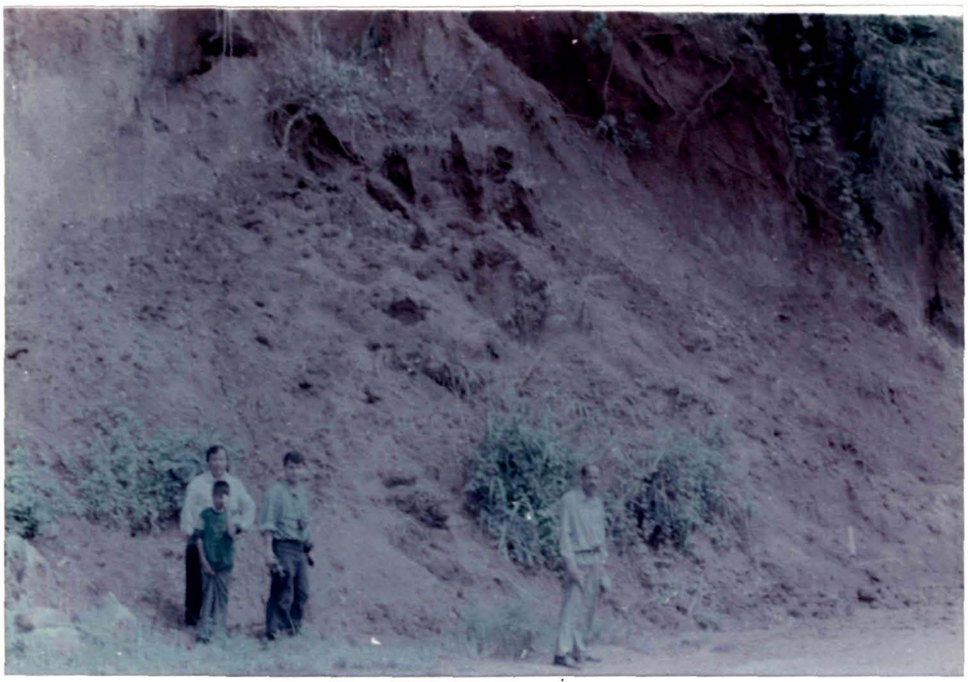


Plate 17 Slump slide at Barapani

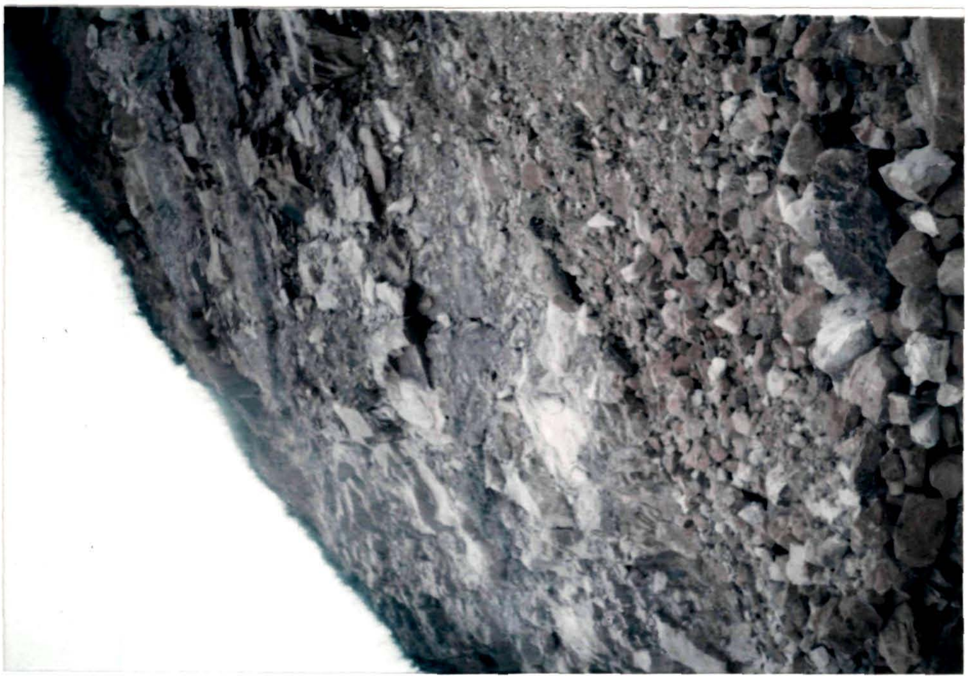


Plate 18 Debris slide at Barapani

Debris Slide: The slide is on Shillong Group of rocks between 67-68 km. post, right side of the highway (plate 18). It appears to be quite active which have broken the retaining wall being provided at flanks. The width of the slide is 45m. and height of crown is 15m. The top of crown has a gentle slope of <40° and the slope of debris material is 75°, while the height of free face is 1m.

Debris Slide: The slide occurs in Carbonaceous Phyllite of the Shillong Group near the 67 km. post, right of the highway. The width of slide is 4m. and height of crown is 10m. The top of crown has a slope of 30° and has pine trees 37-42 years old while the flanks have pine trees of about 17-22 years old, which indicates the order of dormancy of slide in flanks. The sliding debris material has a slope of 75°-80°.

Debris Slide: The slide is in Carbonaceous Phyllite between 66-67 km. post, right side of highway. Its width is 25m. height of crown is 10m. and height of free face is 1m. The top of crown has a slope of 25°-30° and is forested with 32-37 years old pine trees. The flanks have pine trees of about 17-22 years old while the sliding debris material has slope of 75°.

Rock Slide-Rock Fall: The slide occurs on sheared Phyllitic Quartzites of the Shillong Group located between 66-67 km. post, right side of road. The beds are thin with vertical dips showing minor folding. The width of slide is 20m. and height of crown is 20m. The top of crown has a slope of 30°-35°, forested with pine trees 22-27 years old, while the flanks have 15-19 years old pine trees. The gliding rocky material at the toe has a slope of 70°-75°.

Slump Slide: The slide occurred on Phyllitic Quartzites located between 66-67 km. post, left to the highway. The rocks are highly sheared. The slide is on a pre-existing slumped material. The width of slide is 20m. height of crown 10m. and height of free face 3m. The top of slide has a slope of 30°

with pine trees 37-42 years of age. The slumped material at the toe has a slope of 70°.

Debris Slide: This slide is on Phyllitic Quartzites occurring opposite to the 66 km. post. The slide appears quite active having a width and height of crown of 15m. The top of the crown has sparse pine trees, 37-42 years old, having a slope of 45°. The sliding debris material has a slope of 75°-80°.

Debris Slide: The slide is on sheared Phyllitic Quartzites between 65-66 km. post, left of highway. This slide also has been provided with a retaining wall. The width of the slide is 20m., the height of crown 10m and the height of free face is 3m. The top of the crown has a slope of 45° with 32-37 years old pine trees while the debris material has a slope of 75°.

Debris Slide: The slide occurs in weathered Quartzites between 63-64 km. post, left side of highway. Its width is 10m. and height of crown is 8m., while the height of free face is 2.5m. the top of crown is deforested and has a slope of 30°. The slope of the sliding debris material is 75°-80°.

Thus the above descriptions of the different slide prone zones reveal that the most common landslides are the 'slump' type along NH-40 upto Umsning and rock slides in Shillong-Pynursla stretch of the highway. The slides are mainly due to slope failure and slope instabilities induced by slope cuts along the highways. Deep weathering under tropical climatic conditions has reduced the slope cohesiveness making them vulnerable to slide while the deforestation has further accelerated the slope instabilities. It is now very clear that the active landslides in the study area are the result of anthropogenic activities carried on along the major highways for various developmental schemes including building constructions and various other types of commercial establishments.

5.2 Analysis of Geo-Technical Parameters

The performance of a rock under a particular condition depends upon its physical and mechanical properties. The physical properties may be known as index properties, which describe the rock materials and help in classifying them. The mechanical properties may be known as strength properties and they give information about the performance of rock materials, when subjected to a particular loading system.

The following Geo-technical parameters were analysed for rock samples:

1) Rock Mass Strength
2) Bearing Strength
3) Moisture Content
4) Porosity

Similarly, for the Geo-technical analysis of soil the following parameters were analysed:

1) Moisture content
2) Infiltration rate
3) Liquid limit
4) Plastic limit

5.2.1 Geo-Technical Analysis of Rock Samples

Geo-technical analysis for the rocks of the landslide areas were carried out in Geo-technical lab. The following parameters were taken for analysis.

5.2.1.1 Rock Mass Strength

The performance of a rock under a particular condition depends upon physical and mechanical properties of rock materials. The physical properties may be known as index properties, which describes the rock materials and help in classifying them. The mechanical properties may be known as strength properties and they give information about the performance of rock materials, when subjected to a particular loading system.

The strength of a rock mass depends on orientation of the mineral constituents within the rock. These individual mineral crystals are not homogenous, isotropic and perfectly elastic bodies due to sequence of formation of rock masses. The crystal hardness is influenced by various physical and mechanical properties, such as cohesion, brittleness, tensile strength, etc. at the same time due to an orientation of cleavage planes. Direction of application of load is also an important factor while determining the rock properties.

Schmidt Hammer

The Schmidt Hammer is made up of a plunger at the bottom and hammer mass attached to it which is attached to the spring which cohere compressed activates the spring energy and gives the reading of the hardness of the concrete block. It is based on the principle of rebound.

Theory: This test is based on the principle that when a plunger resting on a rock is subjected to impact force due to a hammer striking on the surface of the plunger, the rebound of the hammer depends upon the hardness of the concrete. The rebound of the hammer is recorded on a scale on the hammer itself and it gives the Schmidt's number (table 19).

The Schmidt's Hammer tests the reflection of strain energy from the mass of the rock and not just the immediate surface. Hence, a good connection is to be maintained between hammer and rock and small imperfections crushed flat.

It is generally recommended that the test be repeated at the same point about four or five times or until a constant reading is obtained.

The hammer is spring loaded and it can be used to any conditions (vertical, horizontal or inclined). In vertically upward, gravity is less, so spring rebound easily. Certain values have to be deducted (+ 90) as correction factor. In vertically downward, gravity is more, so rebound will be tough, (- 90) is the correction factor. In a horizontal plane there is no correction factor because there is no impact due to gravity. In the digitized version no such corrections are to be made as the strength is automatically calculated and displayed.

Procedure:

1) We press the plunger of the hammer against the rock surface till a hammering sound is heard. At this moment we press the catch button.
2) We repeat the procedure for at least six times at different locations of the concrete materials.
3) We observe the reading on the scale. The strength index is displayed on the screen of the hammer and it is noted down.

5.2.1.2 Bearing Capacity: Bearing Capacity of a rock may be defined as the stress which it can take before failure. In the test, the load which is applied to the rock is vertical and is applied through a rigid plate (Terzaghi, 1950). The plate dimensions fixes the extent of the rock to be stressed because the rock mass depth which is influenced by the test is equivalent to the diameter of the rigid plate through which the load is applied. The Bearing Capacity of a rock is the actual strength of the rock. This is measured by preparing cube blocks of 3x3" in rock cutting machine and the blocks are placed in the

Table 19 : Schmidt Hammer Test

Sp.No.	Size of Sample	Physical Characters of rocks	Rebound Value R		Average Value of R	St.* (N/mm^2)
			Sf. A	Sf. B		
JS-1	6x6"	Massive	48,48,50, 50,51,51	49,51,51, 50, 48,49	49.66	70
UM-1	6x6"	Massive	29,30,31 31,32,31	30,30,29 31,30,29	30.25	20.2
BA-3	6x6"	Highly Jointed	31,31,34, 32,33,33	32,33,32, 31, 33,32	32.25	25
MS-1	6x6"	Compact	62,60,59, 62,59,61	61,59,62, 60,60,60	60.41	90.3
ML-2	6x6"	Compact	56,61,60, 56,59,57	57,56,57, 59, 61,61	58.33	79.5
TY-1	6x6"	Massive	50,50,49 50,50,49	49,50,48 49,50,49	49.41	63.4
WE-1	6x6"	Massive	52,51,52 52,51,51	51,52,52 52,52,52	51.65	67.1
LY-1	6x6"	Highly Jointed	43,46,45 46,45,45	45,45,46 46,44,45	45.08	54.3
UT-1	6x6"	Highly Jointed	42,41,42 43,41,42	42,41,43 42,42,41	41.8	52.2
LM-1	6x6"	Vertical Joints	47,46,48 48,47,47	48,47,47 48,47,48	47.35	59.4
LN-1	6x6"	Highly Jointed	47,45,42 48,48,47	45,46,46 47,42,43	45.5	55.4
PY-1	6x6"	Highly Jointed	42,42,43 42,42,42	42,43,43 42,42,43	42.3	53.8
SO-1	6x6"	Highly Jointed	49,48,48 49,48,48	49,50,48 48,48,49	48.5	61.7

JS- Jorabat, UM- Umling, BA- Barapani, MS-Umtyngar, ML- Mawphlang, TY- Tyrssad, WE- Weiloi, LY- Laitlyngkot, UT- Umthli, LM- Lumshoshur, LN- Lingkerdem, PY- Pynursla, SO- Sohiong.

* Strength

universal testing machine to determine its strength. The strength is measured in kilo Newton (kN). The analytical results have been laid down in table 20.

Table 20 : Bearing Capacities of the rocks at the landslide spots

Landslide Prone Spots	Bearing Capacity (kN)
Jorabat	330
Umling	40
Barapani	42
Umtyngar	317
Mawphlang	305
Tyrssad	175
Weiloi	167
Laitlyngkot	164
Umthli	160
Lumshoshur	162
Lingkerdem	162
Pynursla	165
Sohiong	208

5.2.1.3 Moisture Content: The Moisture Content of a rock sample is defined as the ratio of weight of water in the voids to the weight of dry solids in the sample i.e. the Moisture Content of a rock is the amount of water present in the rock mass. This parameter is determined by taking samples of the rocks and initially taking its weight (W_1). This weight is noted down. Then the samples are kept to dry in the oven for 24 hrs. under 105°-110° C. The final weight (W_2) is then taken and the difference (W_1-W_2) calculated which gives the Moisture Content of the particular rock. It is expressed in percentage. The Moisture Content analysed for different rock types encountered in the study area have been tabulated in table 21.

Table 21: Moisture Content of the rocks at the landslide spots.

Landslide Prone Spots	Initial Weight (gms.) (W_1)	Final Weight (gms.) (W_2)	Moisture Content (%)
Jorabat	640.4	640.02	0.06
Umling	327.03	326.76	0.08
Barapani	154.03	152.78	0.81
Umtyngar	366.53	366.44	0.02
Mawphlang	163.87	163.65	0.13
Tyrssad	454.7	453.97	0.16
Weiloi	426.24	425.50	0.17
Laitlyngkot	542.89	542.11	0.14
Umthli	253.57	253.31	0.10
Lumshoshur	376.12	375.77	0.09
Lingkerdem	248.34	248.06	0.11
Pynursla	366.42	366.00	0.11
Sohiong	216.86	216.53	0.15

5.2.1.4 Porosity: The Porosity of a rock is the amount of pore spaces present in a particular rock mass. Porosity identifies the relative proportion of solids and voids. Porosity is measured in the following method: Fresh rock samples collected from the field are taken to the geo-technical laboratory and their weights taken within 24 hours of collection time (table 22). The initial weight (W_1) is noted down and the sample is then kept in the oven for 24 hours at 105°-110°C. After that the final weight (W_2) is taken and noted. The Porosity is then calculated by finding out the ratio of the difference between the initial weight (W_1) and the final weight (W_2) by initial weight (W_1) multiplied by 100. It is expressed in percentage.

The porosity of a rock depends on the orientation of the mineral grains in the rock, the grain size and the cemented materials present in the rock mass.

Table 22 : Porosity of the rocks at the landslide spots

Landslide Prone Spots	Initial Weight (gms) (W_1)	Final Weight (gms) (W_2)	Porosity (%)
Jorabat	109.2	109.5	0.27
Umling	60.8	60.995	0.32
Barapani	46.7	47.995	2.77
Umtyngar	44.9	45.1	0.45
Mawphlang	187.1	189.48	1.27
Tyrssad	127.6	129.34	1.36
Weiloi	443.3	449.46	1.39
Laitlyngkot	250.6	253.84	1.29
Umthli	406.5	410.95	1.09
Lumshoshur	48.1	48.64	1.12
Lingkerdem	259.4	262.86	1.33
Pynursla	374.2	378.92	1.26
Sohiong	94.7	95.57	0.92

Other calculated/ analysed parameters for landslide prone areas (rock slides):

5.2.1.5 Vegetative Cover

The vegetation over a particular terrain is an important factor, which determines the nature of slope stability for that terrain. Thick vegetative growth binds the soil that does not give way to landslides while soils devoid of vegetative cover are more vulnerable to sliding. Observations were made on the different landslide prone zones for vegetation (table 23) and accordingly they were described as devoid of vegetation, sparse, moderate and high vegetative growths.

Table 23: Vegetative Cover at the Landslide spots

Landslide Prone Zone	Vegetative Growth
Jorabat	Moderate
Umling	Moderate
Barapani	High
Umtyngar	Sparse

(......contd.)

Landslide Prone Zone	Vegetative Growth
Mawphlang	Sparse
Tyrssad	Moderate
Weiloi	Moderate
Laitlyngkot	Sparse
Umthli	Sparse
Lumshoshur	Moderate
Lingkerdem	Moderate
Pynursla	Moderate
Sohiong	Sparse

5.2.1.6 Slope Profile Angle

The Slope Profile Angles for the different landslide prone zones have been calculated with the help of clinometer compass. Three readings were taken in these spots as the slopes display variations in their profile at different junctions and their average calculated (table 24).

Table 24: Slope Profile Angle of the rocks at the landslide spots.

Landslide spot	Reading 1 (°)	Reading 2 (°)	Reading 3 (°)	Average (°)
Jorabat	50	54	54	52
Umling	57	57	53	55
Barapani	83	81	85	83
Umtyngar	62	58	60	60
Mawphlang	71	71	75	73
Tyrssad	58	53	55	55
Weiloi	55	53	50	53
Laitlyngkot	73	73	73	73
Umthli	70	72	75	73
Lumshoshur	66	71	67	68
Lingkerdem	68	74	72	70
Pynursla	68	66	68	68
Sohiong	62	61	66	64

5.2.2 Geo-Technical Analysis of Soil Samples (Soil Slides).

The Geo-technical analysis for the soils of the landslide areas has been carried also in the lab. The following parameters were taken for analysis.

5.2.2.1 Moisture Content: The Moisture Content of a soil is the amount of water/liquid present in the soil (at normal temperature). The Moisture Content of soils for landslide prone zones were calculated (table 25) in Geo-technical laboratory.

Table 25: Moisture Content of the soils at the landslide spots.

Landslide Spots	Initial Weight (gms) (W1)	Final Weight (gms) (W2)	Moisture Content (%)
Jorabat	5.510	4.444	19.3
Byrnihat	4.554	3.766	17.3
Nongpoh	5.215	4.239	18.7
Umsning	6.012	4.820	19.8
Barapani	6.414	6.122	4.55
Mawiong	6.931	5.004	27.8
Ladmeri	4.859	4.562	6.11
Manai	5.024	4.723	5.99
Mairang	6.086	5.772	5.16
Umtyngar	5.815	5.260	9.54

5.2.2.2 Infiltration rate: The Infiltration Rate is the time required for the water to percolate through the soil to a thickness of 1 cm. This is a rough estimation for the permeability of the soils. The Infiltrometer was used to determine the Infiltration Rate insitu (table 26).

The measure of the infiltration rate is a rough alternative to the measure of permeability of the soils.

Table 26 : Infiltration Rate of the soils at the landslide spots

Landslide Spots	Infiltration Rate (secs)
Jorabat	55
Byrnihat	51
Nongpoh	54
Umsning	45
Barapani	2 mins. 10 secs.
Mawiong	35
Ladmeri	1 min. 55 secs.
Manai	2 mins. 50 secs.
Mairang	2 mins. 18 secs.
Umtyngar	2 mins. 35 secs.

5.2.2.3 Liquid Limit: Liquid Limit is the transition state of soils from the liquid state to a plastic state. Since the soils of the study area display lower plasticity value the standard Casagrande method is discarded and the Cone Penetrometer test is put to use.

The Cone Penetrometer method is used to eliminate most of the shortcomings of standard (Casagrande) Liquid Limit test especially with soils of low plasticity. It is the water content that corresponds to 25mm. penetration of the cone of the Penetrometer. The Liquid Limits were calculated for the different landslide areas (table 27).

Procedure: (1) A soil sample of 200 gms. sieved through 75mm sieve is taken.

2) A uniform paste is made by adding water to the given soil sample. The amount of water added is noted down. Sufficient time must be allowed for uniform distribution of moisture in the soil.

3) The paste is then transferred to a cylindrical trough of the apparatus and the trough is placed exactly below the cone.

4) The Penetrometer is adjusted such that the pointed edge of the cone just touches the soil surface and the pointer of the scale adjusted accordingly.

5) The plunger is released and the cone is allowed to penetrate for a time period of 30 secs.

6) If the penetration depth is less than 20mm., the paste is taken out from the trough and the procedure is repeated after adding more water till the penetration depth lies between 20-30 mm.

Table 27 : Liquid Limit of the soils at the landslide spots.

Landslide Spots	Liquid Limit (%)
Jorabat	37.43
Byrnihat	35.47
Nongpoh	38.46
Umsning	43.00
Barapani	19.12
Mawiong	41.93
Ladmeri	29.51
Manai	24.20
Mairang	25.67
Umtyngar	22.62

5.2.2.4 Plastic Limit: Plastic Limit of a soil can be defined as a property of the soil to deform continuously and permanently without rupture under a stress to the yield value of the soil. The Plastic Limit of the soils has been determined by the following laboratory analysis (Sharpe, 1939).

Procedure:

1) About 10 gms. of soil passing through 75 mm. sieve is taken and placed on a ground glass plate. It is mixed thoroughly with distilled water until it is plastic enough to be rolled into a ball.

2) The soil is rolled between one hand and the glass plate so that a thread of 3mm.diameter is formed.

3) The soil is again kneaded together and rolled so that the Moisture Content gradually reduces in the process of rolling. The process is repeated until the

soil thread (of 3mm. dia) just begins to crumble or show cracks on the surface.

4) The crumbled thread is collected and put into a Moisture Content can for determining the Moisture Content. This Moisture Content is the plastic limit of the soil.

The Plastic Limits were calculated for different landslide spots (table 28).

Table 28: Plastic Limit of the soils at the landslide spots

Landslide Spots	Initial Weight (gms)	Final Weight (gms)	Plastic Limit (%)
Jorabat	6.759	5.106	32.37
Byrnihat	8.254	6.287	31.29
Nongpoh	7.629	5.772	32.17
Umsning	6.147	4.616	33.17
Barapani	6.338	5.109	24.05
Mawiong	5.58	4.155	34.29
Ladmeri	7.338	5.702	28.7
Manai	8.125	6.12	32.76
Mairang	5.465	4.217	29.6
Umtyngar	6.323	5.008	26.25

5.2.2.5 Grain Size (Sieve) Analysis for Soil Samples

Varied numbers of sieves are used for the Grain Size analysis (for different sizes of sediment, base on the users choice to select it. The sieves are vertically arranged from no. 10 on top to no. 75 at the bottom. Then, the soil samples taken for analysis are poured in the no. 10 sieve and this arrangement is carried to the sieving machine. In the machine, two types of forces viz. vertical and horizontal forces are applied. These two forces shakes the sieves and the sediments are percolated through different sieves according to their diameters. The sieves are then taken out of the machine after about 7-10 mins. The soils of the different sieves are kept in packets. Thus we find the different grade of soils according to the number of sieve, and can classify the soils as gravel, coarse sand, fine sand, very fine sand, silt and clay according to the classification laid down by Udden-Wenthworth (refer table in appendix). Their present net-weight is calculated by deducting the weight of packet from the total weight. The weights are taken in an electronic balance for total accuracy.

Pipetting Method: The smallest particle size of soils i.e. clay which are found in the pan are classified into four groups. For this the Pipetting method is used. In this method, a cylinder of 100ml. Size filled with distilled water is taken. The sediment is now poured carefully and stirred for 0.58 secs. Other requirements are 4 beakers of 50ml. capacity and a pipette of 20 ml. capacity. An amount of 20 ml. of the soil solution is taken by the pipette from the cylinder. The arrangement for the experiment is shown in table 29.

The above mixture in the cylinder is allowed to rest for 1'56" and then 20ml. dissolved water is taken at 20cm. depth from the cylinder and then it is kept in a beaker of 50ml. capacity (table 29)

Table 29: Procedure for Pipetting method in tabular form.

Diameter (mm)	Phi size (Ø)	Depth (cm)	Amount of Dissolved water	Time
0.0625	4.00	20	50 ml	0'58"
0.03133	5.00	20	20ml	1'56"
0.0156	6.00	10	20ml	7'44"
0.0078	7.00	10	20ml	31'0"
0.0039	8.00	10	20ml	2°3'0"

The above mixture in the cylinder is allowed to rest for 1'56" and then 20ml. dissolved water is taken at 20cm. depth from the cylinder and then it is kept in a beaker of 50ml. capacity (table 29). This process is repeated for three times where 20ml. solution is taken at 10cm. depth from the cylinder at the interval of 7'44"; 31'; and 2 hr. 3' respectively. The four beakers of 50ml. are marked as q = 5,6,7 and 8 respectively and are carried to the electric oven for drying. The soils at the top of the beaker are weighed with the help of an electronic balance and then prepared for grain size distribution that gives the characters of the grain size.

Before starting off with the sieve analysis care was taken so that there were no soil lumps or other impurities present in the samples. This would not have given authentic results for the experiments performed in the laboratory.

The grain size analysis for the different landslide zones are given in table 30 – 39.

Table 30 : Sieve Analysis results for Jorabat

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	7	7	1.531	1.531
-1.50	22	29	4.814	6.345
-0.25	65	94	14.223	20.569
0.75	92	186	20.131	40.701
1.75	121	307	26.477	67.179
2.75	107	414	23.414	90.593
3.75	42	456	9.190	99.784
5.00	0.892	456.892	0.195	99.979
6.00	0.087	456.979	0.019	99.998
7.00	0.004	456.983	0.0008	99.999
8.00	0.001	456.984	0.0002	100

Table 31: Sieve Analysis results for Byrnihat

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	5	5	1.428	1.428
-1.50	8	13	2.285	3.714
-0.25	33	46	9.429	13.144
0.75	52	98	14.85	28.003
1.75	88	186	25.145	53.148
2.75	120	306	34.289	87.438
3.75	43	349	12.28	99.725
5.00	0.872	349.872	0.249	99.974
6.00	0.079	349.951	0.022	99.997
7.00	0.007	349.958	0.002	99.999
8.00	0.002	349.96	0.0006	100

Table 32: Sieve Analysis results for Nongpoh

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	0	0	0	0
-1.50	9	9	2.744	2.744
-0.25	25	34	7.623	10.367
0.75	56	90	17.076	27.444
1.75	83	173	25.309	52.754
2.75	113	286	34.457	87.211
3.75	41	327	12.502	99.714
5.00	0.837	327.837	0.255	99.969
6.00	0.095	327.932	0.028	99.998
7.00	0.004	327.936	0.0012	99.999
8.00	0.001	327.937	0.0003	100

Table 33: Sieve Analysis results for Umsning

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	8	8	1.713	1.713
-1.50	53	61	11.350	13.064
-0.25	72	133	15.420	28.484
0.75	79	212	16.919	45.403
1.75	127	339	27.199	72.603
2.75	79	418	16.919	89.522
3.75	48	466	10.280	99.802
5.00	0.826	466.826	0.177	99.979
6.00	0.091	466.917	0.019	99.998
7.00	0.003	466.920	0.0006	99.999
8.00	0.002	466.922	0.0004	100

Table 34: Sieve Analysis results for Barapani

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	3	3	0.292	0.292
-1.50	12	15	1.168	1.460
-0.25	35	50	3.406	4.866
0.75	35	85	3.406	8.272
1.75	271	356	26.372	34.643
2.75	511	867	49.727	84.370
3.75	159	1026	15.473	99.843
5.00	0.854	1026.854	0.083	99.926
6.00	0.67	1027.524	0.065	99.991
7.00	0.045	1027.569	0.0044	99.995
8.00	0.043	1027.612	0.0041	100

Table 35: Sieve Analysis results for Mawiong

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	0	0	0	0.00
-1.50	6	6	1.987	1.99
-0.25	31	37	10266	12.25
0.75	47	84	15.565	27.82
1.75	78	162	25.831	53.65
2.75	104	266	34.442	88.09
3.75	35	301	11.591	99.68
5.00	0.875	301.875	0.289	99.972
6.00	0.080	301.955	0.026	99.998
7.00	0.005	301.960	0.002	99.999
8.00	0.001	301.961	0.0003	100

Table 36: Sieve Analysis results for Ladmeri

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	5	5	1.067	1.067
-1.50	24	29	5.120	6.187
-0.25	121	150	25.815	32.001
0.75	71	221	15.147	47.149
1.75	73	294	15.574	62.723
2.75	103	397	21.974	84.698
3.75	69	466	14.721	99.418
5.00	0.981	466.981	0.209	99.628
6.00	0.731	467.712	0.156	99.784
7.00	0.602	468.314	0.128	99.912
8.00	0.412	468.726	0.088	100

Table 37: Sieve Analysis results for Manai

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	9	9	1.623	1.623
-1.50	19	28	3.426	5.142
-0.25	59	87	10.640	15.977
0.75	75	162	13.525	29.750
1.75	160	322	28.853	59.133
2.75	182	504	32.820	92.556
3.75	48	552	8.656	99.542
5.00	0.928	552.928	0.167	99.710
6.00	0.765	553.693	0.140	99.848
7.00	0.519	554.212	0.094	99.941
8.00	0.326	554.538	0.060	100

Table 38: Sieve Analysis results for Mairang

Scale	Weight (gms.)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	22	22	2.252	2.252
-1.50	51	73	5.222	7.475
-0.25	320	393	32.769	40.244
0.75	196	589	20.071	60.315
1.75	189	778	19.354	79.669
2.75	159	937	16.282	95.951
3.75	38	975	3.891	99.84
5.00	0.88	975.88	0.090	99.933
6.00	0.59	976.47	0.060	99.993
7.00	0.032	976.502	0.0033	99.997
8.00	0.029	976.531	0.0030	100

Table 39: Sieve Analysis results for Umtyngar

Scale	Weight (gms)	Frequency of weight percentage	Weight Percentage	Cumulative Weight %
-2.00	8	8	1.832	1.832
-1.50	27	35	6.183	8.015
-0.25	125	160	28.628	36.644
0.75	66	226	15.115	51.759
1.75	72	298	16.489	68.249
2.75	97	395	22.215	90.465
3.75	40	435	9.161	99.626
5.00	0.94	435.94	0.215	99.84
6.00	0.62	436.56	0.141	99.983
7.00	0.037	436.597	0.0084	99.991
8.00	0.035	436.632	0.0080	100

After analyzing for the grain size analysis in different soil slide prone areas, the quantity of the various particle size present has been deduced and is presented in table 40.

Table 40: Particle size of the soils of the landslide prone areas. (quantity in gms).

Landslide Spots	Granule	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt
Jorabat	6.345	14.223	20.131	26.477	23.414	9.190	0.215
Byrnihat	3.713	9.429	14.850	25.145	34.289	12.280	0.2736
Nongpoh	2.744	7.623	17.076	25.309	34.457	12.502	0.2845
Umsning	13.063	15.420	16.919	27.199	16.919	10.280	0.197
Barapani	1.460	3.406	3.406	26.372	49.729	15.473	0.1565
Mawiong	6.0	31.0	47.0	78.0	104.0	35.0	0.961
Ladmeri	6.187	25.815	15.147	15.574	21.974	14.721	0.581
Manai	5.049	10.640	13.525	28.853	32.820	8.656	0.461
Mairang	7.474	32.769	20.071	19.354	16.282	3.891	0.1563
Umtyngar	8.015	28.628	15.115	16.489	22.215	9.161	0.3724
Total	60.05	178.953	183.24	288.772	356.099	131.154	3.6583

From the above table it is seen that the soils of the study area are mainly falling under "Fine Sand" category and silt is almost negligible in occurrence.

Other Analysed Parameters for Soil Slide Prone Areas

5.2.2.6 Slope Angle

The slope profile angle for the different soil slide prone areas were determined with the help of clinometer. Three readings were taken for the measurement of slope as the slopes display variations in their profiles and the average reading calculated for each of them (table 41).

Table 41: Slope angle for different landslide prone areas.

Landslide Spot	Reading 1 (°)	Reading 2 (°)	Reading 3 (°)	Average (°)
Jorabat	48	47	49	47
Byrnihat	43	47	45	45
Nongpoh	50	54	54	52
Umsning	60	61	61	61
Barapani	72	69	70	70
Mawiong	44	42	42	42
Ladmeri	65	65	65	65
Manai	59	55	57	57
Mairang	60	61	60	61
Umtyngar	62	64	60	62

5.3 Selby's Classification Rating

A classification has been devised for assessing the Rock and Soil Mass Strength in the field using only simple, portable and cheap equipments. The classification is based upon engineering experience but has been designed for geomorphic situations. This classification is known as Selby's Classification. The following parameters are included in the classification:

1) Strength of intact rock (by Schmidt Hammer)
2) State of weathering of the rock
3) Spacing of joints, bedding planes, faults, foliation within the rock mass.
4) Orientation of joints with respect to the hillslope/ cutslope.
5) Width of the joints, bedding planes, etc.
6) Lateral or vertical continuity of the joints.
7) Gouge or infilling material in the joints.
8) Movement of water within or outside the rock mass.

5.3.1 Strength of intact rock: The strength of the rocks found in the landslide areas has been calculated and analysed by the "digitized Schmidt Hammer" insitu as described earlier. Also samples were collected and taken to the laboratory and their strength estimated for comparative study. No major differences in readings were noticed. On the other hand actual strength of the fresh rock samples of the landslide prone zones were determined by 'bearing capacity' test.

5.3.2 State of weathering of the rock: The rocks along the National Highway 40 are highly weathered and decomposed. Major portions of the rock exposures has suffered extensive weathering and reduced to soil.

5.3.3 Spacing of Joints, Bedding Planes, Faults, and Foliation within the rock mass: The discontinuities present within the rock mass show little variations in their spacing. The spacings are distributed almost evenly throughout the rock bodies. There are infilling materials present in such openings.

5.3.4 Orientation of Joints with respect to the hill slope/cutslope: There are almost vertical joints present in the rocks of the slide areas. The quartzites are highly jointed rocks and hence most of the rock slides are occurring in these rocks.

5.3.5 Width of the joints, bedding planes, etc.: The joints that are present in the rock masses show widths ranging from 0.2 cms. to 2 cms. The joints almost show uniformity in their spacings.

5.3.6 Lateral or vertical continuity of the joints: The joints often show continuity in their occurrence on the rocks affected by sliding.

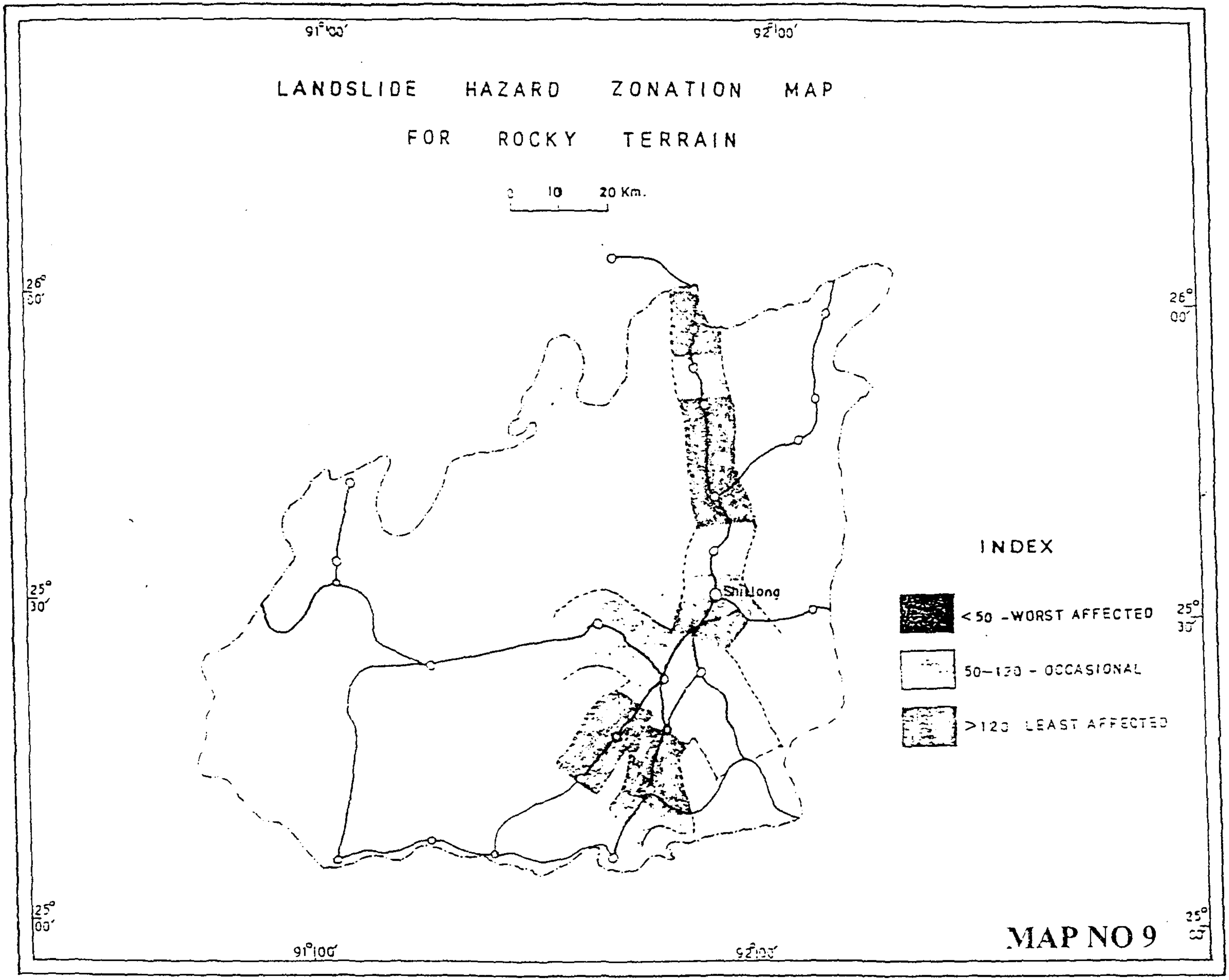
5.3.7 Gouge or infilling material in the joints: As the joint spacings are minimal there is less scope for any foreign material to intrude into the voids between joints. So most of the joints are devoid of any infilling material.

5.3.8 Movement of water within or outside the rock mass: Due to over saturation the rocks are weakened as water seepage takes place through these openings and are exposed to rigorous weathering.

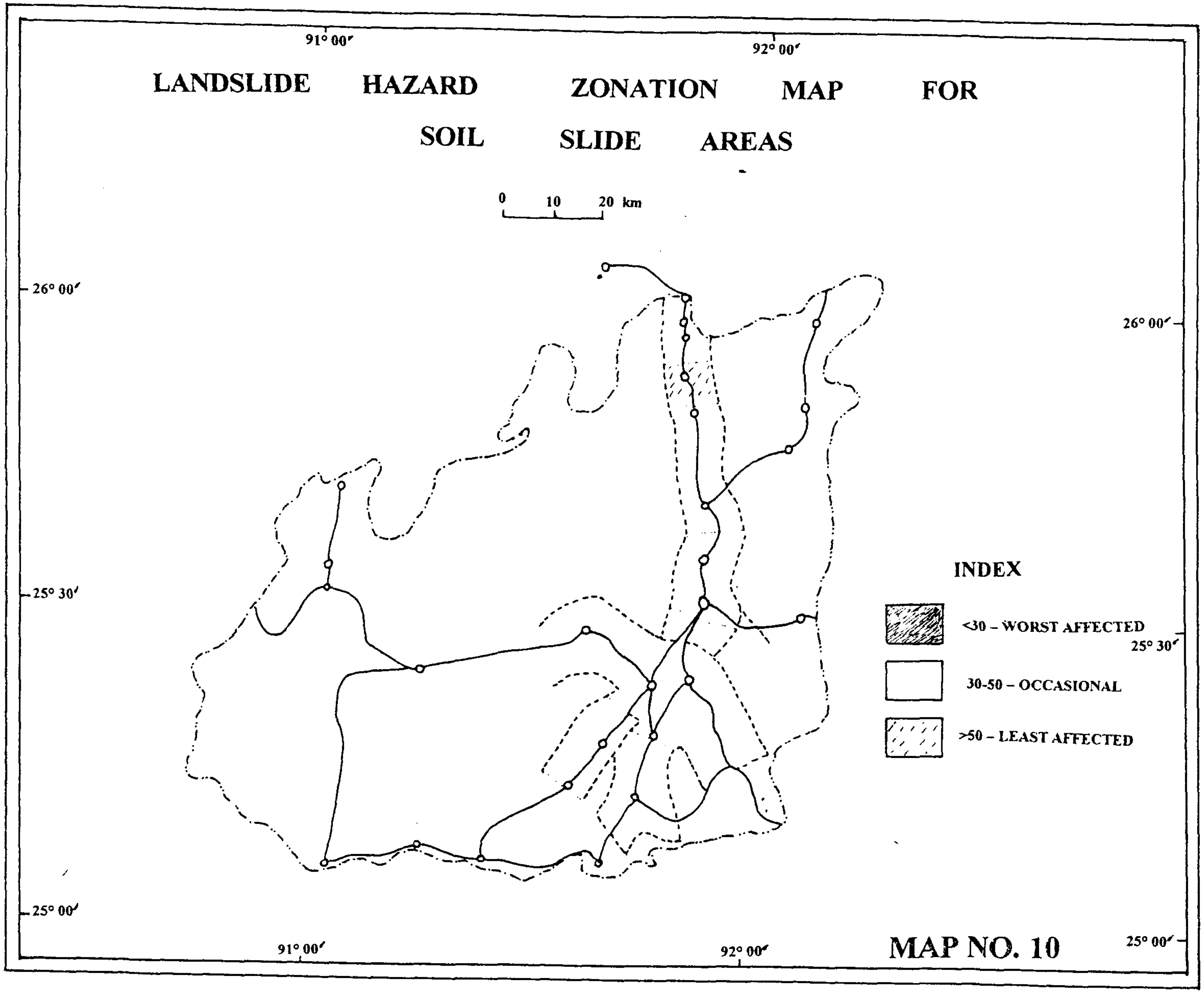
Apart from the above mentioned parameters included by Selby for his classification a few others have been incorporated in the present study to make it broader and more result oriented for the final ratings. They are: Bearing Capacity, Moisture Content, Porosity, Morphometric Analysis: (a) Drainage Density (b) Drainage frequency (c) Relative relief and (d) Slope, Rainfall, Slope Profile Angle and Vegetation.

Each of these parameters have been discussed in detail and their methods of analysis described under relevant headings. From the calculated results of the different parameters under Geo-technical, Geological and Morphometric heads, points were allotted to each one of them according to their weightage (table 42a & 42b) for rocks, and similarly for soil (table 43). Then the total scoring was calculated for each landslide spots (table 44 - 47) and ranking given for the worst affected and the least affected zones in the study area. Subsequently, landslide hazard zonation maps (map 9 and 10) has been prepared for the entire area to demarcate susceptible roadside areas for landslide occurrences in rocky and soil terrains, so that proper management plans could be initiated to minimise the occurrence of landslides in the future.

From Selby's classification rating it has been found out that the least affected area is the road stretch around Jorabat and the highly prone zone is the road stretch around Barapani. Jorabat has suffered the minimum damage since the area is comprised of hard and compact Granite Gneisses. Umling on the other hand has experienced frequent landslides because of excessive water seepage and over saturation of the soils. Here the rocks are highly weathered. Barapani and its adjoining area experience frequent landslips but not on a major scale because of the thick overgrowth of vegetation on the hillslopes. The frequent landslips are attributed to the closely spaced joints in the phyllites which is the major rock type encountered along the highway. At Umtyngar, Laitlyngkot, Umthli, Lumshoshur, Lingkardem, Pynursla and Sohiong the slides are as a result of human interference. Many quarries have come up for extracting boulders and stones used as a building material making the slope unstable and prone to landslides. The vegetative cover is also sparse to moderate out here leading to immediate failure in the form of


91°00'
92°00'
LANDSLIDE HAZARD ZONATION MAP
FOR ROCKY TERRAIN
0 10 20 Km.
26° 00'
25° 30'
25° 00'
Shillong
INDEX
<50 -WORST AFFECTED
50-120 - OCCASIONAL
>120 LEAST AFFECTED
91°00'
92°00'

MAP NO 9



LANDSLIDE HAZARD ZONATION MAP FOR
SOIL SLIDE AREAS
0 10 20 km
91° 00′
92° 00′
26° 00′
25° 30′
25° 00′
INDEX
<30 – WORST AFFECTED
30-50 – OCCASIONAL
>50 – LEAST AFFECTED

MAP NO. 10

rockslides. Mawphlang, in Shillong-Mawsynram road also laments of the same cause- human interference. Here, the Schistose rocks have closely spaced joints which lead to the failure of slopes in the form of landslides along the weak planes very often.

We see a long stretch of landslide prone zone along the road quite frequently blocking the busy road (plate 19). Further south-west, Tyrssad houses massive Quartzites which has suffered little weathering. The landslides here are again initiated due to human interference – stone quarrying. Weiloi has Quartzo-Feldspathic- Gneisses of massive variety and the slides here though are not in large dimensions are prone to future failures due to large scale deforestation and continuous tilling of hillslopes for cultivation. In the soil slide areas, due to the large scale deforestation by humans the top soils has been completely washed away by runoff and hence the soils are easily prone to sliding.

Barapani area, even though it has got thick vegetative cover the rate of sliding is higher since the rocks (phyllites) has been extensively eroded due to large scale weathering. In the Shillong- Mairang road the soil slides are in huge dimensions as the soils in these region are non- plastic in nature. Moreover anthropogenic activities such as building of houses on the slopes by the locals have rendered the hill slopes unstable. The drainage of the rainwater is also not controlled as a result of which the runoff finds its way cutting through the hillslopes and the road making it unsafe and hazardous. There are no retaining walls to protect the soils sliding down and quite often the roads get blocked and traffic movement is hampered. The loose sandstones are grinded and used as an alternative to river sands for construction.

Table 42a :Selby's Rock Rating Weightage

Parameters	Rating	Parameters	Rating
1. Rainfall	*	5. Vegetative Cover	*
		6. Infilling Material	
		Thick Infill	2
2. Bearing Capacity		Thin Infill	1
>300 kN	10		
200-300kN	5	7. Action of Weathering	
100-200kN	3	Unweathered	10
<100kN	1	Moderately Weathered	7
		Highly Weathered	5
		Completely Weathered	1
3. Rock Mass Strength			
100-60 N/mm^2	20	8. Slope Angle	
60-50 N/mm^2	18	<10°	10
50-40 N/mm^2	14	10°-30°	5
40-35 N/mm^2	10	30°-50°	2
35-10 N/mm^2	5	>50°	1
4. Joints		9. Morphometric Analysis	*
i) Joint Spacing			
>3m.	30	10. Water Movement	
3-1m.	28	None	5
1-0.3m.	21	Low	4
300-50mm.	15	Moderate	3
<50mm.	8	Great	1
ii) Joint Orientation		11. Moisture Content	
<10°	20	<0.1%	4
10°-30°	18	0.1-0.2%	3
30°-50°	14	0.2-0.3%	2
50°-70°	9	>0.3%	1
>70°	5		
		12. Porosity	
iii) Joint Width		<0.1%	5
<0.1mm.	7	0.1-0.3%	4
0.1-1mm.	6	0.3-0.5%	3
1-5mm.	5	0.5-1.5%	2
5-20mm.	4	>1.5%	1
>20mm.	2		
		TOTAL RATING - 174	
iv) Joint Continuity			
Non- continuous	7	< 50 – Worst Affected	
Few-continuous	6	50-120 - Occasional	
Continuous		>120 – Least Affected	
(no, thin & thick infill)	5,4,1		

* Refer Table 42b

Table 42b : Selby's Rock Rating Weightage

Parameters	Rating	Parameters	Rating
1. Rainfall - < 2,000 mm	10	9. Morphometric Analysis	
2,000-5,000 mm	5	i) Drainage Density	
5,000-10,000 mm	2	<3	5
>10,000 mm	1	3-6	4
5. Vegetative Cover		6-9	3
No Vegetation	0	9-12	2
Sparse Vegetation	1	>12	1`
Moderate Vegetation	2	ii) Drainage Frequency	
Thick Vegetation	5	<5	4
		5-10	3
		10-15	2
		>15	1
		iii) Relative Relief	
		<100	10
		100-200	9
		200-300	8
		300-400	7
		400-500	6
		500-600	5
		600-700	4
		700-800	3
		>800	2
		iv) Average Slope	
		<10°	10
		10°-20°	8
		20°-30°	6
		30°-40°	4
		40°-50°	2
		>50°	1

Table 43: Selby's Soil Rating weightage

Parameters		Rating
1. Rainfall -	< 2,000 mm	10
	2,000-5,000 mm	5
	5,000-10,000 mm	2
	>10,000 mm	1
2. Vegetative Cover		
	No Vegetation	0
	Sparse Vegetation	1
	Moderate Vegetation	2
	Thick Vegetation	5
3. Sieve Analysis		
	Silt and Clay	10
	Sand	5
	Gravel	1
4. Slope Angle		
	<10°	10
	10°-30°	5
	30°-50°	2
	>50°	1
5. Moisture Content		
	<5%	5
	5-10%	4
	10-15%	3
	15-20%	2
	>20%	1
6. Liquid Limit		
	>90%	4
	60-90%	3
	30-60%	2
	<30%	1
7. Plastic Limit		
	>90%	4
	60-90%	3
	30-60%	2
	<30%	1
8. Infiltration Rate to penetrate 1 cm.:		
	>5min	4
	3-5min	3
	1-3min	2
	<1min	1

Parameters		Rating
9. Morphometric Analysis		
i) Drainage Density		
	<3	5
	3-6	4
	6-9	3
	9-12	2
	>12	1
ii) Drainage Frequency		
	<5	4
	5-10	3
	10-15	2
	>15	1
iii) Relative Relief		
	<100	10
	100-200	9
	200-300	8
	300-400	7
	400-500	6
	500-600	5
	600-700	4
	700-800	3
	>800	2
iv) Average Slope		
	<10°	10
	10°-20°	8
	20°-30°	6
	30°-40°	4
	40°-50°	2
	>50°	1
TOTAL POINTS -76		
<30 – WORST AFFECTED		
30-50 - OCCASSIONAL		
>50 – LEAST AFFECTED		

TABLE 44: ANALYTICAL RESULTS OF GEOLOGICAL,GEOTECHNICAL AND MORPHOMETRIC PARAMETERS

LANDSLIDE SPOTS	GEOLOGICAL PARAMATERS							GEOTECHNICAL PRAMATERS				MORPHOMETRIC PARAMETERS				RAINFALL (mm)	WEATHERING	SLOPE ANGLE (°)	VEGETATIVE COVER
	RT	JS (cm)	JO (°)	JW (cm)	LVJ	IM	WM	BC (KN)	MC (%)	RMS (N/mm^2)	P %	DD	DF	RR (m)	AS (°)				
JORABAT	QFG	M	0	0	NC	–	MD	330	0.06	70	0.27	<3	<5	200-300	20-30	<2000	UW	52	MD
UMLING	G	M	0	0	NC	–	MD	40	0.08	20	0.32	3--6	5--10	100-200	10--20	2000-5000	HW	55	MD
BARAPANI	Phy	5--10	25-32	0.2-0.3	C	Tc.I	G	42	0.81	25	2.77	3--6	<5	300-400	30-40	2000-5000	HW	82-85	HIGH
LAITLYNGKOT	K.G	47-55	75-80	1-2	C	T.I	MD	164	0.14	54	1.29	3--6	5--10	<100	10--20	2000-5000	MW	70-75	SPARSE
UMTHLI	Qtz	45-52	80-VT	1-2	C	T.I	MD	160	0.10	52	1.09	6--9	10--15	100-200	20-30	2000-5000	MW	75-80	SPARSE
LUMSHOSHUR	Phyl	50-60	67-72	1-2	C	T.I	MD	162	0.09	59	1.12	3--6	5--10	100-200	20-30	2000-5000	MW	65-70	MD
LINGKARDEM		55-62	62-70	1-2	C	T.I	MD	162	0.11	55	1.33	3--6	<5	300-400	30-40	2000-5000	MW	67-72	MD
PYNURSLA	Qtz	55-65	60-70	1-2	C	Tc.I	MD	165	0.11	54	1.26	6--9	5--10	400-500	20-30	2000-5000	MW	65-70	SPARSE
UMTYNGAR	G	30-50	60-75	1-2	C	T.I	MD	317	0.02	90	0.45	6--9	5--10	<100	10--20	2000-5000	MW	55-65	SPARSE
MAWPHLANG	Sht	60-75	75-80	1-2	C	T.I	MD	305	0.13	79	1.27	6--9	5--10	100-200	10--20	2000-5000	MW	70-75	MD
TYRSSAD	Qtz	M	0	0	N.C	–	MD	175	0.16	63	1.36	6--9	10--15	<100	10--20	2000-5000	MW	55	MD
WEILOI	QFG	M	0	0	N.C	–	MD	167	0.17	67	1.39	3--6	<5	300-400	20-30	2000-5000	MW	53	MD
SOHIONG	Qtz	70-85	60-65	1-2	F.C	Tc.I	G	208	0.15	62	0.92	6--9	5--10	<100	10--20	2000-5000	MW	60-67	SPARSE

R.T.- ROCK TYPES, J.S.-JOINT SPACING, J.O.- JOINT ORIENTATION, J.W.-JOINT WIDTH, L.V.J.- LATERAL VERTICAL CONTINUITY OF JOINTS, I.M.-INFILLING MATERIAL,
W.M.-WATER MOVEMENT, B.C.- BEARING CAPACITY, M.C.- MOISTURE CONTENT, R.M.S.- ROCK MASS STRENGTH, P.- POROSITY,
D.D.- DRAINAGE DENSITY, D.F.- DRAINAGE FREQUENCY, R.R.- RELATIVE RELIEF, A.S.- AVERAGE SLOPE
Q.F.G.- QUARTZO FELDSPATHIC GNEISS, Gr.-GRANITE, Phyl.-PHYLLITE, Qtz.- QUARTZITE, K.G.- KHASI GREENSTONE, Sht.- SHIST
M- MASSIVE, F.C.& N.C.-FEW & NON-CONTINUOUS(C), Tc.I-THICK INFILL, T.I-THIN INFILL, MD-MODERATE, G-GREAT, HW,MW,UW-HIGHLY,MODERATELY & UNWEATHERED

Table 45: **Analytical Results of Soil Slide Parameters**

Landslide Spot/ Parameters	Geotechnical M.C. (%)	I.R. cm/m	L.L. (%)	P.L. (%)	S.A.	Sl.An. (in °)	Morphometric Analysis R.F. (in mm.)	D.D.	D.F.	R.R.	A.S. (in °)	V.C.
Jorabat	19.3	<1	37.43	32.37	Medium Sand	47	< 2000	<3	<5	200-300	20-30	Mod
Byrnihat	17.3	<1	35.47	31.29	Fine Sand	45	< 2000	<3	<5	<100	<10	Mod
Nongpoh	18.7	<1	38.46	32.17	Fine Sand	52	2000-5000	3--6	5--10	100-200	10--20	Thick
Umsning	19.8	<1	40.1	33.17	Medium Sand	61	2000-5000	6--9	5--10	<100	<10	Thick
Barapani	4.55	1--3	19.12	24.05	Fine Sand	70	2000-5000	3--6	<5	300-400	30-40	Thick
Mawiong	27.8	<1	41.93	34.33	Fine Sand	42	2000-5000	3--6	5--10	100-200	20-30	Mod
Ladmeri	6.11	1--3	29.51	28.7	Very Coarse S.	65	2000-5000	6--9	5--10	<100	10--20	Sparse
Manai	5.99	1--3	24.2	32.59	Fine Sand	57	2000-5000	3--6	5--10	100-200	10--20	Mod
Mairang	5.16	1--3	25.67	29.6	Very Coarse S.	61	2000-5000	<3	<5	<100	10--20	Mod
Umtyngar	9.54	1--3	22.62	26.25	Very Coarse S.	62	2000-5000	6--9	5--10	<100	10--20	Sparse

M.C.-Moisture Content, I.R.- Infiltration Rate, L.L.- Liquid Limit, P.L.- Plastic Limit, S.A.- Sieve Analysis, Sl.An.- Slope Angle, R.F.- Rainfall, D.D.- Drainage Density, D.F.- Drainage Frequency, R.R.- Relative Relief, A.S.- Average Slope, V.C.-Vegetative Cover, Mod.- Moderate

TABLE 46: ROCK SLIDE RATING

	PARAMETERS																		
LANDSLIDE SPOTS	J.S.	J.O.	J.W.	J.C.	I.M.	W.M.	B.C.	M.C.	R.M.S.	P	D.D.	D.F.	R.R.	S	R.F.	W	S.A.	V.C.	TOTAL POINTS
JORABAT	30	20	7	7	2	3	10	4	20	4	5	4	8	6	10	10	1	2	153
UMLING	30	20	7	7	2	1	1	4	5	3	4	3	9	8	5	5	1	2	117
BARAPANI	15	18	5	1	2	1	1	1	5	1	4	4	7	4	5	5	1	5	85
LAITLYNGKOT	21	5	4	4	1	3	3	3	18	2	4	3	10	8	5	7	1	1	103
UMTHLI	21	5	4	4	1	3	3	3	18	2	3	2	9	6	5	7	1	1	98
LUMSHOSHUR	21	5	4	4	1	3	3	4	18	2	4	3	9	6	5	7	1	2	102
LINGKARDEM	21	9	4	4	1	3	3	3	18	2	4	4	7	4	5	7	1	2	102
PYNURSLA	21	9	4	4	2	3	3	3	18	2	3	3	6	6	5	7	1	1	101
UMTYNGAR	21	5	4	4	1	3	10	4	20	3	3	3	10	8	5	7	1	1	113
MAWPHLANG	21	5	4	4	1	3	10	3	20	2	3	3	9	8	5	7	1	2	111
TYRSSAD	30	20	7	7	2	3	3	3	20	2	3	2	10	8	5	7	1	2	135
WEILOI	30	20	7	7	2	3	3	3	20	2	4	4	7	6	5	7	1	2	133
SOHIONG	21	9	4	6	2	1	5	3	18	2	3	3	10	8	5	7	1	1	109

J.S.-JOINT SPACING, J.O.- JOINT ORIENTATION, J.W.-JOINT WIDTH, L.V.J.- LATERAL VERTICAL CONTINUITY OF JOINTS, I.M.-INFILLING MATERIAL,
W.M.-WATER MOVEMENT, B.C.- BEARING CAPACITY, M.C.- MOISTURE CONTENT, R.M.S.- ROCK MASS STRENGTH, P.- POROSITY,
D.D.- DRAINAGE DENSITY, D.F.- DRAINAGE FREQUENCY, R.R.- RELATIVE RELIEF, A.S.- AVERAGE SLOPE, V.C.- VEGETATIVE COVER
R.F.- RAINFALL, W- WEATHERING, S.A.- SLOPE ANGLE

Table 47: Soil Slide Rating

Landslide Spot/ Parameters	Geo-Technical M.C.	I.R.	L.L.	P.L.	S.A.	Morphometric Analysis Sl.An.	R.F.	D.D.	D.F.	R.R.	A.S.	V.C.	Rating
Jorabat	2	1	2	2	5	2	10	5	4	8	6	2	49
Byrnihat	2	1	2	2	5	2	10	5	4	10	10	2	55
Nongpoh	2	1	2	2	5	1	5	4	3	9	8	5	47
Umsning	2	1	2	2	5	1	5	3	3	10	10	5	49
Barapani	5	2	1	1	5	1	5	4	4	7	4	5	44
Mawiong	1	1	2	2	5	2	5	4	3	9	6	2	42
Ladmeri	4	2	1	1	5	1	5	3	3	10	8	1	44
Manai	4	2	1	2	5	1	5	4	3	9	8	2	46
Mairang	4	2	1	1	5	1	5	5	4	10	8	2	48
Umtyngar	4	2	1	1	5	1	5	3	3	10	8	1	44

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Chapter 6

Mitigation and Management of Landslides

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6.1 Disaster Management

All matters pertaining to natural disaster relief at the central level are dealt with by the Department of Agriculture and Co-operation (DAC) in the Union Agriculture Ministry. The Relief Commissioner in the DAC is in charge for coordinating relief operations intended for all natural disasters. He continuously receives information relating to forecast or warning of calamities from the Director General, Indian Meteorological Department or the Central Water Commission. He not only monitor the developments but also provides the feedbacks to concerned quarters. There are committees and groups like Cabinet committee, National Crisis Management committee and Crisis Management group. At the state level, the states have their own Relief Commissioners. There is a State Crisis Management Group comprising senior officers of the important departments to consider the infrastructures and guidance received, from time to time, from Government of India and formulate action plans to deal with natural disasters. The states are divided into districts and each district is headed by the Deputy Commissioner who is further assisted by the Additional Deputy Commissioner, District Revenue Officer and other district level officers, Sub-Divisional Officers, Tehsildars, Naiv Tehsildars and other subordinate staff. A control room is set up at the district level to monitor day to day rescue and relief operations. The Deputy Commissioner directs, supervises and monitors relief measures for disasters. He also maintains close liaison with the Central Government authorities and co-ordinates all governmental and non-governmental efforts in disaster situations. Although the Crisis Management Group has pre-set plans for disasters and accordingly medical personnel and army are deployed immediately but we don't have special commandoes equipped with latest search and rescue technology.

A high power committee to prepare Disaster Management plan for the country was set up by the Government of India in August 1999. Its terms of reference was modified in February 2000 to include all types of disasters. The committee submitted its interim report and suggested that the district plan would be the main plan to deal with disasters to which the district is prone. The district plan would include prevention, mitigation and preparedness and response plan for the district as a whole. The state level plans will layout state wise or region wise prevention plan and prevention strategy, mitigation plan and mitigation strategy, preparedness plan and response plan. The national plan will primarily be a response plan having prevention plan of inter-state and sub-continental features, prevention strategy of inter-state and international issues mitigation plan and mitigation strategy of inter-state and international issues, preparedness plans at the national level and South Asian Association for Regional Co-operation (SAARC) and international initiatives.

The high power committee has suggested that schools, colleges and universities should be integrated with disaster preparedness and response mechanism. Besides, it also suggested involvement of NGOs, CBOs, PRIs etc. to minimise response time, the committee advocated establishment of a civil defence warden system involving panchayat members as wardens and providing communication network through wireless stations and radio systems. Another important suggestion given by the committee is a State Disaster Management Act similar to that of the Representation of Peoples Act providing overriding powers to the government so as to deal with the crisis situations.

6.2 Disaster Preparedness

It is the management planning for a prompt and efficient action at all levels to save lives, to reduce sufferings and to minimize damage to property, when a natural disaster occurs (Eistein, 1987). A comprehensive effort for disaster preparedness includes public education, awareness campaigns, organization of people, disaster training preparing evacuation plans and providing evacuees with emergency food, water and shelter. Such an effort may be helpful in reducing the loss of life due to natural calamities. The pre-disaster preparedness period is more important than the post disaster one. During the disaster period, there is no substitute for self-help in the sense that one cannot rely on outside help as communication systems outside might have been disrupted due to the calamity. When information reaches outside the affected area, people rush to help the victims, but by the time external aid comes in, the victims should help themselves. Survivors in the disaster stricken area should begin search and rescue operations helping the injured on their own. The struggle for survival needs to be encouraged and for this public awareness and community education are a must. Disaster preparedness and evacuation can reduce causalities, epidemic and damage to property and the impact associated with the disaster.

6.3 Disaster Prediction

The Doppler Radars Geo-stationary weather monitoring satellites have greatly advanced the ability to predict weather related disasters and have lengthened the time between warning the disastrous consequences.

The entire forecast relies on a mathematical model or an empirical understanding of the physical phenomenon. The weather patterns provides the knowledge that can be continuously updated with observations. These observations and the mathematical models track the progress of storms. As the model improves, the accuracy of the predictions or forecast of storms will also improve. Early warning systems are part of the preparedness measures of any disaster prone country. The Government or Meteorological Department and other specialized organizations of the Government generally make these warnings. Warning systems has three components:

a) Prediction based on scientific analysis.

b) Decision on when to work

c) Communication warning

6.4 Role of Science and Technology in Natural Disaster Management

The advancement of science and technology by leaps and bounds is a boon to mankind, if utilized properly. The application of science and technology for reducing and managing disaster is being implemented through ways targeted at promoting research and strengthening institutional capabilities for technology, development, education and training (Carrara and Meranda, 1976). To achieve this end, available scientific and technological knowledge is being optimally used as seen from the vulnerability analysis, hazard evaluation, risk mapping and disaster reduction projects.

Landslides belong to that family of short-lived and unexpectedly occurring phenomenon that comprises catastrophic Geology (Pachauri, 1984). They cause extensive damage to roads bridges, human dwellings, agricultural lands, orchards, forests, etc. resulting in loss of property as well as life. Economical degradation of hilly areas has also been increasing due to greater frequency in the occurrence of landslides. Landslides are branded in nearly all terrains and can occur in different climates and in most assemblages of earth materials (Chnsankar, 1982). All that is needed for their formation is a sufficiently strong triggering mechanism to overcome the natural stability of the rock and soil. When this shear resistance threshold is exceeded, landsliding results and it can take a variety of movements and forms.

Several organizations in India are engaged in research and developmental activities in the landslide prone areas. Mention can be made of the Central Road Research Institute, New Delhi, Geological Survey of India, Border Roads Organization, Central Building Research Institute, Roorkee, Wadia Institute of Remote Sensing, Dehradun, IIT, Mumbai.

Integrating multiple databases e.g. topographical maps, geological maps, remote sensing data, and the geo-technical investigations may delineate landslide prone areas. Hazard Zone Mapping (HZM) is relatively new concept (Pant, 1992) being used for landslide forewarning. Because of the large extent of areas susceptible to landslide hazard, the HZM would need the involvement of many organizations. Efforts should be made to standardize the methodology adopted for HZM.

6.5 Landslide Assessment, Prevention and Control

Geological engineering and designs and solutions for the remedy of landslide problems need a strong database to determine, which control and prevention methods are most appropriate. Detailed studies are necessary to access and calculate such factors as the size and shape of the unstable mass, the nature and composition of the rock types and their structures, the attitude of joints and bedding features and the water characteristics of the area. Thus a combination of Geologic, Geomorphic and Geotectonic studies with soil and rock mechanics is necessary. These data can then be evaluated in terms of a total benefit – cost ratio for the project to determine the level of safety index – the quantitative analysis of the resistive forces versus the shearing forces. When this ratio is 1.0, the area is stable, but generally a safety of more than one is necessary and desirable.

6.5.1 Earth Materials

Cohesive fine grained soil and sediments become saturated. These materials are especially sensitive when disturbed by the removal of vegetation or by excavation.

The following features were prominent in the study area.

* Unconsolidated materials with low shear strength readily changing to new angles of repose.
* Inclined Bedding, Foliation and Schistosity dipping towards the highway.
* Decomposed crystalline rocks that are susceptible to a large increase in moisture content. Weathering of such rocks has quickly reduced their shear strength to critical limits.
* Fracture systems that possess low strength and acted as media for rapid water infiltration and lubrication.
* Unfavourable rock sequences wherein the various units easily uncoupled and moved differentially.

6.5.2 Water conditions

During field work in landslide areas it was noticed that groundwater was seen seeping through the soil or rocks in most of the landslide prone zones of the study area indicating they are under high pore water pressure.

Landslide is a phenomenon, which is by and large associated with developmental (constructional) activities leading to the modifications of the slope segments particularly making the profiles steeper in sections. This often causes slope instability with a tendency to fall as and when the equilibrium is disturbed. The landslides prone areas are conspicuously confined mainly within the Shillong Group of rocks in the study area especially where the dips are steeper.

6.5.3 Anthropogenic Causes of Landslides: In the state of Meghalaya, the developmental activities are mainly concentrated along the main roads. Therefore the incidences of landslides are also concentrated primarily within these areas. The rocks present in the study area are extensively used by the local people. So innumerable rock-quarries are seen along the highways and other accessible areas. The Quartzite, which forms the country rock of the area, is quarried in many places and extensively used as building material. They are fairly hard and compact as revealed by the strength tests carried out by the researcher. They are used in constructional works alternative to bricks after cutting them to proper sizes. It is interesting to note that the culverts and bridges of most of the motorable roads are made up of this rock. The very hard varieties are found to be useful as road materials. Steep and unstable slopes have been initiated from the quarrying of Quartzites, and we have seen that most of the landslide prone zones are Quartzite bearing including Tyrssad, Sohiong, Weiloi, Laitlyngkot, Umthli, Lumshoshur, Lingkerdem and Pynursla.

However, the places where the Shillong Group of rocks have horizontal to sub-horizontal disposition and the slope segments gentler, the landslides are rare or absent. But along steeper slopes and steeper dips the rocks fail at times during rains in vicinity of settlements. It is due to the exposure of bedding and joints by excavations for constructional purposes along which the rock fails due to increased pore water pressure especially during monsoon.

Another factor for the frequent occurrence of landslides along the highways is that roads have been constructed without due recognition of the slope profiles and other 'Geo-technical' properties of rocks where landslides and slumps are frequently associated with them. Abrupt steep slope cuts in excess of 60° all along the road networks have made the slope profiles unstable that cause frequent landslides.

Thus we see that maximum landslides in Meghalaya are the result of unplanned development ignoring geomorphic characteristics of the terrains. Suitably modifying road alignments and grading the slope profiles could avoid them. It will also reduce the heavy expenditure been incurred on the maintenance of landslide prone road sections.

6.6 Geo-Environmental Degradation

The onset of different kinds of geohazards in an area is an indication that the environmental degradation of that particular area has started. The study of causative factors of degradation and their mitigation is primarily a part of geoenvironmental management.

'Environmental Management' is essentially a process of rational utilization of natural resources and their conservation practices. It just not ends in recognizing the need to protect environment but goes beyond it. It integrates the need of man's sustenance with his environment. Environmental management considers ecological conservation along with natural resource development as environmental and socio-economic problems that cannot be tackled in isolation. The need to coordinate and integrate approaches for natural resources management is increasingly being recognized. The resource utilization always has multiple objectives with conflicting interests. As a result, the interrelationship between environment and man becomes very complex and requires management strategies that integrate different perspectives, mediate competing conflicts and interests and coordinate actions in a unified way. The whole concept of environmental management tends to transform the 'predator'man into a 'conservator' man.

The environmental perceptions have changed considerably since United Nation's (UN) conference on human environment held in Stockholm (1972). The paradigm has shifted from 'development only' or 'exploitation only' to 'sustainable development'. The concept of sustainable development was spawned in mid 1960's and has become a main feature of UN's development and environment philosophy. The emergence of the concept of sustainable development in recent years has brought in general realization that social perceptions must shift towards ecological compatible and qualitative growth within the limits of the ecosystem's carrying capacity. It implies that a regional environment has only limited assimilative and supportive capacities to developmental process. This forms the pivot around which environmental management must move.

The use of biosphere is punctuated with two inescapable facts. The first is that the biosphere's capacity to tolerate the human impact is finite. The second is that the ability of the earth's natural system to tolerate different types of impact varies from place to place. Therefore, geo-environmental characterization becomes an important component in an environmental management scheme. The sustainable development must possess both economic and ecologic sustainability. It enforces optimal utilization of natural resources. If somehow difficulty arises in the optimization process, this is due to the lack of or limited understanding of the causes and consequences of environmental degradation. Therefore, it is the prerequisite of environmental management to have Geo-environmental characterization of a terrain through which the targets of sustainable development can be achieved. Therefore the inventory of the natural resources as well as identification of different Geo-hazards or geomorphic risks and their causative factors in a terrain has to be evaluated for environmental characterization.

The definition of a natural hazard may be given as an unforeseen disaster causing extensive damages to lives and properties within a short period of time. Every natural earth processes operating may take the form of a hazard at a certain time especially when it assumes or activates at a larger dimension or magnitude. A natural hazard comprises of floods, cyclones, mass movements, volcanic eruptions, desert locusts and earthquakes. Their occurrences are beyond the control, experience, expectations and predictive power of man because of their extra-ordinary suddenness, enormous magnitude and restricted spatial occurences.

Among the natural hazards mass movement is considered one of the most important catastrophic processes involving the modification of surface morphology. The phenomenon of weathered surfacial material moving down the slope by gravity is termed mass movement. It comprises all gravity induced movements, such as landslides, creep, rockfalls, mudflows, earthflows, avalanches and even the falling of boulders. Mass movements are important occurences in all climatic regions but their greatest frequencies are recorded in humid regions. The rate of mass-movement may be rapid (landslides, avalanches, etc.) or extremely slow (soil creep), so slow as to be almost imperceptible to human observations without the aid of sensitive and sophisticated instruments.

Slope, climate, lithology of the area and seismic activities are the principal natural factors that lead to landsliding. But now, with the instantaneous increase in intensity and various developmental activities propagated by man in the mountainous areas, the causes for landslides are becoming more anthropogenic than any other natural ones. With a total neglect towards ecology and nature, man himself has generated the phenomenon of landslides and has become their victim.

Throughout the present century mountainous regions all over the globe have been experiencing an increasing trend of man-nature interaction leading to disastrous consequences. This is noticed through the spread of settlements, extension of transport facilities, degradation of forests for cultivation and construction of vast reservoirs for irrigation and production of hydro-electric power in the mountainous areas. Disregarding the dynamic stability in the ecological balance existing in nature, man, through his rapid and unplanned activities, has triggered off a number of landslides. Of the various human activities those that are related to the developmental processes are the most potent in causing these hazards. The increasing momentum of these developmental activities enlarges the potential scale of damage to life and property and also to the ecological resources.

This man-nature interaction is brought out most dramatically along the mountain roads because it is here that mankind emerges as ecologically dominant being within a relatively short period of time. To construct and then to subsequently widen the roads he mercilessly and unscientifically blasts the rocks without taking care of the stability of the slopes. Quarrying near the roadside slopes further weakens and softens the rockmass strength, which during heavy downpour (rainy season) saturate with water and slides down in the form of landslides.

Introducing these higher levels of abstractions of the relationship between development and landslides to north-east India and more particularly to the state of Meghalaya, it can be concluded that landslide occurences are more numerous during the post independence period than during the pre-independence period (Saikia, 1997). It is here that man through his developmental activities has weakened the hillslope by cutting the rocks and felling the trees for a wide range of construction purposes. High rainfall and enormous weathering activity along the highways have aggravated the problem of these hazards.

In spite of this bitter truth dangerously unstable slopes are being occupied and terraced, forests are being cut and roads are being constructed with very little concern for the fragile environment

6.7 Mitigation Measures

In any disaster situations, a quick rescue and relief mission is inevitable, however considerable damage can be minimized if adequate preparedness levels are achieved. Going along this trend, the disaster management setup in India, in the recent years has oriented towards a strong focus on preventive approaches, mainly through administrative reforms and participatory methods.

The stabilization of landslides must be executed through proper layout plans, which lists the individual tasks in order. A careful survey and cause (analysis of the slides) should be made. Depending upon that the rehabilitation should be undertaken. There are several methods that can singly or in combination offer desirable solutions.

6.7.1 Treatment of Slope Shape: The stability of slopes can be substantially increased by reducing the load of soil at the crown or by its enlargement at the toe of the landslide. According to estimates if 4% of scrapping mass volume is displaced, its stability is increased by 10%.

These methods are used when an exceptionally dangerous condition has developed or failure has already occurred, and when the slide area is small or of modest size. Thus man made cuts are deliberately produced for the purpose of changing the slope geometry and reducing shear stress of the materials.

1) Removal of Slide: This can only be done for small slides or those where the expense can be justified on a benefit –cost ratio. It guarantees safety.
2) Unloading head of the slide: This method is only usable where there is easy access to the upper part of the slide and for those landslides that move because of such superimposed pressure, as in various types of slumps on the NH-40 near Barapani.
3) Regrading and slope reduction: Such methods may be helpful when it has been determined that slope irregularities are the principal cause for building up stress differentials that can lead to landsliding. Slope changes also provide better drainage and equalization of pore-water pressure.
4) Hillside benching: Construction of man made terraces and berms can be effective in reducing the landslide hazard in some instances. Such methods are used when the slopes are especially long or steep and the toe of the slide has been undercut or altered. Benches prevent the buildup of slope-long stresses; but they should be designed for easy maintenance and coupled with drainage ways to divert water from collecting.
5) Balance Moments: In this method upslope area is brought to pre-cut stability by removing additional material on top of landslides. The

volume removed should be roughly equal to volume originally excavated in the cut.

Advantages of this method are:

i) No laborious masonary and concreting works are necessary

ii) It can be started immediately without previous time consuming research work.

However in the cutting of communication and canals or in the case where the landslide toe cannot be loaded, unloading the upper part can stop the slope movement. The treatment of the slope shape should be designed simultaneously with the sub-drainage.

6.7.2 Drainage of Landslides

With the arrangement of a proper drainage network thus regulating the flow of water the landslide occurrences can be minimized.

6.7.2.1 Surface Drainage: In dealing with surfacial water, the strategy is to prevent it from entering the landslide area whenever possible and to drain off all water that is on the ground. Surface ditches, circumferential around the crown of the slide, divert the sheetwash that would otherwise enter the slide area and produce a water surcharge on the unstable materials. Moisture can be kept out of upslope or downslope areas, by installing near horizontal wells.

Ditches and collector system on the slide may also be used to drain ponds and remove standing water. Some slopes may be regarded to allow more uniform drainage from fragile and to prevent its impoundment on the land surface. Cracks and other openings are to be filled with grouting or sealant to prevent water penetration into regolith or bedrock. Sealants include such impermeable materials as clay, concrete or bitumen. In exceptional cases, the entire slide area may be paved to allow rapid runoff and to prevent percolation.

When landslide takes place, the stabilization requires difficult and expensive treatment and if it occurs during construction of major projects like roads (plate 19), the work is jeopardized and losses caused by delay in the construction deadline occur. The question often arises whether the failure could have been prevented. So a careful design to exclude risk of landslide event at a cost of a large increase in expenses is advisable.

In order to prevent failures systematic engineering geological investigations, careful selection of sites for construction, perfection of the design at the earth work and suitable technique of construction should be undertaken.

The Geological investigations include the classification of rock and soil materials comprising slope and investigation of structural defects like bedding, joints, faults and their orientation in relation to the slope. The site location of engineering structural features should be based on geological consideration.

The suspicious slopes should be investigated to determine if there are loads threatening the stability of slopes (plate 20a & b) and whether lateral support has been or is going to be removed. The excavation design and fills in the areas susceptible to sliding should follow the rule that toe of the slope should remain weighted as far as possible.

. Till now no proper drainage has been provided for the runoff to drain down. The lack of proper drainage will continuously affect the hillslopes and make it more landslide prone. If the drainage system is scientifically designed and provided, future chances of landslides will definitely decrease.

Plate 19 Abrupt steep slope cuts of more than 60° all along road networks have made the slope profile unstable.

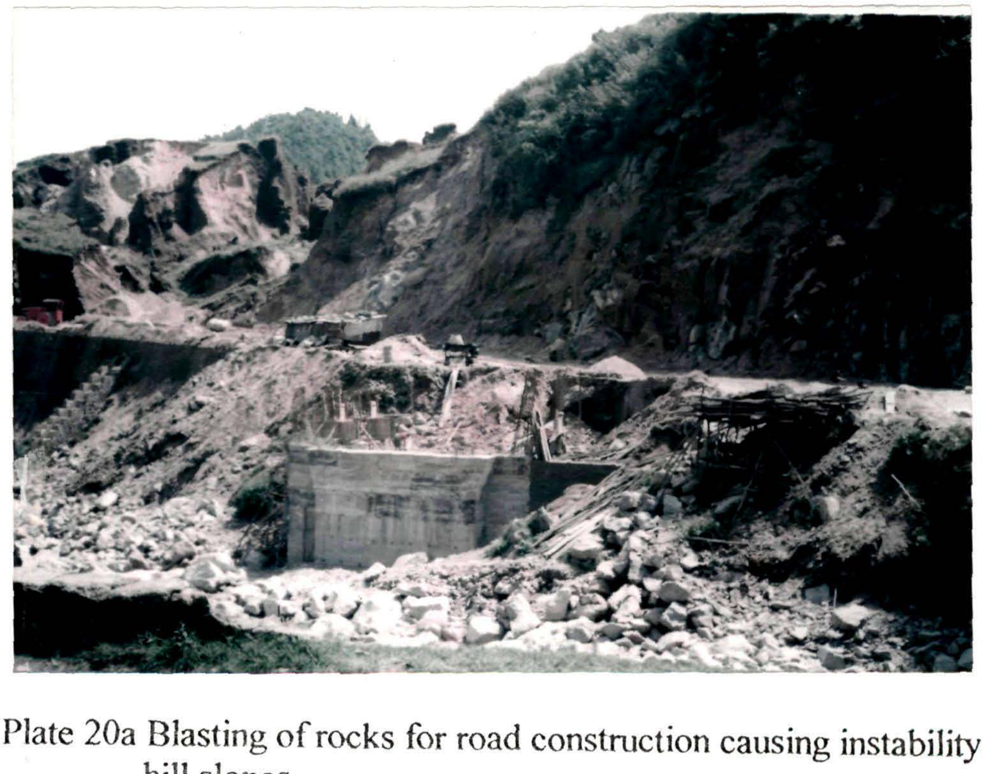

Plate 20a Blasting of rocks for road construction causing instability of hill slopes.

The detrimental loads should be prevented from being placed and should be removed if already placed. A better one with proper compaction may replace weak material at the foot of a slope. Proper design of preventive drainage based on careful observations should be constructed.

The surface area affected by sliding is generally uneven, and transversed by deep fissures. In depressions and fissures water accumulates and wet ground develops. Since water is practically a contributing factor to slides, thorough drainage may substantially help in controlling the slide.

First, all streams and temporary water courses should be prevented from entering the threatened area and all the springs within the slide area, especially at its crown, must be entrapped and developed outside the slide. This can be done by using surface pipes.

After a partial stabilization, open ditches of adequate dimensions and gradient are excavated for discharging rainwater. At the same time, the ground surface should be trained and drainless depressions and all cracks filled so as to ensure a continuous runoff of the surface water. During this treatment the grass cover should not be disturbed, as it decreases the possibility of water percolation. The ditches should be provided with impervious pavements. These paving should be well maintained.

6.7.2.2 Subsurface Drainage

For managing subsurface waters, the technique is to dewater the earth materials whenever possible and to lower the water table and pressure head when appropriate. There are a variety of ways for accomplishing this. Galleries and tunnels can be effective if size and cost are not important considerations. Horizontal drains and tile can also be installed near the surface. These are especially effective in granular, highly permeable

Plate 20b Cutting of slopes for constructional purposes (human settlement).

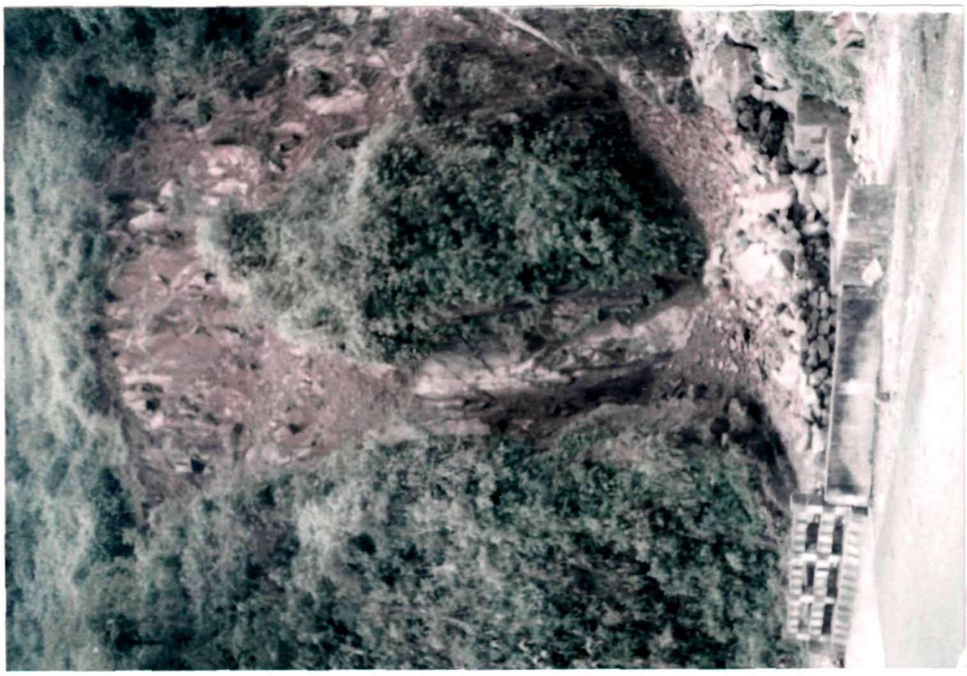

Plate 21 Over saturation of earth materials due to excessive precipitation leads to slope failure.

materials. In some cases pumping or collection of water by vertical drains, holes and wells is necessary. These devices act as pumps for water removal. Occasionally, a continuous siphoning system can be installed especially in permeable aquifers. In other instances, pipes and trenches may be used to divert underground water away from the hazardous area.

As the ground water is one of the major causes of slope instability (plate 21), the subsurface drainage is a very effective remedial measure. A drained slope remains at steeper angle than an undrained one. The disadvantage of the sub-drainage is that it can be designed only after geological and hydrological studies are conducted and therefore it enters into operation belatedly.

Vertical exploration borings arranged as pumping wells and older wells if existing at the locality should be immediately exhausted. With the increasing density of exploration and pumping holes network, the geo-technical, hydrological conditions of the area become clearer and serve basis for the proposal of definitive drainage measure. These include use of galleries and horizontal drainage. The most conventional is the long horizontal drainage boring which intercept ground water by insisting perpesated tubes into the ground.

6.7.2.3 Stabilization by vegetation

Slope movements generally disturb vegetation cover. The afforestation of the slope is an important task of corrective treatment. It is carried out during the last stage, or after partial stabilization of the landslide. The afforestation helps in two ways – drying out the surface layer and their consolidation by a network of roots, which prevents formation of shrinkage cracks. Most suitable for plantation are those that have the largest consumption of water and highest vegetation. Therefore, it is more advantageous to plant deciduous trees (alders, poplass, urillows, ash trees, birches) than conifers.

Scientists systematically studied the influence of vegetation on sliding movements and maintained that in selecting suitable trees for sliding scopes, their effects on soil structure should also be taken into consideration. For this reason, spruces should not be planted which more over have only shallow roots and by their relatively rapid growth increases the loading of slope.

6.7.2.4 Retaining Walls

There are almost an infinite variety of styles and materials that can be used in attempts to dam the downslope movement of a landslide. Such structures are also called dikes, cribs, bulkheads and walls, but their purpose is always the same – to impede motion of an unstable area. They can be composed of timber, concrete, stone, gabions (wire networks filled with stone rubble), grout, metal ribbing and other types of fencing. Retaining walls are restricted to small areas and their effectiveness is generally limited. To be successful they must be anchored with tie rods to adjacent stable terrain, and the backside must contain adequate drainage to divert water buildup.

The height of the retaining walls should be decided only after calculating the risk factor for the particular landslide spot where it has to be provided. When such basic things are not taken into consideration the walls are unable to hold the load/ pressure of the slopes for long and finally collapse.

Retaining walls are occasionally erected to increase the stability of slopes or to consolidate existing slopes. This is often done in landslides close to a track in railway or highway cuts. The use of retaining wall is preferred in three cases.

a) Low walls, supporting slopes in clayey soils to prevent loosening of the toe and to protect it from frost action.
b) Low walls or other supports fastening the toe of existing landslides.
c) Large retaining walls, subject to full pressure, if no other design of a cutting is possible.

A low wall, which has also the function of supporting cubble drains, can confine the toe and directing drained coater either into deep holes or into the longitudinal chains situated at the back of the wall.

6.7.2.5 Overbridging

In some cases it is more economical not to stabilize the slopes but to layout the road on a bridge spanning the dangerous area. The possibility of laying out the road on a bridge across the large sheet slides depends on the depth of the moving mass. With shallow sheet slides and with a stable rock at accessible depth, the piers can be constructed to support the bridge structure. The bridge piers must not intercept the free creep movement of the slope deposits.

6.7.2.6 Rock Bolts

Stabilization of rock masses by means of rock bolts, which is used to prevent movement of rock slopes are sometimes used to stabilize rock slide as well.

The use of some type of metal dowels has become popular in certain situations in the last few decades. They work best in rocks that are jointed or bedded with planes of discontinuity inclined downslope. They are usually composed of steel rods, drilled and inserted at angles to the planes of weakness, and contain a wedge or expansion device to secure them to the rock. In unusual instances they may exceed 12m. in length.

Generally a rock bolt tensioned to a particular load is installed in the rock slope containing adverse discontinuities and slope relationship. The bolt tension reduces the disturbing force acting down the plane of discontinuity and increases normal force and hence the frictional resistance between the base of the block and the plane.

6.7.2.7 Stabilization of Slopes by Piles

The installation of piling or some type of vertical plug has occasionally been employed in slides that contain unconsolidated material. They are not in wide use and are often unsuccessful because material can move between the piles. The vibration during their driving and emplacement can also produce accelerated movement of the earth materials. Their use must be restricted to very local situations.

6.7.2.8 Buttresses: These structures consist of rock or earth filled material that is placed on or into the toe of the slide to provide additional weight to increase the shear strength of materials in the slide. When properly designed, buttresses can be effective with landslides having rotational movement because the added mass produces a binding force that can feed back into the system and provide extra stability for upslope materials. They can also be effective in the slip-out type of landsliding. Buttresses can fail if they do not project sufficiently deep and where drainage was not adequately designed.

6.7.2.9 Shear Keys: These are prismatic shaped excavations that are filled with compacted fill. They are installed on the slide, generally near the top or where the increased uniformity will provide stability. These shear keys are not in wide use for stabilization.

6.7.2.10 Hardening of soil

a) Electro – Osmosis: The first of these methods, drainage by electro-osmosis, has some final effects as the subdrainage, but differs in that water does not move towards the drainage by gravity, but by the activity of the electrical field. If two electrodes are installed into the soil, the water contained in the soil moves from anode to cathode. The cathode consists of a perforated pipe, water penetrates into it and can be removed by pumping. The method is best suited for silty soils. However field tests are necessary to estimate best parameters of energy supplies and effectiveness of drainage because gravity forces and pressure of electrolytes which increase its conductivity and reduce its flow by electro-osmosis.

b) Thermic Treatment

Exceptionally employed method in which a compressor drives air with pressure 0.15 to 0.5 atm. into mixing burner in which oil conveyed from special pump is burnt. The exhaustive gas with the temperature about 1,000° C is driven into bore hole and penetrates into pores of the soil which is baked into hard material.

c) Microwave energy for soil stabilization

An entirely new method of soil stabilization by microwave energy of the electro-magnetic field was proposed by scientists. A primary advantage of this method as compared to traditional thermal methods of soil stabilization is that microwave field penetrates deeply into the soil and is intensely absorbed by it. This brings about soil heating over a comparatively short period of time.

6.7.2.11 Grouting with Portland cement

This method has been successfully used for hardening the railway sub-grade and mud prochets underneath the road bed. Now a days, it is used for the stabilization of landslides on railways, as this method can be employed without disturbance of traffic. The effect of grouting consists in displacing water from fissures, which are filled up with cement mortar. The latter hardens and creates stable skeleton between the blocks. Before using this method a clear picture of the depth and the shape of the slip surface must be provided.

6.7.2.12 Break of Slip surface by Blasting

This method is more promising with landslides along rather straight planes with hard rock underneath. This method is based on the following concepts.

a) The explosion will loosen the rock and uplift of the ground water will be reduced.

b) The straight parallel will be broken and the rock fragments will become mixed with overlying clay material and increase its resistance in friction.

6.7.2.13 Impervious layers: Asphalt and other impervious rocks over upslope or downslope areas help stabilize landslides by keeping moisture out, reducing weight and preventing decrease in shear strength.

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Chapter 7

Summary, Conclusions and Recommendations

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From the various analysis carried out under geological, geo-technical and morphometric headings and from the rating curve it can be concluded that Khasi Hills have innumerable vulnerable landslide prone spots mostly along the highways. Those areas where landslide are now minimal but due to the continuous exploitation of the surfacial lands through quarrying and new constructions, they have been rendered hot spots for slope instabilities in the near future unless precautionary measures are not taken to abate them.

7.1 Research findings

1) The process of weathering is more pronounced on the soft and friable rocks along the highways particularly the phyllites and quartzites while the harder ones like Khasi Greenstone and Porphyritic Granite have withstood the weathering processes to a great extent compared to the friable varieties.

2) Landslides have occurred particularly along those tracks that have immense water seepage indicating that the rainfall and consequently surface runoff are the major triggering mechanisms that causes landslides.

3) Landslides are frequent and more intense on slopes that have slope angles exceeding 50°.

4) From the lithological studies, it was found that the study area represents that of complex geological as well as structural settings. The terrain is composed of meta-sedimentary and igneous (Pluton) rocks. As a result Regional Metamorphism is very much prominent along the contact zones of these two varieties. The terrain being of sedimentary origin and affected by low-grade metamorphism, the sedimentary features (structures) such as current bedding, are still seen intact in the rocks.

5) The morphometric analysis including Relative Relief, Slope, Drainage Density and Drainage Frequency have been analysed. The Relative Relief of 100-200 m. category has the maximum area coverage in the study area (33.82 %). The 10°-20° slope category has the maximum coverage of 47.50 %. The Drainage Density of 3-6 category leads with 56.03 % and Drainage Frequency have the highest ranking in 5-10 category with a percentage of 61.35 %.

6) Relation between Slope Profile and strength properties reveals that the same rock type shows varied strength (Rock Mass Strength testing by Schmidt Hammer) when readings are taken insitu at different slope angles, which primarily are acted upon by the force of gravity. On the other hand the Bearing Capacity of a particular rock mass (tested in laboratory) remains the same, irrespective of samples being taken from sites of different slope orientations.

7) From the strength properties of the intact rocks it was found that a particular rock type show varied strength in separate outcrops (Schmidt Hammer Test) indicating that the rocks have been affected by different degrees of weathering at different places.

8) From the geo-technical analysis of soil it has been found that the soils are mostly non-plastic in nature and hence landslides are triggered off immediately after the soil is fully saturated with water. At places, where the soil displays some amount of plasticity, (e.g. Mawiong), the after effect is not slide but soil –creep.

9) The infiltration rates of water in soils are very high in all the landslide spots, the highest being observed in Mawiong and the lowest in Manai.

10) The Moisture Content of soils is found to be highest in Mawiong and the lowest value in Barapani soils. On the other hand the moisture content of rocks is found to be highest in Barapani region and lowest in Umtyngar.

11) Barapani has the maximum Porosity value for rocks and the lowest Porosity has been recorded by the Jorabat Granites.

12) From the Bearing Capacity test Jorabat Granites was established as the strongest and phyllite rocks at Barapani has been recorded as the weakest.

13) Water holding capacity i.e. liquid limit of soils was found to be maximum at Umsning and minimum at Barapani area. Consequently, the highest value of plastic limit was shown by the soils at Mawiong and lowest by Barapani soils.

14) From the Grain Size-Analysis of soil it has been found that the soils are mostly sandy in composition, the reason why the soils are non-plastic and landslides are initiated instantaneously.

15) For rocky terrains, rockslides are frequent where the joints and fractures are prominent. From the structural analysis it has been found that multiple sets of joints are present throughout the entire study area including vertical, horizontal, oblique and parallel sets of joints. The most frequent strike direction of joints trend in NE-SW conforming to the direction of major lineaments, which also has a maximum trend towards NE-SW.

16) Landslide Hazard Zonation rating for rock slide as well as soil slide has been done using Selby's Rating Technique. The parameters taken into consideration are Geological (joint spacing, orientation of joints, joint width, lateral/vertical continuity of joints, infilling material, water movement /seepage), Geo-technical (Rock Mass Strength, Bearing Capacity, Moisture Content, Porosity), and Morphometric parameters (Drainage Density,

Drainage Frequency, Relative Relief and Slope), Weathering, Rainfall and Slope Angle.

17) Accordingly Landslide Hazard Zonation maps have been prepared separately for soil slide and rock slide areas.

18) From Selby's rating method it has been established that the most hazard prone area for soil slides in the Khasi Hills is Barapani and least hazard prone area is Byrnihat, while for rock slides the most hazard prone area is Barapani and least prone area is Jorabat.

7.2 Recommendations

The following recommendations have been put forward to further check the Geo-environmental hazard- landslide in Meghalaya. The landslides cannot be completely prevented but can be avoided if suitable measures as given below are taken before a developmental scheme is implemented.

1) Deforestation in vicinity of the highway and road networks to be stopped and a buffer zone of multitier canopy cover to be developed along the roadways.

2) Proper grade maintenance of slope. The slope cut faces should be rounded rather than making them sharp. Retaining walls to be made. Benching and terracing of slopes. Proper drainage galleries and drains to be provided. Wire meshes or cribs to be provided in rock fall areas. Slope profiles to be suitably modified in slide prone areas.

3) Vegetative cover along the highway areas not to be disturbed. Total ban on agriculture, grazing and additional residential constructional activities along both sides of the highway and road networks.

4) Proper support system techniques and measures should be introduced in the landslide prone zones to minimize the occurrences. It should be seen that the supporting techniques used are reliable and durable for a longer duration.

5) The quarries and man made slope instabilities to be minimized to reduce frequent occurrences of sliding. Mining regulations should be enforced and Slope Profile modifications to be graded for landslide management.

6) Since we have seen that any type of developmental schemes introduced bring Geo-environmental degradation of one kind or the other, and environmental protection has not to be anti-developmental, therefore, it should be mandatory for each and every developmental schemes to include cost of landscape conservation and reclamation.

7) The constructional activities in the state should integrate appropriate designing in their structures against landslide risks considering the landslide proneness of the area. At the same time a relief and rescue system should be evolved in Meghalaya to become operative in the eventuality of any devastating landslide.

8) The Geo-hazard Zonation map should condition the development in the entire state. Resource exploitation should be avoided in high to very high Geo-hazard zones and further enlargement of such zones to be checked by creating a buffer over the moderate Geo-hazard zone. It implies that the moderate zone requires spread of landscape reclamation and conservation measures immediately.

9) The network of infrastructural facilities along with the developmental activities should be spreaded throughout the state with emphasis on generation of value added end product resource utilization. Promotion of heavy industries to be discouraged in the dissected hilly upland and small scale environment friendly industrial base should be preferred. This calls for

the introduction of agro-forestry, horticulture, diary-livestock, poultry, fisheries, apiculture, sericulture and tourism industries in the state. The whole aim should be to upgrade the socio-economic conditions of the inhabitants of the state by resource utilization and activities not injurious to the landscape health of the state such as the unscientific practice of Jhuming.

10) Huge tracts of land in the state are in the process of transforming into wastelands due to unplanned and over exploitation of the natural resources. The resource base potential of the state should only be harnessed as per terrain characteristics so as the man induced Geo-hazards in the basin do not overtake the terrain inherited Geo-hazards.

11) The land holding/ tenure system in this part of the country (NE India) gives little or no scope for enforcement of environment protection laws thereby: promoting only indiscriminate land resource utilization. This single factor has introduced wide spread Geo-environmental degradation in the state. The present land tenure system needs to be suitably amended for the conservation of natural resources and reclamation of degraded landscape i.e. to promote sustainable development.

12) The unplanned growth of Shillong city and its suburbs falling in the high geo-hazard zone is to be checked. Land scarring through indiscriminate quarrying operations should be stopped within the urban limits to retain the aesthetic view. The quarrying operations should be shifted outside the city municipality area.

13) The government departments as well as the concerned non-governmental organizations should undertake afforestation schemes. Lumbering of immature trees (timber business) should be totally banned in the state and reserve forest coverage to be increased, since trees and vegetation play a major role in maintaining the stability of slopes.

14) Social awareness campaigns should be launched to make the people understand the importance of the conservation of the environment for their future generations and that a proper balance is maintained between man and environment.

15) Constant regular monitoring of the landslide prone areas should be done so that imminent dangers do not occur causing extensive damages to life and property.

7.3 Perspectives

The general public is finally starting to realize the hazards of landsliding. Because of the nearly ubiquitous character of landslides, there are few regions that can afford to ignore them in land-use planning. An increased governmental commitment to public safety by introducing relevant policies is a must and the necessity for dealing with the landslide problems. Such policies will make additional demands on the scientific and engineering professions for accurate prediction of unstable areas, for more precise calculations of cost-benefit ratios and for the development of safety measures at new construction sites.

Fortunately the disciplines of soil and rock mechanics, which had very slow growth during their formative years, are now coming of age. The data that such specializations can produce when coupled with interdisciplinary investigations including Geology, Geomorphology, Environmental Science and Engineering – can yield scientific conclusions that must be used in the decision making process for landslide management.

The forces that are causing the topic of landslides to come under increasing scrutiny today will probably still be influential in tomorrow's world. With continued population growth, urban and sub-urban areas will expand into more marginal and potentially dangerous terrain. Furthermore there will be increased development in regions whose slope stability is more fragile than many of those in current use. The developing countries including India will need much expertise as they develop their economy and resources. Land use planning in such nations will need careful evaluation if tragedies are to be averted as the cost of land acquisition, as needed for highway projects and in other developments is rising sharply. Thus it becomes vital to know how large a safety corridor to purchase so as to maintain the integrity of the investment. It makes a big difference whether slopes are to be designed with 25 percent or 50 percent grades. Only careful regolith and rock studies can supply the answer.

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Appendix

Appendix
Udden –Wenthworth's size classification

Sieve-Mesh Number	mm.	ϕ	Udden-Wenthworth size classification	
		-20		
	4096	-12		
	1024	-10	Boulder (-8 to –12ϕ)	
	256	-8	Cobble (-6 to –8ϕ)	
	64	-6		
	16	-4	Pebble (-2 to –6ϕ)	: Gravel
5	4	-2		
6	3.36	-1.75		
7	2.83	-1.50	Granule	
8		-1.25		
10	2.00	-1.0		
12	1.68	-0.75		
14	1.41	-0.50	Very coarse sand	
16	1.19	-0.25		
18	1.00	-0.0		
20	0.84	0.25		
25	0.71	0.5	Coarse sand	
30	0.59	0.75		
35	0.50	1.0		: Sand
40	0.42	1.25		
45	0.35	1.50	Medium sand	
50	0.30	1.75		
60	0.25	2.00		
70	0.210	2.25		
80	0.177	2.50	Fine sand	
100	0.149	2.75		
120	0.125	3.00		
140	0.105	3.25		
170	0.088	3.50	Very fine sand	
200	0.074	3.75		
230	0.0625	4.00		
270	0.053	4.25		
325	0.044	4.30	Coarse silt	
	0.037	4.75		
	0.031	5.00		
	0.0156	6.00	Medium silt	: Mud
	0.0078	7.00	Fine silt	
	0.0039	8.00	Very fine silt	
	0.00195	9.00		
	0.00098	10.00		
	0.00049	11.00		
	0.00024	12.00	Clay	
	0.00012	13.00		
	0.00006	14.00		