GEOMORPHOLOGY AND ENVIRONMENTAL MANAGEMENT OF UMIAM BASIN, EAST KHASI HILLS, MEGHALAYA

Mrs. Mandira Agarwal

THESIS
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Phone :
Grams : NEHU

North - Eastern Hill University

Mayurbhanj Complex
Nongthymmai, Shillong - 793014 (Meghalaya)

Professor **R.K.Rai,**
Department of Geography,
School of Human & Environmental Sciences

CERTIFICATE

I certify that the thesis entitled ***"Geomorphology and Environmental Management of Umiam Basin, East Khasi Hills, Meghalaya"*** *submitted by* ***Mrs. Mandira Agarwal*** *for the degree of Doctor of Philosophy in the School of Human & Environmental Sciences, North-Eastern Hill University, Shillong embodies the record of original investigation carried out by her under my supervision. She has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. degree. This work has not been submitted for any degree of any other University.*

R.K.Rai
3-12-94
(R.K.RAI)
Supervisor
Department of Geography
North Eastern Hill University
Shillong.

SHILLONG
The 3rd December, 1994

RK Rai
Head
Department of Geography
North Eastern Hill University
Shillong.

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SHILLONG
The 3rd December, 1994

Mandira Agarwal 3.12.94.
(MANDIRA AGARWAL)

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CHAPTER - I

INTRODUCTION

INTRODUCTION

Geomorphology is a vital component in Environment Resource Management. Its influence on the pattern of development at a particular place is immense. Geomorphology is the study of land- water system. It is the science which is concerned with the study of landforms. Invariably when man uses 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. Geomorphology provides scientific basis to the study of terrain, particularly the sources or causes of geohazards and geomorphic risks associated with it. Geomorphology involves both terrain evaluation and investigation of the processes which shape the landforms (Fairbridge 1968). Geomorphic knowledge plays a valuable role in the management of land resources which means planned utilisation of land and mitigation of geohazards. It emphasises the land-man interactions in which geoenvironmental processes and socio-economic activities interplay (Kumar and Pandey 1989). A knowledge of the processes which fashion landforms is necessary for understanding landscapes. Thus, there is a direct interaction between Geomorphology and Environment (Pitty 1985).

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 utilisation (Vink 1983). Geomorphology traditionally focus 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 (Craig and Craft 1982). 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 organisms particularly, "man" (Imeson 1985). Man has established himself as a geological agent by causing consequences of industrialisation (Flawn 1970), which often degrade the environment.

Urbanisation and development are related to topographic, hydrographic and socio-economic features. So, Geomorphology always comes in the forefront wherever environmental exploitation takes place (Coates 1974). As a result, geomorphological studies have begun to consider ecological factors in more depth (Viles 1988).

Within the contemporary concern for Environmental Management, many problems relate to the interactions between man, land and water. Environmental management recognises a need of an integrated approach for rational utilisation 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 geohazard from one geomorphic domain to other.

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.

A basic desire of man "had been", "is" and "would be" to have improvement in living conditions. This single desire of man had led in the continuing refinement of science and technology, and its application in new and newer developmental schemes for harnessing the life supporting components of biosphere - land, water and air. The developmental activities and the ongoing refinement in the application of science and technology are never ending endeavours of human activities.

So, a scenario exists which we may accept or ignore, where, for sustained "better living" of man, all developmental activities proceed to harness natural endowments and degrade environment. Thus, development and environmental degradation is a Complex equation to be handled scrupulously to avoid environmental crisis.

The environmental crisis is a global phenomenon and is cumulative in nature i.e., a minor deterioration of environment in a small watershed may have disastrous effects in the down-stream component basins. This is particularly relevant for hilly and mountainous terrains. The changes induced in the mountains have immediate repercussions in the valleys and plains below (Schumm 1963; Ahnert 1970; Curray and Moore, 1971; Winiger 1983; Gerrard 1991). Hence, environmental appraisal is of paramount importance before any developmental activity is formulated for an area. The understanding of geomorphology of the area to be harnessed, is the basic step in any environmental appraisal study. The slopes 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 an area. These parameters are interlinked with each other and any one of them may assume dominance over the others in shaping particular landforms. The same parameters determine the suitability of a location for construction of dams, railways, highways, electrical power lines, industrial Complexes, townships, irrigation distribution channel network, defence, strategic installations etc. In a way, geomorphology helps in rationalising 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 "Geomorphology and Environmental Management of Umiam Basin, East Khasi Hills, Meghalaya" has been conceived to understand the geomorphology of the Umiam Basin and to evaluate the environmental degradational processes in the area for proper management. Such studies help in utilising the land-water systems of an area for sustainable development without freezing the developmental activities in the name of "Environmental Protection".

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 Smith (1935), Kesseli (1946), Russell (1949), Bryan (1950), Kesseli (1950), Mather (1950), Hammond (1954), Kesseli (1954), Hammond (1957), Ahnert (1962), Hammond (1962), Robinson (1963), Hammond (1965) etc. strongly advocated an empirical approach or descriptive approach to Geomorphology. Zakrzewska (1967) however, opined 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), Horton (1945), Strahler (1950a, 1950b, 1952a, 1952b), Schumm (1956), Strahler (1957, 1958), Morisawa (1958), Chorley (1959), Scheidegger (1961), Chow (1964), Hammond (1964), Leopold et al. (1964), Strahler (1964), Chorley (1966), King (1966) , Durry (1967), Doornkamp and King (1971), Hart (1986), etc. This transformation proved to be the turning point in the study of Geomorphology because, by this time, it was recognised as an important component of Environmental studies (Craig and Craft 1982; Vink 1983; Pitty 1985; Gerrard 1991). In the Indian scene, significant contributions have been made by Singh (1969), Pal (1972, 1973), Singh (1974), Dixit (1976), Soni (1984), Rai (1987), Singh (1991), Mithra and Rao (1993) etc.

As far as the area of study is concerned, Oldham (1858) was the pioneer to document the geology of Khasi Hills region. Subsequently, Medlicot (1869), La Touche (1883), Smith (1896), Palmer (1923), Evans (1932), Das Gupta (1934), Ghosh (1952), Banerjee (1964), Mathur and Evans (1964), Gogoi (1975), Mazumdar (1976), Murthy et al. (1976), Mazumdar (1986) gave the geological account of the area. But, so far, not much published information is available on the geomorphology of the area. Anon (1974) and Mazumdar (1978) have however, given a very generalised regional physiography while discussing the geological framework of the Northeastern India.

CHOICE OF THE AREA :

The Umiam river basin offers a variety of landforms in diverse geological milieu. The area exposes many geological sections in an otherwise covered terrain. In its upper catchment, the river has been dammed to form the Umiam lake (plate-1) at Barapani for a hydroelectric project which was commissioned in 1965 (Anon 1985). The water from the lake is diverted to the adjoining Umtru basin where the powerhouse is located. This has affected the downstream morphology of the river. The lower catchment of the river towards its confluence with Kopili river has significantly different landfroms than the upper catchment segment. The entire Umiam river basin offers excellent sections showing the process of ongoing environmental degradation in different geomorphic domains.

Shillong, the capital of Meghalaya is located within the upper reaches of the basin and is expanding rapidly. The Umiam lake proximal to Shillong covering an area of about 10 sq.km is capable of supporting tourist industry. The hydroelectric project is also in the process of expansion and has encouraged growth of a nucleus of industrial base downstream of the dam. The terminal part of the basin towards its confluence with Kopili river supports tea industry. Evidently, the entire Umiam basin is at the threshold of development. Keeping in view the above developmental potentiality of the basin and the ongoing developmental schemes, the area has been selected for the present study.

THE AREA OF STUDY :

The study area covers an area of 1429.510sq.km and defines the seventh order Umiam river basin. The area falls in the Survey of India Toposheet Nos. 78 O/10, 78 O/11, 78 O/13, 78 O/14, 78 O/15, 83 B/4, 83 B/8, 83 C/1, 83 C/2, and 83 C/5. It is bounded by the coordinates $25^{o}28'00"$ N : $26^{o}10'07"$ N and $91^{o}42'00"$ E : $92^{o}24'30"$ E. The major part of the basin is confined in East Khasi Hills district (68.6%), Meghalaya, with its lower fringe area spilling over to the districts of Kamrup (0.9%), Nowgong (6.5%) and Karbi Anglong (24.0%), Assam (Fig. 1). Out of its 151.01km length, the Umiam river has only 15.50km segment in Assam.

The basin is elongated in NE-SW direction. It forms a northeasterly flowing drainage system of the Central Uplands of

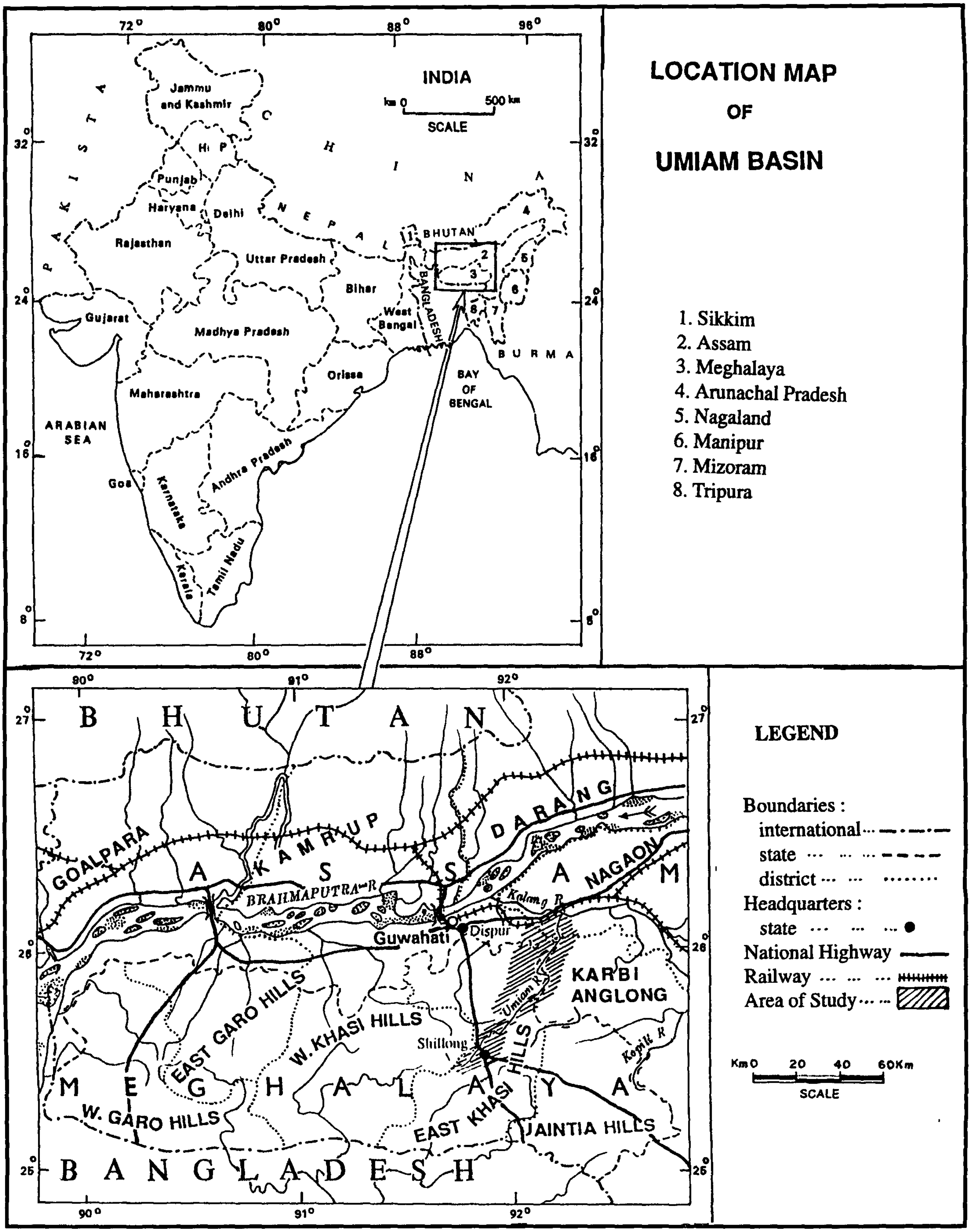

LOCATION MAP
OF
UMIAM BASIN
INDIA
km 0 500 km
SCALE
1. Sikkim
2. Assam
3. Meghalaya
4. Arunachal Pradesh
5. Nagaland
6. Manipur
7. Mizoram
8. Tripura
Jammu and Kashmir
H P
Punjab
Haryana
Delhi
Rajasthan
Uttar Pradesh
Bihar
West Bengal
Gujarat
Madhya Pradesh
Orissa
Maharashtra
Goa
Karnataka
Andhra Pradesh
Kerala
Tamil Nadu
ARABIAN SEA
BAY OF BENGAL
PAKISTAN
CHINA
NEPAL
BHUTAN
BANGLADESH
BURMA
72° 80° 88° 96°
32° 24° 16° 8°
LEGEND
Boundaries :
international
state
district
Headquarters :
state
National Highway
Railway
Area of Study
Km 0 20 40 60 Km
SCALE
B H U T A N
B A N G L A D E S H
A S S A M
M E G H A L A Y A
GOALPARA
KAMRUP
DARANG
NAGAON
KARBI ANGLONG
BRAHMAPUTRA R
Kalang R
Umiam R
Kopili R
Guwahati
Dispur
Shillong
EAST GARO HILLS
W. GARO HILLS
W. KHASI HILLS
EAST KHASI HILLS
JAINTIA HILLS
90° 91° 92°
27° 26° 25°

Fig.(1)

Meghalaya. It is bounded in northeast by Kopili-Kalang river system, by Um Ngi and Umiew river system in the southwest (draining into Bangladesh), Khri river system in the northwest and Umkhen river system in the southeast. Some of the important villages in the basin from its summit (southwest) are Marbisu, Mawreng, Sohiong, Mawlendeep, Sumer, Umden, Pamlaban, Umsaw, Umta, Barmarjong, Mayang, Pataguri, Nelli etc. The capital city, Shillong, lies towards the southwestern end of the basin and is connected with Guwahati by NH-40. Barapani is about 18km north of Shillong and is easily accessible through NH-40.

The Umiam is a seventh order trunk stream and is known as Wah Umiam in its upper reaches, Umiam or Bagra in the middle reaches and Killing in the lower reaches. Its important feeders from southwest to northeast are : Wah Umphanmiet, Wah Lyngkut, Um Rangsaw, Um Ban, Wah Ro Ro, Um Ew, Phud Umshing, Um Shiprah, Um Lator, Um Let, Um Sader, Um Swat, Um Bi, Um Thalong, Amshai Nadi, Um Siang etc. Towards the terminal part of the basin, Umiam is joined by Um Siang, a left bank tributary, near Amjonggaon in East Khasi Hills district. At this point, Umiam leaves behind the hilly tract and enters the Assam Plains. This segment of Umiam in Assam plains is known as killing river. It is a peculiar feature of Umiam basin that one of its feeder stream, Um Siang, has acquired the order, higher than the trunk stream, but, its catchment area as well as its length and discharge remaining much smaller. As a result, hydrologically, Um Siang remains subordinate to Umiam, its increased order is due to higher bifurcation ratio.

The Umiam river debouches into Kopili river near Dharamtul (Noa Bil) in Nowgong district (Assam) which in turn joins the Kalang river, a distributary of the Brahmaputra river on its left bank at Hathiyamukh in Nowgong district. The Kalang channel bifurcates from the Brahmaputra at Jakhlabandha in Nowgong district to rejoin it at Singimaria in Kamrup district.

OBJECTIVES OF THE PRESENT WORK

The thrust of the present study is to integrate geomorphology with land resource utilisation to have minimum geoenvironmental degradation in the basin. The study, therefore, is undertaken with the following main objectives.

(1) Identification and classification of different geomorphic domains and landform elements in the area. To study the evolution of the basin, the nature of operative geomorphic processes over the diverse geological milieu.

(2) To evaluate various geomorphic attributes and to identify the various geomorphic risks in the terrain and to evolve cause and effect relationship between the two.

(3) To identify the various Terrain Inherited Geohazards and Man Induced Geohazards and to evaluate the processes of geoenvironmental degradation in the area.

(4) To develop methodology for Geohazard Zonation in the basin for rationalising developmental activities and resource exploitation for sustainable development and to evolve strategies for Geohazard mitigation.

PHYSIOGRAPHY :

Physiographically, Meghalaya together with Mikir Hills

(Karbi Anglong district of Assam) represents the Plateau remnant of the northeastern extension of the Indian Peninsular Shield. This composite Plateau remnant is termed herein "Shillong Massif". It is a "3rd order" modulation of the earth surface (Fairbridge 1968) and has been block uplifted since Jurassic period to its present height. The rise of the Massif varies from about 600m to more than 1800m above m.s.l. as evident by the exposure levels of marine beds on the Massif at present.The uplift is not uniform throughout the plateau. The Massif has a checkered evolutionary history of emergence, submergence and peneplanation with several phases of erosion, sedimentation, diastrophism, intrusion and movement of land and sea. It has experienced the influence of an alternate phase of transgression and regression of sea waters from Mesozoic to early Tertiary times. Based on the above facts, the Massif has been divided into upper, middle and lower plateau (Fig.2). The upper plateau ranges from 600m to >1900m elevation above m.s.l., the middle plateau ranges from 300m to 600m elevation above m.s.l. and the lower plateau ranges from 100m to 300m above m.s.l. Some high undulations having very steep slopes occur over the plateau due to the presence of local "horst". In the northern part of the Massif, broken ranges of irregular hills stretch across Assam. Low round topped hills are present in the south and southeastern border of the plateau. At some places, in the central and southeastern plateau, magnificent gorges, about 400m deep are present. Thus the main physiographic units in the entire plateau

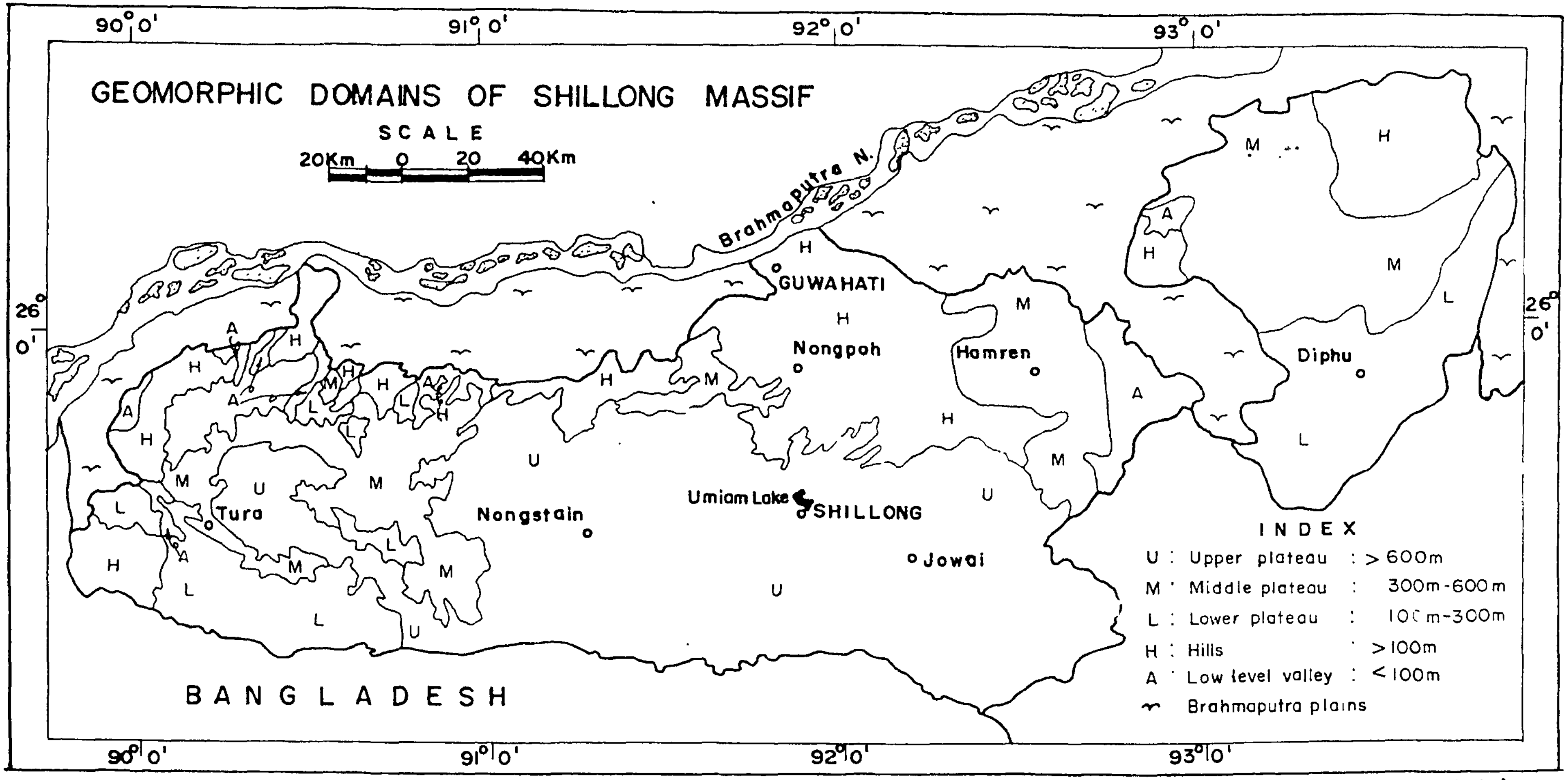

GEOMORPHIC DOMAINS OF SHILLONG MASSIF
SCALE
20Km 0 20 40Km
90° 0'
91° 0'
92° 0'
93° 0'
26° 0'
Brahmaputra N.
GUWAHATI
Nongpoh
Hamren
Diphu
Tura
Nongstain
Umiam Lake
SHILLONG
Jowai
BANGLADESH
INDEX
U : Upper plateau : > 600m
M : Middle plateau : 300m-600m
L : Lower plateau : 100m-300m
H : Hills : >100m
A : Low level valley : < 100m
Brahmaputra plains

Fig.(2)

are based on degrees of undulations and slopes which is the net result of severe dissection by streams, rivulets and rivers. The undulations mostly have rounded tops in the northern part of the plateau comprising Gneissic Complex.

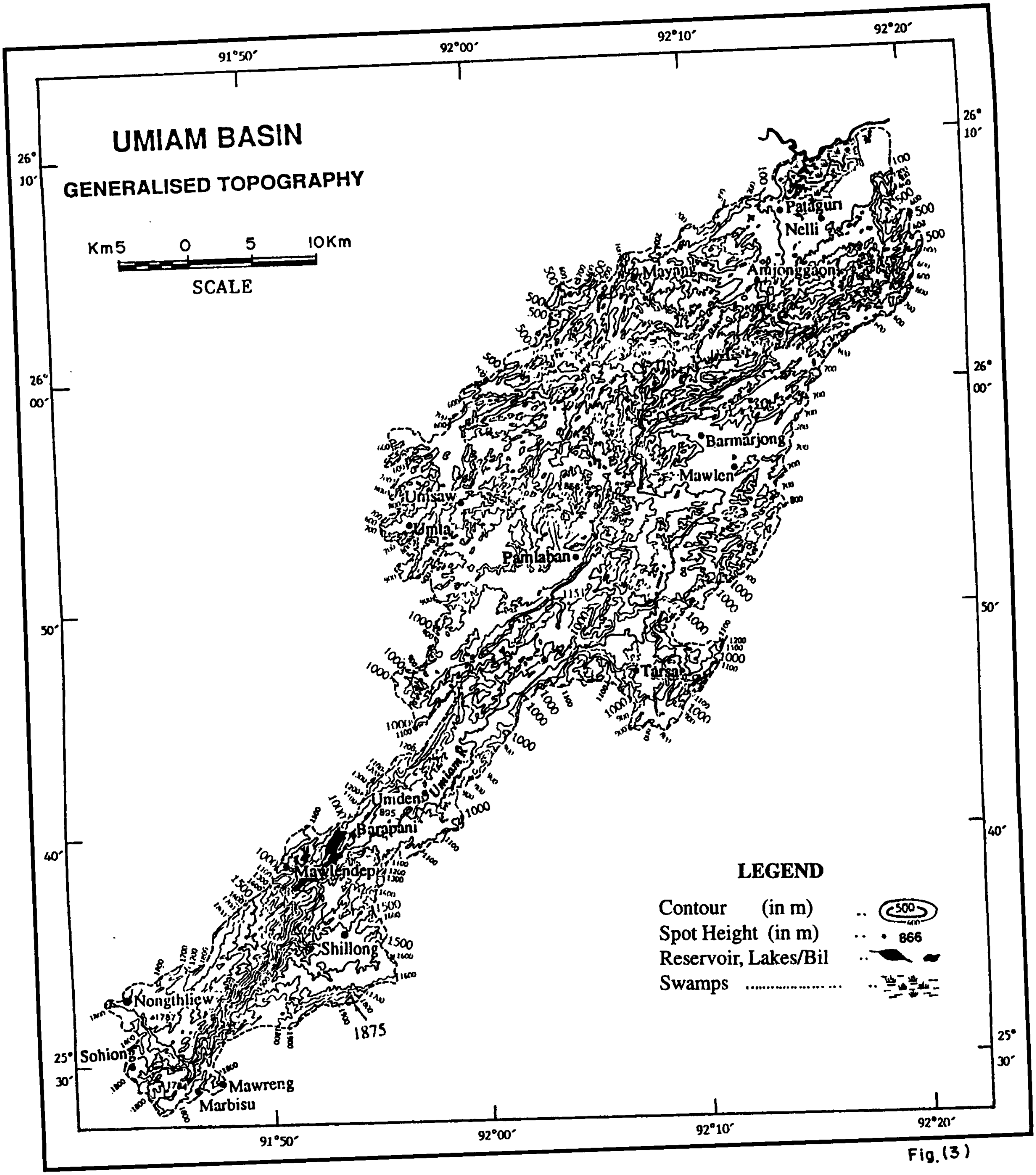
Physiographically the Massif can be divided into following Tectono-Geomorphic units:

1. Upper Plateau, Middle Plateau and Lower Plateau comprising Gneissic Complex.
2. Upper Plateau comprising Shillong Group.
3. Upper Plateau, Middle Plateau, and Lower Plateau comprising Granitoids.
4. Upper Plateau, Middle Plateau and Lower Plateau comprising Cretaceous-Tertiary sedimentary sequence, mostly confined in southwest, south and southeastern part of the Plateau.
5. Lowland Valleys over the Gneisses and Granitoids in the northern border of the Plateau.
6. Pediment zone mostly concentrated in the northern border of the Plateau.
7. Alluvial Plains in the northern part of the Plateau.
8. Hills of Granitoids and Gneisses in the western and northern part of the Plateau.

The Umiam basin is confined to the eastern part of the Shillong Massif. Conspicuously, the water divide in the upper reaches of the basin defines the crestal line of the highest ridges in the entire Massif. Shillong Peak, the highest spot in Meghalaya (1964m above m.s.l.) is located on this part of the water divide, southwest of Shillong. The northern boundary of the basin is not a physiographic feature but is formed of man made "bunds" and "dikes". The general elevation in the basin varies from less than 60m in the northeast to more than 1900m in the southwest.

Morphologically the basin is spear-head shaped pointing downstream and can be divided into two parts roughly at latitude 25^{O} 45'N; the downstream part is broad while the upstream part is narrow. The shape of the basin is controlled by the geology of the area. By and large, the various Plutons and a NE-SW trending shear zone passing through the Umiam lake have remarkably influenced the basin configuration. The Mylliem, the South Khasi and the Nongrang Plutons have restricted the lateral expansion of the basin in the southwestern part. Similarly, the Kyrdem Pluton has controlled the basin expansion in east of Umiam lake. These Plutons are manifested as low, rounded and linear hills. The basin expansion, west of Umiam lake is restricted by the Precambrian Gneissic Complex which has expression of low ridges.

The downstream part of the basin is widest between Umta in the northwest and Tarsa in southeast. Characteristically, this part of the basin has high, linear to curvilinear hills (Fig.3) carved out of the Nongpoh Pluton. These hills are flanked towards east by curvilinear ridges made up of Shillong Group of rocks. At the terminal part of the basin, the linear ridges and hills gradually lose their elevation and merge with alluvial terraces through colluvial aprons around Amjonggaon, Pataguri and Nelli. These terminal ridges emerge as isolated hills and mounds (monad-


UMIAM BASIN
GENERALISED TOPOGRAPHY
Km 5 0 5 10 Km
SCALE
LEGEND
Contour (in m)
Spot Height (in m)
866
Reservoir, Lakes/Bil
Swamps
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′
Patiguri
Nelli
Mayang
Amjonggaon
Barmarjong
Mawlen
Umsaw
Umla
Pamlaban
Tarsai
Umiam R.
Umden
Barapani
Mawlendep
Shillong
Nongthliew
Sohiong
Mawreng
Marbisu
1875
Fig. (3)

nocks) in the alluvial plains. Significantly, large part of these alluvial terraces is occupied by swamps and bils and is prone to periodic flooding.

The narrow portion of the basin conspicuously depicts terraced plateau configuration. It has linear gorge sections upto 400m depth, entrenched *in Shillong Group of rocks particularly* between Marbisu and south of Mawlendep. This magnificent gorge section carved out by Umiam river coincides with the southwestern segment of the shear zone. North of Shillong, the terraced plateau loses its majestic elevation (1300m - 1800m) abruptly and is juxtaposed with a narrow and linear NE-SW trending depression (900m-1100m). The Umiam lake occupies the head segment of this depression which is the manifestation of a graben structure (Agarwal 1989).

FLORA AND FAUNA :

The basin has wide variation in elevation, consequently the nature of vegetation also shows diversification. In general, the hill-valley and plateau segments above 1000m have mainly pine forest (Pinus longifolia and Pinus khasiaea). These pine forest largely are devoid or poor in bushy undergrowths.

The hill-valley and plateau segments below 1000m generally contain mixed forest of Bamboo, Rhododendron, Camellia and bushy undergrowth. Large tracts of the hill slopes and plateau segments have been deforested by "Jhumming" or shifting cultivation and timber exploitation (logging and lumbering).

The part of the basin comprising the territory of Assam has significantly lower elevations, and is endowed with heterogeneous vegetation. It comprises evergreen, semi-evergreen, moist deciduous forests and bamboo brakes. These forest cover are rich in species like Tetrameles nudiflora, Mesua ferrea, Bombusa palida, Dendrocalamus hamiltonii, Melocanna bambusoides (Roy et al. 1991). However, the present vegetation cover is under great threat due to excessive exploitation. The deforested patches give appearance of grasslands.

The fauna is represented by bears, deers, leopards in the higher reaches while the lower reaches particularly in Assam sector, elephants are found in addition. Rare sights of rhinoceros are also recorded from the Assam part of the basin.

WORK PROCEDURE :

The present study was carried out in the following three stages.

(i) Pre-Field Phase
(ii) Field-Work Phase
(iii) Post-Field Phase

(i) Pre-Field Phase :

The basic objectives during this stage was collection of secondary data. Initially, the available literature was perused which helped in formulating the strategy for subsequent work. The Geological, Hydrological, Meteorological, Seismological data were collected and relevant toposheets, maps were procured. The secondary data was synthesised to prepare the preliminary database. During this stage of work, general geomorphic units and nature of land degradation in the area were identified with the help of satellite imageries, multidated toposheets and aerial photographs and a preliminary photointerpretative map was made. Concurrently laboratory work was carried out for relief analysis, slope analysis and drainage analysis on 1:50,000 scale.

(ii) Field-Work Phase

On the basis of the preliminary database, field checks were planned and field work carried out in critical sectors to collect geoenvironmental data viz., geomorphological, land degradation, landuse, lithological, structural etc. At this stage of study, micro relief features, landslide and the various geohazards were identified and analysed, representative landforms, geological sections and geohazard related features were photographed for documentation.

(iii) Post-Field Phase :

At this stage, all data were classified collated and processed for interpretations. The processed data outputs resulted in various maps measuring 2.20m x 0.80m on 1:50,000 scale. The preliminary photointerpretative map was supplemented with field data; the analytical interpretation outputs were prepared as tables and various "thematic" maps reduced to thesis compatible size (A4). A method for preparation of

Geohazard Zonation map of the basin was developed to categorise terrain as per the existing geoenvironmental instabilities.

PLAN OF WORK

The geoenvironmental appraisal of the basin has been dealt in seven chapters. The first chapter defines the nature of work, location of the area, its physiographic entity in relation to the Shillong Massif.

In the second chapter, the regional geological framework, the tectonic evolution of Shillong Massif and the geological setting of the basin are discussed.

Chapter three deals with the weathering, soil characteristics, mass wasting - landslides in the basin.

Terrain analysis is discussed in the fourth chapter. The different geomorphic attributes viz., absolute relief, relative relief, dissection index, average slope, drainage frequency, drainage density of the basin as well as their correlation have been dealt in this chapter.

In chapter five, fluvial morphology and morphometric analysis are described. The morphometric characteristics of the different component basins and their correlation have been discussed in the chapter.

In chapter six, the geomorphic characteristics of the basin viz., the different landform elements, micro relief features, erosion surfaces and their evolution have been discussed.

Nature of geohazards, the various processes of environmental degradation and the Geohazard Zonation in the basin have been dealt in the seventh chapter. Strategies for sustainable development of the basin are also enumerated in this chapter.

In the last, the summary and conclusion with recommendations are summarised for harnessing the land resources in the basin.

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CHAPTER - II

GEOLOGY AND STRUCTURE

GEOLOGY AND STRUCTURE

Geology of an area is primarily responsible for the evolution of the landforms under the operation of physico-chemical processes on the earth's surface. Therefore, the pre-requisite of any geoenvironmental appraisal is the knowledge of geology of the area. The geology of the basin is herein discussed in relation to its regional framework.

(A) REGIONAL GEOLOGICAL FRAMEWORK

Geologically, Meghalaya is contiguous with the Karbi Anglong district (Hamren & Diphu subdivisions) of Assam forming a composite tectonogeomorphic entity. It is the northeastern extension of the Indian Peninsular Shield forming a cratonised Plateau wedge between the Himalayan and Patkai-Arakan Yoma mobile belts. This tectonogeomorphic domain is herein described as "Shillong Massif". The northeastern structural grain of this Massif continues into Brahmaputra plains and forms magnificent monadnocks particularly between the Kamrup and Karbi Anglong (Mikir Hills) districts of Assam. According to Murthy et al. (1976b) and Mazumdar (1986) the Shillong Massif is a geomorphic arch bounded on all sides by faults. The southern boundary is the famous E-W trending Dauki faults. The northern boundary is marked by the Brahmaputra lineament. To the west, the Massif is detached from the main Indian shield by the N-S trending Rajmahal Garo lineament. The eastern boundary is the NE-SW trending Disang thrust separating the Massif from the sediments of Bengal-Assam shelf. As such the Shillong Massif is horst, forming a plateau region block uplifted to its present height of about 600m to 1900m above m.s.l. since Jurassic (Anon 1974).

Oldham (1858) was the first to initiate the geological work in Meghalaya after the inception of Geological Survey of India in 1851. He came to Cherrapunji from Rangpur in the erstwhile Bengal State now Bangladesh. He was followed by Medlicot (1869). In the post independence period large areas of Shillong Massif have been mapped by the officers of the Geological Survey of India and the geology of the Massif is very well established by now (Fig.4). However, due to restricted area provisions much of the information is classified and unpublished. The compiled geological framework of the Massif is given by Anon (1974), Choudhury and Rao (1975), Mazumdar (1976), Murthy et al. (1976b, 1976c) and Mazumdar (1986), the generalised stratigraphic succession is given in Table (1). The different lithostratigraphic Groups are described below.

GNEISSIC COMPLEX : The Gneissic Complex is exposed in the central and northern parts of the Shillong Massif. This has often been referred to as "Archaean Gneissic Complex" or "Precambrian Gneissic Complex" (Banerjee 1964; Anon 1974; Murthy et al. 1976b, 1976c). As per the Geological Society of America, Geological Time Scale, 1983 "Archaean" has to be used only for rocks older than 2500 m.y., which calls for geochronological data. In

TABLE-1

GENERALISED STRATIGRAPHIC SUCCESSION OF SHILLONG MASSIF
(Modified after Anon 1974 and Mazumdar 1976)

Recent	Newer Aluvium (Thickness not known)		: Represented by sand, silt and clays
	Unconformity		
Pleistocene	Older alluvium (Thickness not known)		: Represented by sand, clay, pebble, gravel, and boulder deposits
	Unconformity		
Mio-Pliocene	Dupitila Group (approx. 1050m)		: Represented by unclassified mottled clays, feldspathic sandstone and diamictite
	Unconformity		
Oligo-Miocene	Garo Group	Chengapara Formation (approx. 700m).	: Represented by sand, siltstone, clay & marl.
		Baghmara Formation (approx. 530m)	: Represented feldspathic sandstone, pebble diamictite, clay, silty clay.
		Simsang Formation (1150m)	: Represented by siltstone, sandstone, alternations, sand.
Eocene	Jaintia Group	Kopili Formation (500m)	: Represented by shale, sandstone, marl.
		Shella Formation (600m)	: Represented by alternations of coal bearing sandstone, limestone.
		Langpar Formation (100m)	: Represented by calcareous shale, sandstone, limestone.

Table-1 contd..

Upper Cretaceous	Khasi Group	Mahadek Formation (150m)	: Represented by arkose (Glauconitic)
		Bottom Conglomerate (25m)	: Represented by conglomerate, arkose.
		Jadukata Formation (140m)	: Represented by sandstone-conglomerate alternations
	---------- Unconformity ----------		
Upper Cretaceous	Sung Valley Complex		: Pyroxenite, serpentinite, syenite, carbonatite etc.
	---------- Intrusive Contact ----------		
Jurassic	Sylhet Trap (approx. 600m)		: Basalt, alkali basalt, rhyolite, acid tuff.
	---------- Unconformity ----------		
Permo-Carboniferous	Lower Gondwana Group (approx. 200m)		: Sandstone, shale, conglomerate, coal.
	---------- Unconformity ----------		
	Porphyritic Granitoid		: These dot the Meghalaya Plateau. Those entirely within the Gneissic Complex and those intrusive into the Shillong Group, are of the same age. Because the South Khasi batholith transects both the older sequences.
	---------- Intrusive Contact ----------		

Table-1 contd..

Proterozoic	Khasi Greenstone	: Basic silts and dykes mostly within the Shillong Group.
	------ Intrusive Contact ------	
Proterozoic	Shillong Group	: Formerly termed the `Shillong Series'. They are a Conglomerate - sand stone - siltstone - shale rhythm. Weakly metamorphosed in the northern parts. Metamorphosed in Proximity with Porphyritic granitic Plutons. Occurs as a cover on older rocks. Strike persistently NE with open folds alternating with zones of steep dips.
	------ Unconformity ------	
Precambrian	Nonporphyritic	: They are variety of textural and compositional types developed exclusively Migmatitic within the gneissic complex where grade of metamorphism reaches amphibolite Granitoids facies.
	------ Diffused Contact ------	
	Gneissic Complex	: Formerly described as "older gneisses" or "Gneiss series" or "Archeans" A telescoped sequence of stratigraphic, deformational and metamorphic events which needs further elucidation, mostly show only one phase of recrystallisation, probably due to a late major regional metamorphism. Augen gneisses, pretectonic. With respect to this phase of deformation and recrystallisation, are considered relicts of a still earlier orogeny.

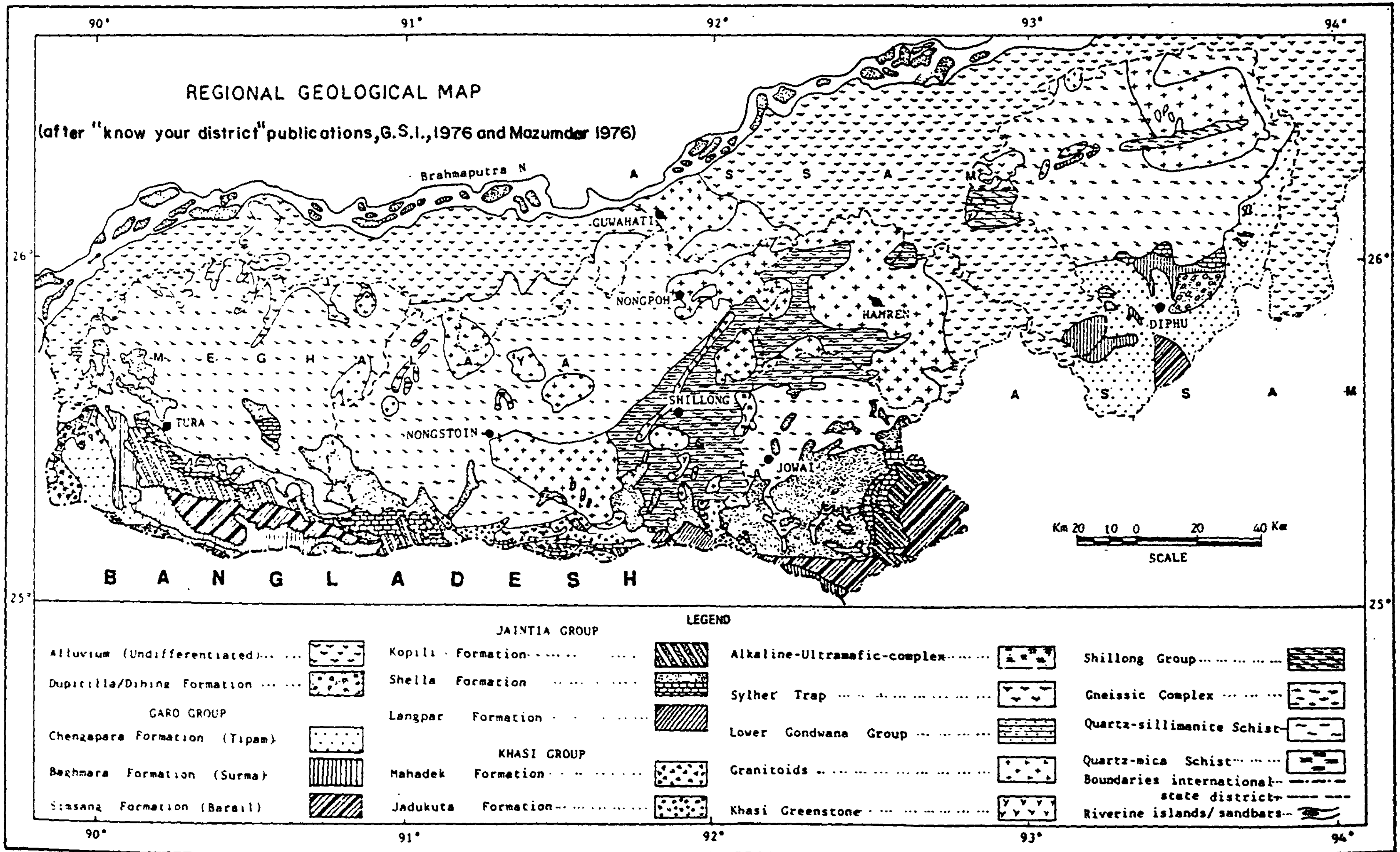

REGIONAL GEOLOGICAL MAP
(after "know your district" publications, G.S.I., 1976 and Mazumder 1976)
90°
91°
92°
93°
94°
26°
25°
Brahmaputra N
GUWAHATI
NONGPOH
HAMREN
DIPHU
SHILLONG
NONGSTOIN
TURA
JOWAI
A S S A M
M E G H A L A Y A
B A N G L A D E S H
Km 20 10 0 20 40 Km
SCALE
LEGEND
Alluvium (Undifferentiated)
Dupitila/Dihing Formation
GARO GROUP
Chengapara Formation (Tipam)
Baghmara Formation (Surma)
Simsang Formation (Barail)
JAINTIA GROUP
Kopili Formation
Shella Formation
Langpar Formation
KHASI GROUP
Mahadek Formation
Jadukuta Formation
Alkaline-Ultramafic-complex
Sylhet Trap
Lower Gondwana Group
Granitoids
Khasi Greenstone
Shillong Group
Gneissic Complex
Quartz-sillimanite Schist
Quartz-mica Schist
Boundaries international
state district
Riverine islands/ sandbars

Fig.(4)

absence of such data this Complex is being preferred to be called herein as the " Precambrian Gneissic Complex." It comprises schistose members as well as gneisses of varying composition. Gneisses are by far the dominant constituents of the Complex represented by biotite gneiss, biotite granulite, biotite - hornblende gneiss, quartz-sillimanite gneiss etc., locally containing cordierite, garnet, clinopyroxene and chondrodite.

These lithounits are considered equivalents to the formations of the Indian Shield (Evans 1964). The schistose members are represented by amphibolite, mica schist, quartz-sillimanite schist, metabasite etc. locally with garnet, andalusite, sillimanite etc. The mineral assemblage within the gneisses and the schistose members indicate high P-T regime of regional metamorphism (upper amphibolite-granulite facies).

Structurally the Gneissic Complex shows very complex and polyphase folding concurrently with multistage metamorphism. Three phases of folding have been identified by Murthy et al. (1976b).

(i) The earliest is an isoclinal phase of broad recumbent-reclined folds regionally having E-W axial surfaces.

(ii) The superposed tight isoclinal folds having ENE-WSW and NE-SW axial surfaces.

(iii) The third phase is marked by broad N-S warps.

The dominant S-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 show parallelism with the Eastern Ghat trends of Orissa and E-W strikes with Satpura trends (Banerjee 1964). The Gneissic Complex was cratonised prior to the initiation of the Shillong Basin.

NON PORPHYRITIC MIGMATITIC GRANITOIDS : This class of rocks occur throughout the Gneissic Complex in all scales as veinlets, interfolial permeation, patches, lenses and small irregular bodies. Conspicuously it shows diffused boundaries with the rocks of Gneissic Complex often producing "Nebulites". These granitoids show the following three important variants and represent mobilizates of Mehnert (1968). These mobilizates have not permeated the Shillong Group of rocks implying that the attendant migmitisation to be pre Shillong Group.

(a) **Dioritic Mobilizates :**

It is a spotty or speckled rock. The spots arises because of aggregates, clots and knots of biotite, epidote, hornblende, magnetite, quartz, plagioclase, sphene etc. This texture is caused by decussate arrangement of the above minerals. Rest of the constituents of the rock are the same minerals that form the clots but, in random orientation.

(b) **Grano-Dioritic Mobilizates :**

With the diminished proportion of the mafics particularly hornblende and relative increase of potash felspar and quartz, the dioritic mobilizates passes into Granodioritic phase. It shows texture similar to Dioritic mobilizates.

(c) **Granitic Mobilizates :**

These are typical granites, with or without foliation. These rocks are medium grained and represent the latest (youngest) "Plutonic" migmatites. By far this is the dominant migmatite type within the Gneissic Complex and forms "Domes".

SHILLONG GROUP : It overlies the Gneissic Complex with an unconformity and comprises friable quartzite with subordinate phyllites, siltstone-slate, quartz-sericite schist and minor diamictite. The rocks occur in an NE-SW elongated tract in Khasi hills and extend upto the northwest fringe of Karbi-Anglong district (Mikir Hills) of Assam (Anon 1974).

By and large the Shillong Group of rocks are weakly metamorphosed except at few places showing higher grades. The primary sedimentary structures are well recognisable such as bedding, laminations, current bedding, ripple marks, penecontemporaneous deformational structures etc.

The Shillong Group of rocks show a zone of subvertical dips with local reversals from west of Mawphlang to Barapani and its NE extension, away from this zone, dips show gentle rolling disposition. Such folding represents "Intermediate crestal type folding" of Beloussov (1962).

KHASI GREENSTONE : The Khasi Green Stone occurs as isolated linear bodies in the Shillong Group of rocks. These are intrusives both in the argillaceous and arenaceous facies of Shillong Group. The overall structural pattern suggests their phacolithic nature about NE-SW axis, sending dikes and appophyses in the Shillong Group of rocks. The Khasi Greenstone is represented mainly by dolerite, epidiorite and amphibolite. The Khasi Greenstone has so far not been recorded from outside the Shillong Group of rocks (Murthy et al. 1976b). These metabasites appear to have been emplaced along tensional fracture system. At places granitoid leucosomes are seen permeating the Khasi Greenstone.

PORPHYRITIC GRANITOID : These occur as a large number of Plutons of varying shapes and dimensions throughout Massif. Some of the important Plutons are -

1. Bartha Langso Pluton
2. Kharkouta Pluton
3. Kyrdem Pluton
4. Mawdoh Pluton
5. Mylliem Pluton
6. Nongpoh Pluton
7. Nongrang Pluton
8. Rambrai Pluton
9. Rongeng Pluton
10. South Khasi Pluton
11. Baut Bazar Pluton
12. Kaziranga Pluton

These Plutons are porphyritic, potash rich depicting large megacrysts of microcline in a groundmass of plagioclase, quartz, biotite and microcline.

Physiographically these Plutons have domal expressions. Some of the Plutons particularly South Khasi and Mylliem show intrusive relationship with Shillong Group of rocks. Available geochronological ages of these Plutons varies from 479 ± 26 m.y.

to 690 ± 19 m.y. and do not show any systematic geographical age progression (Chinote et al. 1988, Van Breemen et al. 1989, Kumar 1990, Ghosh et al. 1991). The Plutons exhibit crude foliation locally and homophanous nature at places. It is seen that some of the Plutons have straight boundaries with the enclosing rocks viz., Gneissic Complex and the Shillong Group indicating diapiric emplacement along existing megafractures. According to Mazumdar (1976), these Plutons are comparable in composition and diapiric emplacement to the porphyritic Plutons of Assam, representing late tectonic events. As per Mazumdar (op.cit) the materials for these Plutons were spread in the lower levels of the crust as thin sheet of appropriate composition and the event occurred after the emplacement of the Khasi Greenstone.

LOWER GONDWANA GROUP : It occurs in the Singrimari (Halliday-ganj) area, at the western tip of Garo Hills ($25^{o}43'$N : $89^{o}54'$E) within 4km of Indo-Bangladesh border. The outcrop extends over a length of 1km and a width of 400m just east of Manikachar road, Fox (1934) was the first to report the lower Gondwana rocks in the area.

The lower Gondwana Group is represented by Talchir and Karharbari Formations. The former is represented by basal tillites, sandstone with conglomerates, siltstone and shale. The latter is represented by very coarse to coarse grained sandstone with conglomerate, siltstone, shale and coal. (Raja Rao 1981, De and Boral 1982).

The Talchir Formation unconformably overlies the Gneissic Complex and granitoids. It is conformably overlain by Karharbari Formation. The beds show a general N-S strike with dips of 10-20 towards west. West of Singrimari, the Gondwana beds get concealed under thick Brahmaputra alluvium.

SYLHET TRAP : The Sylhet Traps are exposed in a narrow E-W patch between latitudes $25^{o}15'$ N and $25^{o}12'$N and longitudes $91^{o}15'$E and $92^{o}15'$E (Medlicot 1869). They are of the nature of plateau flood basalts. The strip is about 80km long and 4km wide along the southern border of the Shillong plateau. The traps are confined to the south of the Raibah fault. The maximum exposed thickness is about 550m - 600m. The traps overlie the upper Cretaceous-Eocene sediment sequence. The sediments and the traps form a monocline becoming a flexure. At places the sediment cover is eroded away exposing traps as inliers.

The Sylhet traps comprises predominently basalts and minor alkali basalts (nepheline tephrite), rhyolite and acid tuffs. They occur as flows and are 5m-7m in average thickness. They show flow breccias at their top. Texturally the traps show following variations :

1) Non porphyritic
2) Micro porphyritic
3) Mega porphyritic

The vesicles are filled by secondary quartz, calcite and zeolites. Basalt dikes are fairly common within the flows and adjoining to the Gneissic Complex. The dikes occur as swarms within the trap rocks. The general trend of the dikes is NNE-SSW, NE-SW and E-W in the Khasi and Garo Hills. At places alkaline rocks (Lamprophyres) are also seen as dikes in association, possibly related to the same event. The Sylhet traps are considered to be equivalent to the Rajmahal Traps of pre Upper Cretaceous age (Krishnan 1982). Radiometric ages vary from 92 ± 3 m.y. for lower part to 138 m.y. from different parts of the Sylhet trap as per officers of the Geological Survey of India.

ULTRAMAFIC-CARBONATITE COMPLEX : This complex occurs in Sung Valley in East Khasi Hills as an oval shaped body covering about 26sq.km forming a bowl like depression. It is intrusive into Proterozoic Shillong Group. It is flanked by the Mylliem and kyrdem Plutons on either side. The Complex is emplaced along the junction of two prominent lineaments trending E-W and NNW-SSE of which the latter appears to be a major fault. Fission track dating of apatite from carbonatite has given an Upper Cretaceous age (84 ± 13 m.y. to 90 ± 10 m.y.) for the Complex (Chattopadhyay and Hashimi 1984). It is a manifestation of a major igneous activity in the Massif soon after the eruption of Sylhet Traps with little time gap between the two events.

The major rock types in the Complex are serpentinite, pyroxinites, syenite, carbonatite etc. The body shows zoning and partial development of ring structure. A number of NE-SW trending faults effect the Complex.

CRETACEOUS-TERTIARY SEDIMENTARY SEQUENCE : The Cretaceous-Tertiary Sedimentary pile occurs along the southern fringe of the Shillong Massif. It is a thick and extensive sedimentary sequence, physically continuous with the Cretaceous-Tertiary sequence of the Bengal Basin. This sedimentary sequence is divisible into four Groups viz., Khasi Group, Jaintia Group, Garo Group and Dupitila Group respectively (Table-1). The interformational contacts within the pile is continuous without any sedimentological or faunal break. Recent work of the geologists of the Geological Survey of India has placed the contact between the Cretaceous and the Tertiary at the base of the Langpar Formation of the Jaintia Group which is based mainly on palaeontological studies (Anon 1989).

(a) **Khasi Group :**

The Khasi Group represents the Cretaceous section of the pile and is represented by Jadukuta Formation, Bottom conglomerate Formation and the Mahadek Formation. The Jadukuta Formation nonconformably overlies the Sylhet Traps and represents an arenaceous facies comprising conglomerate at the base overlain by pebbly sandstone, coarse grained sandstone with carbonaceous streaks. This formation is limited to the north of the Raibah fault which formed the limit of the shore line. The progressive migration of the shoreline towards north is marked by the presence of thick conglomerate bed, north of the Raibah fault, known as the Bottom conglomerate Formation. These two Formations are overlain by Mahadek Formation with continuous contact. It 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 coarse to medium grained sandstone which is mainly quartzwacke. The upper part of the Mahadek Formation is often Glauconitic imparting it a greenish coluration (Anon 1974).

(b) **Jaintia Group :**

The Jaintia Group marks the onset of change in depositional environment. It is best developed in Cherrapunji area. Vestiges of it is found as north as Um Rilang ($25^{o}43'$ N : 91^{o} $47'$ E) lying west of Umiam Lake (Anon 1974; Raja Rao 1981) in Khasi Hills and Darugiri ($25^{o}40'$ N : $90^{o}50'$ E) in Garo Hills. It represents commencement of calcareous facies deposited in a stable shelf segment of the basin. This Group is divisible into three Formation viz. Langpar Formation, Shella Formation, and the Kopili Formation.

The Langpar Formation represents the beginning of the Tertiary segment of the sedimentary pile of Shillong Massif. It overlies the Mahadek Formation with a gradational contact. The Langpar Formation represents a sequence of carbonaceous siltstone, calcareous shale, sandy limestone and marks a distinct change in sedimentary facies. The base of the Langpar Formation marks the boundary of Cretaceous-Tertiary sequence in Meghalaya (Anon 1989). The succeeding Shella Formation conformably overlies the Langpar Formation and comprises alternations of three sandstone and limestone members (Murthy et al. 1976a). These have

(Plate–1): Umiam Lake formed by damming the River (left corner) at Barapani. Foreground showing slope forms.

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. The Shella Formation is succeeded by Kopili Formation with a gradational contact. The rocks represent alternations of thin sandstone and shale with minor thin beds of limestone. The base of the Kopili Formation represented by a shale horizon often contain phosphatic nodules.

(c) **Garo Group :**

The Garo Group represents the upper Tertiary sequence and is well exposed in Garo Hills. It is divisible into three Formation viz., Simsang Formation, Baghmara Formation, and the Chengapara Formation (Anon 1974). Lithologically and faunal assemblage wise these three formations are akin to the Barail, Surma and Tipam formations of Assam-Arakan basin (Anon 1989; Roy and Asthana 1989). The oldest of the three i.e. the Simsang Formation overlies conformably the Kopili Formation and represents a cycle of massive festoon cross bedded sandstone, siltstone members. The succeeding Baghmara Formation has gradational contact with the underlying Simsang Formation and is mainly confined in the eastern tracts of Garo Hills. It is represented by impersistent beds of felspathic sandstone with minor mudstone. Pebbly sandstone-conglomerate, massive clay and silty clay-sand beds. The overlying Chengapara Formation also has gradational contact with the underlying Baghmara Formation. It comprises poorly cemented fine grained micaceous sand blue to brown siltstone and clays with this beds of marls at the base.

A prominent angular unconformity marks the top of Chengapara Formation in the western parts of Garo Hills. This angular unconformity is well exposed in the Tura-Dalu road section near Nokehi and north of Mahendraganj (Anon 1974).

(d) **Dupitila Group :**

The Chengapara Formation overlies unconformably by the Dupitila Group, representing the Mio-Pliocene stratigraphic sections (Mathur and Evans 1964; Anon 1974). It consists of alternations of coarse felspathic sandstone with thin layers of pebbles of vein quartz and mottled sandy clays.

QUATERNARY AND RECENT DEPOSITS : Isolated patches of older alluvium unconformably overlies the eroded top of the Tertiary rocks. It is mainly confined along the southern and western borders of Garo Hills and along the southern flanks of Khasi Hills. Meghalaya; northern and eastern flanks of Hamren subdivision, and as isolated patches along western and eastern flanks of Diphu subdivision of Karbi Anglong Assam. 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. Recent alluvium consisting of fine silty sand and light to dark grey clay with rare pockets of coarse sand and pebbles occur in river valleys. The sands invariably contain abundant mica. The recent alluvium are mainly confined along the northern flanks of Garo and Khasi hills in Meghalaya. The Brahmaputra plains flanking the Massif is by and large made up of recent alluvium.

PALAEOGEOGRAPHY AND PALAEOENVIRONMENT :

The Precambrian basement of the Shillong Massif is a remnant of the northeastward extension of the Indian peninsula. It remained a positive landmass experiencing orogenic movements leading to complex folding and fracturing of the ancient rocks till precambrain times and was subjected to peneplanation. The central part of the plateau during the Precambrian time developed a linear trough into which the Proterozoic Shillong Group of rocks were deposited over the peneplained Precambrian basement. Subsequently these were uplifted, folded and metamorphosed due to the intrusion of acid magmatic Plutons and basic ultrabasic bodies (Khasi Greenstone).

The post Precambrian landmass suffered peneplanation till the beginning of Permo-Carboniferous when the Gondwana sediments commenced deposition as seen in Singrimari area. The landmass again suffered peneplanation till Jurassic times resulting into the formation of flat leveled surfaces preserved over the uplifted plateau as seen today. By the end of jurassic the southern flank of the plateau had eruption of plateau basalts along linear E-W fissures, known as Sylhet Traps. The close of eruption marked the subsidence of southern block and uplift of northern block along the E-W trending Raibah fault. At the same time the Cretaceous (Maestrichtian) sea transgressed into the rapidly sinking southern block. The sea extended from Baghmara to Mahadebkhola in the Jadukuta river and lashed against fault bounded high cliffs eastwards, south of the Shillong Plateau. The sea encroached north over a large fault bounded depositional basin traceable upto Jaintia Hills and deposited the marine beds over the Precambrian, and Permo-Carboniferous peneplained basement.

At the end of Mahadek times a differential tectonism raised Garo Hills marine shelf into a positive area while in the Shillong Plateau, part of the sea transgressed Mawkma. Thus evidences exists that Permo-Carboniferous and Tertiary deposition took place as north as Latitude 25^{o}43' N on this landmass. The Quaternary sediments were laid in the glacio-lacustrine to fluviatile environments over the surfaces of the Tertiary cover sediments.

TECTONIC EVOLUTION OF THE SHILLONG MASSIF :

Tectono-stratigraphically, the Massif can be divided into three domains each having distinct evolution.

(a) The Peninsular Shield Extension comprising the Gneissic Complex.

(b) Intracratonic sedimentary basin represented by the Shillong Group.

(c) The Mesozoic-Tertiary sedimentary sequence along with the Sylhet Trap occupying the southern fringe of the plateau.

Satellite imagery, aerial photographs and topographic maps of Meghalaya and adjoining areas reveal long and persistent lineaments segmenting the Massif. According to Murthy et al. (1976b), these lineaments are manifestations of deep seated fracture systems having repeated reactivation. The various lineaments have been classified as per their activity and geological domain. The lineaments have been Grouped into four classes with interval of 20^{o} on either side of N-S, NE-SW, NW-SE, E-W alignments. (Fig.5) These classes conform the lineaments of Murthy et al. (1976b). Of these four classes, the NE-SW and NW-SE have predominently controlled the geometry of the Massif. The Massif has suffered maximum dissection and fragmentation along these trends indicating their continued reactivations. The NE-SW trending Proterozoic interacratonic Shillong basin and the Karbi Anglong segment (Mikir Hills) of the Massif is fragmented by the NW-SE Kopili fault system. The important lineaments are given below :

Domain wise Important Lineaments :

a) Precambrian 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	:	Fractures mainly

b) Proterozoic Shillong Group

NE - SW dominant	:	Fold axes, long axis of the basin, fractures, trends of intrusions of basic bodies.
E - W minor	:	Fractures

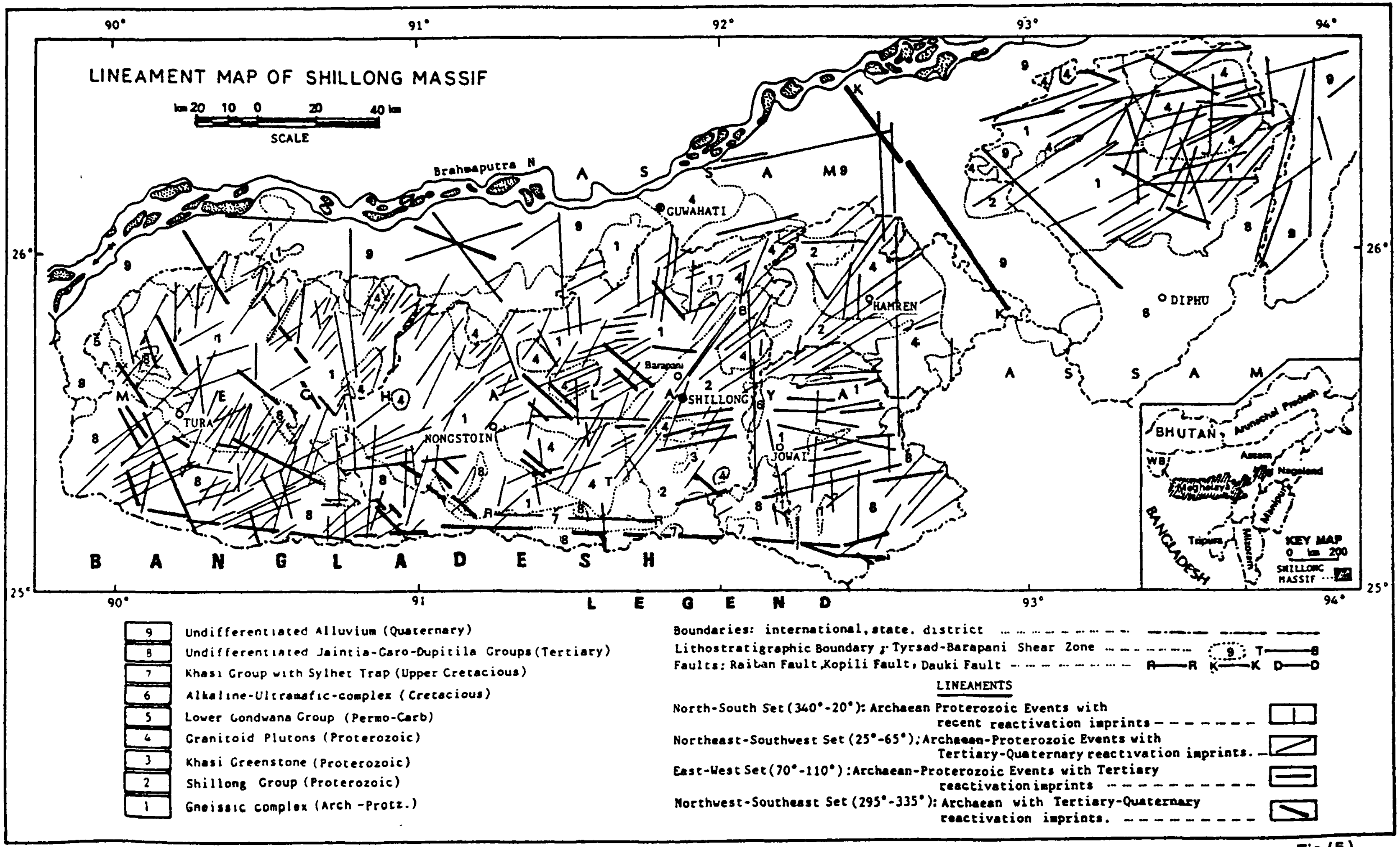

LINEAMENT MAP OF SHILLONG MASSIF
km 20 10 0 20 40 km
SCALE
Brahmaputra N
ASSAM
GUWAHATI
SHILLONG
Barapani
NONGSTOIN
TURA
JOWAI
HAMREN
DIPHU
BANGLADESH
MEGHALAYA
BHUTAN
Arunachal Pradesh
Assam
Nagaland
Manipur
Mizoram
Tripura
WB
KEY MAP
0 km 200
SHILLONG MASSIF
90°
91°
92°
93°
94°
25°
26°
LEGEND
9 Undifferentiated Alluvium (Quaternary)
8 Undifferentiated Jaintia-Garo-Dupitila Groups (Tertiary)
7 Khasi Group with Sylhet Trap (Upper Cretacious)
6 Alkaline-Ultramafic-complex (Cretacious)
5 Lower Gondwana Group (Permo-Carb)
4 Granitoid Plutons (Proterozoic)
3 Khasi Greenstone (Proterozoic)
2 Shillong Group (Proterozoic)
1 Gneissic complex (Arch-Protz.)
Boundaries: international, state, district
Lithostratigraphic Boundary ; Tyrsad-Barapani Shear Zone
Faults: Raitan Fault, Kopili Fault, Dauki Fault
LINEAMENTS
North-South Set (340°-20°): Archaean Proterozoic Events with recent reactivation imprints
Northeast-Southwest Set (25°-65°): Archaean-Proterozoic Events with Tertiary-Quaternary reactivation imprints.
East-West Set (70°-110°): Archaean-Proterozoic Events with Tertiary reactivation imprints
Northwest-Southeast Set (295°-335°): Archaean with Tertiary-Quaternary reactivation imprints.

Fig.(5)

c) <u>Proterozoic Porphyritic Granitoids</u>

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) <u>Mesozoic Sylhet Trap (Jurassic ?)</u>

E - W most dominant	:	Line of effusion, dikes and flexures.
NW - SE minor	:	Dikes in the northern parts of the upland
NE - SW minor	:	- do -

e) <u>Jurassic-Cretaceous Sedimentary Pile</u>

E - W dominant	:	Raibah lineament

f) <u>Tertiary Sedimentary Pile</u>

E - W dominant	:	Facies contact, Dauki fault zone to the south, Jorhat-Tezpur fault zone to the north.
N - S strong	:	Dhubri Fault
NW - SE minor	:	Borchi Fault Kopili Fault

Most of these lineaments are intraformational, so the slip components, if any, associated with them is not discernible readily. Hence, it is not always possible to differentiate the lineaments into faults and megasutures in the Massif. However, the lineaments coupled with scarp faces or bluffs are essentially the manifestations of fault systems.

The alignments of the trunk streams dissecting down to the Precambrian milieu are the imprints of Quaternary fluvial cycles over the Pre-Tertiary exhumed surfaces of the Massif. Such over printing has progressed along the lineaments reflecting their antiquity, reactivation and deep seated nature. The southern fringe of the Massif has the Pre-Tertiary topography concealed below the cover sediments. The drainage network have entrenched deep gorges along the lineaments initiating exhuming process. In contrast, the northern fringe has exhumed topography with wide embayments advancing southwards into the Massif along these lineaments.

The fundamental and earliest lineament trends are E-W. Later, in the Precambrian, this trend was superseded by NE-SW trend which probably persisted during the intrusion of the porphyritic granitoids. The Precambrian is thus marked successively by the dominance of E-W trend. The porphyritic granitoids appear to have been emplaced along the NE-SW trend. The Khasi Greenstone is also emplaced along the NE-SW lineament within the Shillong Group. This lineament appears to be a deep suture along which major vertical tectonics have played vital role in shaping the evolution of the Massif. The boundary between the Precambrian and the Jurassic Sylhet Traps is an important E-W lineament. This E-W trending lineament is the famous Raibah Fault dipping towards south. According to Murthy et al. (1976b) this fault was active till Cretaceous. Further south, the Dauki fault, also, a E-W lineament is known to have been active till Tertiary and has been responsible for the uplift of the Massif.

The Precambrian Gneissic Complex is the northeastern extension of the peninsular shield. This segment forms the core part of the Massif. It is the basement for the subsequent events. The central part of the complex covering Khasi and Jaintia Hills, developed a linear and narrow NE-SW trending basin during the late Proterozoic. 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 Precambrain 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 intracratonic 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 fissures i.e. Raibah fault system along which the southern block subsided and the northern block upheaved. The end of Jurassic saw deposition and 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 got 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 southern Khasi and Garo Hills, shallow lacustrine basins were formed. In these basins the Dupitila sediments (Mio-Pliocene) were deposited. Over these the subrecent to recent (Quaternary) 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 and Mikir hills than in Khasi-Jaintia Hills.

Many of the lineaments are still active as evidenced by the high micro seismic activities in and around the Shillong Massif. Some of the lineaments when traced towards north into the Brahmaputra plains as well as towards south into the Surma plains show evidences of Neotectonic movements. Probably these activities are the manifestation of release of built up stress mainly through vertical movements coupled with little or no lateral displacement.

(B) LOCAL GEOLOGICAL FRAMEWORK

The Umiam basin is confined to the eastern part of the Shillong Massif exposing by and large Shillong Group of rocks, Granitoid Plutons and the Gneissic Complex (Fig.6). The generalised lithostratigraphic sequence of the are is given in Table (2).

The lithounits flanking the basin have been also considered for maintaining geological continuity as they too have

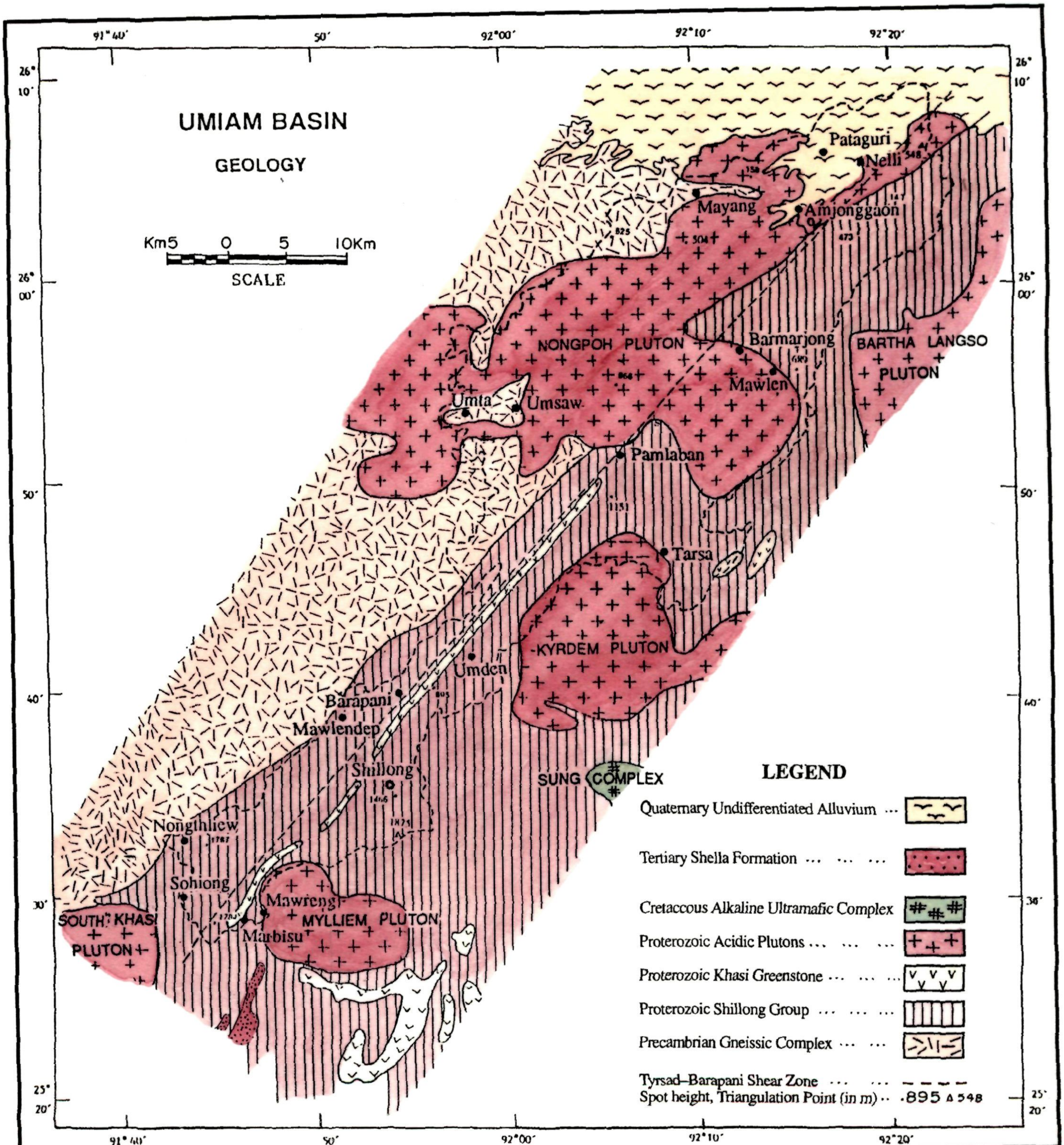

UMIAM BASIN
GEOLOGY
Km5 0 5 10Km
SCALE
NONGPOH PLUTON
BARTHA LANGSO PLUTON
KYRDEM PLUTON
SUNG COMPLEX
MYLLIEM PLUTON
SOUTH KHASI PLUTON
Pataguri
Nelli
Mayang
Amjonggaon
Barmarjong
Mawlen
Umta
Umsaw
Pamlaban
Tarsa
Umden
Barapani
Mawlendep
Shillong
Nongthliew
Sohiong
Mawreng
Marbisu
LEGEND
Quaternary Undifferentiated Alluvium
Tertiary Shella Formation
Cretaceous Alkaline Ultramafic Complex
Proterozoic Acidic Plutons
Proterozoic Khasi Greenstone
Proterozoic Shillong Group
Precambrian Gneissic Complex
Tyrsad–Barapani Shear Zone
Spot height, Triangulation Point (in m) .895 Δ 548
91°40′
50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
30′
25° 20′

Fig.(6)

Table-2

Lithostratigraphic Succession in the Basin

Quaternary	Undifferentiated Terrace Deposits	: Older and Newer alluvium colluvium
- - - - - -	Unconformity - - - -	- - - - - - - - - -
Tertiary	Shella Formation	: Ferruginous coarse grained sandstone and shale.
Cretaceous	Sung Valley Complex	: Alkaline mafic-ultramafic rocks.
- - - - - -	Intrusive Contact	- - - - - - - - - -
Proterozoic	Granitoid Plutons	: Medium to coarse grained and megacrystic leucogranitoids.
- - - - - -	Intrusive contact	- - - - - - - - - -
Proterozoic	Khasi Greenstone	: Basic sills and dykes : mainly dolerite, epidiorite and amphibolite.
- - - - - -	Intrusive contact	- - - - - - - - - -
Proterozoic	Shillong Group	: Cyclothem of Psammitic and pelitic meta sedimentary facies represented by an association of quarzite /Phyllitic quartzite and siltstone-shale-slate-phyllite with basal conglomerate. Locally mica-schist and ferruginous quartzite.
- - - - - -	Unconformity	- - - - - - - - -
Precambrian	Gneissic Complex	: Quartz biotite gneiss, hornblende biotite gneiss, amphibolite, mica-quartz schist, mica-sillimanite schist-migmatised.

exercised control on the basin configuration (Fig.6).

GNEISSIC COMPLEX : The Gneissic Complex is confined towards the northwestern flank of the basin. However, within the basin, it is exposed as minor strips along the left bank periphery only. It stretches from the upper reaches of the basin from near Nongthliew in the southwest to the lower reaches near Mayang.

The Gneissic Complex is an amalgamation of the oldest lithounits in the area and forms the Precambrian basement. It is unconformably overlain by the Shillong Group as well as the younger cover sediments.

It is represented by quartz biotite gneiss, hornblende biotite gneiss, amphibolite, mica quartz schist and mica sillimanite schist. These rocks are migmatised to varying extent as evidenced by the presence of leucosomes of different sizes mostly aligned concordant to gneissosity and folia. The gneisses are mostly medium grained, greyish to pinkish rocks composed of pink to grey coloured felspars (K-felspar), quartz, biotite with magnetite as accessories. The gneissosity is defined by alternations of granoblastic quartzo-felspathic materials and micaceous or prismatic mineral rich layers. With increase in micaceous mineral content the gneisses grade into schists reflecting the original composition variation. Locally presence of fibrolite, sillimanite blades and cordierite in the rocks indicate that they have undergone upper amphibolite facies of regional metamorphism (Mazumdar 1976, 1986). These rocks also depict a late Proterozoic-early Palaeozoic thermal overprint (500-700 m.y.) related to the emplacement of Granitoid Plutons (Chinote et al. 1988; Ghosh et al. 1991).

The Gneissic Complex show polydeformation resulting in complex fold patterns. The earliest folds are represented in the basin as tightly appressed synformal to antiformal discontinuous structures with NNE-SSW and NE-SW axial planes. These fold traces have guided the development of major stream segments and drainage networks in the basin (c.f. Fig.7). At the same time these complex folds and repeated reactivation of the basement fractures have serrated the left bank periphery (c.f. Fig.21).

SHILLONG GROUP : The major part of the basin is occupied by the Shillong Group of rocks. The narrow upper reaches of the basin from Sohiong in the southwest to near Tarsa in the northeast is completely entrenched in Shillong Group. The contact with the underlying Precambrian Gneissic Complex runs along the left bank periphery of the basin.

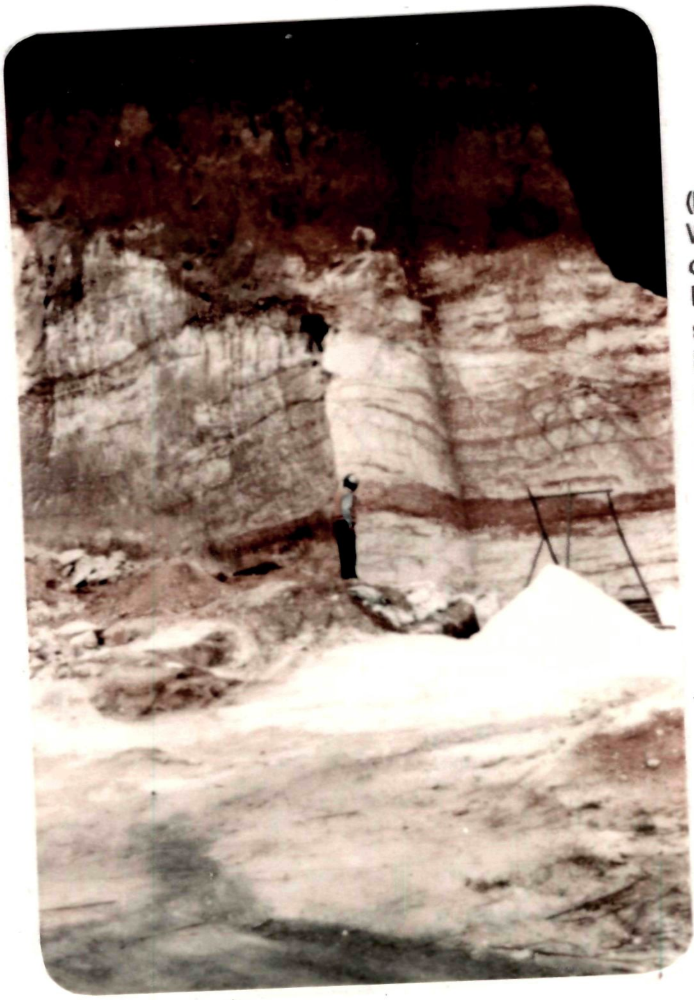
Downstream of Tarsa, the Shillong Group occupies only the southern half of the lower reaches of the basin. Conspicously, north of Tarsa it is disrupted by the Nongpoh Pluton. Where the lower reaches of the basin commences to widen out. However, it again continues towards northeast from near Barmarjong to beyond Nelli in the terminal part of the basin.

The Shillong Group is a metasedimentary facies comprising a clastic cyclothem with psammitic and pelitic components. It is mainly represented by an association of Quartzite, phyllitic quartzite, phyllite, slate-silstone-shale, basal diamictite and mica schists. The different lithounits show lateral as well as vertical variations. The psammitic rocks are ferruginous in nature and on weathered surfaces, have lot of limonitic or goethitic encrustations.

The Shillong Group commences with a basal oligomictic diamictite comprising clasts of vein quartz in phyllitic to sandy matrix. Quartzite-phyllite are the dominant rock types of the Shillong Group in the basin and forms prominent ridges, ledges, escarpments and gorges due to differential erosion. Locally, the quartzite are highly friable, the weathered horizons look like silica sand and are used in building-construction activities in place of river sand (Plate-2).

Thin discontinuous bands of intraformational diamictite is present locally showing elongated clasts of vein quartz in an argillaceous matrix. The elongation of these clasts is not compatible to the regional deformation suffered by the rocks. Such elongation is attributed to localised shearing whereby the clasts were stretched parallel to local shear planes.

In general, the rocks are weakly metamorphosed to greenschist facies and retain their sedimentary fabric indicating absence of any large scale deformation. Cross bedding, oscillation ripple marks are some of the important geopetal fabric still



(Plate-2):
Weathered quartzite quarry for "sand." Note ferruginous stains along bedding/schistosity planes and joints, and depth of soil profile.

(Plate-3):
Subvertical dips in phyllitic quartzite in vicinity of Tyrsad-Barapani Shear Zone. Daylighting of bedding/schistosity along slope cuts has induced "rockfall" (upper right corner).

preserved in the psammitic units of the Group. However, the rocks are regionally metamorphosed and show open folds with axial traces parallel to bedding.

At places, andalusite, chloritoid, garnet and staurolite are present indicating locally higher grade of metamorphism (Mazumdar 1986). This localised event is the thermal overprinting, a manifestation of acid and basic magmatism on the weakly metamorphosed metasediments.

The general trend of bedding as well as schistosity of the rocks is NE-SW with shallow dips towards either side due to gentle warping and rolling. However, locally steep dips are encountered particularly in vicinity of nalas and streams. Such steepness of dips indicate structural dislocation and tilting of beds. Conspicuously, a zone of vertical to subvertical dips is noticed running parallel to Umiam river, related to the Tyrsad-Barapani shear zone (Plate-3).

Structural benches are commonly seen to occur at different levels, related to vertical movements along basement fractures. The bedding and basement reactivated fractures in rocks show remarkable control over 1st order and 2nd order stream segments.

KHASI GREENSTONE : They are dark green to black, fine to medium grained metabasic intrusive within Shillong Group. It has concordant to discordant relationship with the Shillong Group. They occur as detached tabular NE-SW trending bodies (Plate-4), northeast of Sohiong, north of Barapani, Raitong, Pamlaban and Barmarjong. The Khasi Greenstone is represented by metadolerite, epidiorite, amphibolite generally with weak schistosity defined by the dimensional preferred orientation of the prismatic minerals (Choudhury and Rao 1975; Murthy et al. 1976b; Mazumdar 1986). Mineralogically, the rocks comprise Amphiboles (actinolite-tremolite), Pyroxene, plagioclase, quartz, chlorite and biotite. The mineral assemblage indicate that the rocks are metamorphosed to Greenschist facies and have suffered retrogression.

The metabasic lenses stand out as linear ridges due to massive nature of the rock. But, the lenses proximal to the Tyrsad-Barapani shear zone are pulverised and consequently highly weathered. These weathered rocks have produced lateritic soil over them and have coated the adjacent rocks and soils with ferruginous stains.

GRANITOID PLUTONS : The basin and its adjoining area is studded with a number of Granitoid Plutons. Not only the Plutons occurring within the basin but the ones lying adjacent to it have exercised far greater control on the basin configuration than the other lithotypes.

The South Khasi Pluton, the Mylliem and Nongrang Plutons are exposed in the southwestern part of the basin. These Plutons act as competent barrier and have retarded lateral

(**Plate–4**): Khasi Greenstone exposure in Umiam River bed downstream of the dam.

(**Plate–5**): Older (Pleistocene) lateritic terrace along Umiam lake periphery.

expansion of the basin between Marbisu and Nongthliew, the headwaters of Umiam river. The Kyrdem Pluton is located towards the central part of the basin south of Tarsa.

These Granitoids are the product of the widespread late Proterozoic - early Palaeozoic (500-700 m.y.) acid magmatism in this northeastern part of India (Chinote et al. 1988; Ghosh et al. 1991). The Plutons are intrusive into the Precambrian Gneissic Complex and the Shillong Group of rocks. At the same time, enclaves of Khasi Greenstone are noticed within the Plutons indicating that the Plutons are younger than the Khasi Greenstone.

The Plutons are in general represented by megacrystic granitoids, invariably associated with pink felspar. Mineralogically, these granitoids comprise quartz, plagioclase, microcline, perthite and biotite. The megacrysts are mainly microcline and are upto 2cm long but megacrysts upto 5 to 6cm are also noticed locally. Crude gneissosity is preserved, the fold trace lines reveal presence of complex folds. Such relict complex folds in the Plutons is suggestive of their being the product of migmatisation and anatexis of the Gneissic Complex. The structural trend lines show swerving (elliptical) around the Plutons and are the signatures of the diapiric nature of the Plutons. These folds, structural trends and basement fractures have controlled the stream segment development in the basin (c.f. Fig. 7).

SUNG VALLEY COMPLEX : This is an oval to elliptical shaped depression outside the basin, south-east of Umiam lake (Fig.6). The complex is represented by an assemblage of alkaline-mafic-ultramafic-carbonatite rocks emplaced in Shillong Group.

The complex has not directly affected the basin configuration. However, similar depressions found as intermontane valleys within the basin could well be over similar rocks.

SHELLA FORMATION : This formation represents the part of Tertiary cover sediments in the basin. It is found outside the south-western limit of the basin as remnant of cover sediments. The formation occurs as relicts of thin sandstone, siltstones and clay beds, south of Marbisu and southwest of Mylliem Pluton overlying unconformably the Shillong Group. These remnants are the vestiges of the Tertiary sea incursion towards the north. The thin cover sediments indicate that they persisted further north towards the headwaters of Umiam river but, continuing erosion of these thin cover rocks has led to their southward retreat.

The retreat has exhumed the pre-Tertiary topography over the Shillong Group of rocks around Marbisu - Sohiong areas. The drainage network has not carved out deep valleys over the exhumed surface proximal to the present limit of cover sediments. This indicate that the retreat of cover sediments from the southwestern part of the basin is a recent phenomenon.

TERRACE DEPOSITS : These are undifferentiated Quaternary sediments overlying the Precambrian - Proterozoic milieu. In comparison to other lithotypes they have very localised distribution. Over the uplands these deposits are mainly confined along stream channels as thin impersistent strips. While on the lowlands towards the terminal part of the basin they occur as blanket deposits forming extensive terraces.

In the uplands thin strips of paired terraces are conspicuously seen along the Umiam flanks after the gorge section opens up into a wide valley forming the Umiam lake, and downstream of it. Along the eastern periphery of the lake around 980m elevation above m.s.l. it is possible to differentiate these deposits into two units. The older unit (Early Pleistocene) is compact, well oxidised and lateritic (plate-5). The younger unit unconformably overlies it, representing the Holocene, comprises friable, soft sandy-silty grey coloured sediments and localised colluvial aprons. Much of the older unit is concealed below the Holocene colluvium, talus scree and palaeolandslide debris at the base of hillslopes. Small patches of these terrace deposits continue downstream of the Umiam lake upto the confluence of Um Latar (near village Umlalteng) at elevation upto 820m above m.s.l. Similarly, a wide patch occurs between the confluence of component basins 17 and 30 (around the village Tarsa) with elevations from 780m to 760m above m.s.l. Interestingly, minor patches of late Pleistocene carbonaceous clays and peat is noticed in Upper Shillong area (around 1760m above m.s.l.) as valley fills, 8-10m below present ground surface. Presence of carbonaceous clays and peat at 1760m above m.s.l. indicate existence of shallow lakes during Pleistocene in the upper reaches of the basin.

However, the best development of the terrace deposit is seen in the lowlands, around and downstream of Amjonggaon after Umiam leaves the hilly tract. These sediments form widespread Late Pleistocene terraces in this area. Significantly the older oxidised Pleistocene sediments are not seen in this part of the basin. In general, here, these deposits show two levels of development. The lower level terraces occur between 55m and 50m above m.s.l. and form part of newer alluvium in the present day flood plains. The higher level terraces represent the older alluvium occurring between 60m and 55m above m.s.l. It defines the older flood plains of Umiam - Kopili - Brahmaputra bank oscillations. Due to it, these terraces have received detritus components from Umiam as well as Kopili - Brahmaputra rivers. This triangular lowland is a palaeo - indentation into the upland by Kopili - Brahmaputra river systems. At present, the Kopili - Brahmaputra rivers have migrated towards north leaving behind basin lowlands. Such changes are the direct response to Neotectonics (Trifonov 1978; Wallace 1986; Gregory and Schumm 1987).

Rare recent channel lag deposits and point bar accretions occur locally in Umiam bed. However, between component basins 59 & 62, 23 & 61 and 71 & 72, the Umiam segment has discrete channel accretions varying in size from 50m x 150m to

150m x 300m. These accretions occupy elevation from 840m to 820m, 640m and 560m above m.s.l., respectively.

STRUCTURES

The principal planar surface in the Gneissic Complex is the foliation and gneissosity. The trend of regional S-surface is NE-SW with moderate to steep dips on either side. On mesoscopic scale, S-shaped folds and reclined folds, refolded on more open pattern dominate the structural styles (Mazumdar 1986). As a result away from the nose of the folds the subsequent axial plane cleavages or acquired S-surfaces show transposed schistosity of the earlier phase of folds. According to Mazumdar (1986) the grade of metamorphism in the Gneissic Complex is of upper amphibolite facies.

The principal planar surface in the Shillong Group of rocks is the bedding, with NE-SW strike and moderate dips towards southeast. The foliation due to regional metamorphism is parallel to subparallel with bedding. The schistosity is prominent in pelitic members.

Broadly speaking, the fold pattern in Shillong Group is crestal type (Belloussov 1962) with steep dips near the crestal parts and shallow dips in adjacent parts. The following chief fold styles are recognised in the Shillong Group.

1. Appressed intrafolial folds, trend of the folds is subparallel to bedding or foliation. The dominant trend is NE-SW with low to moderate plunge.

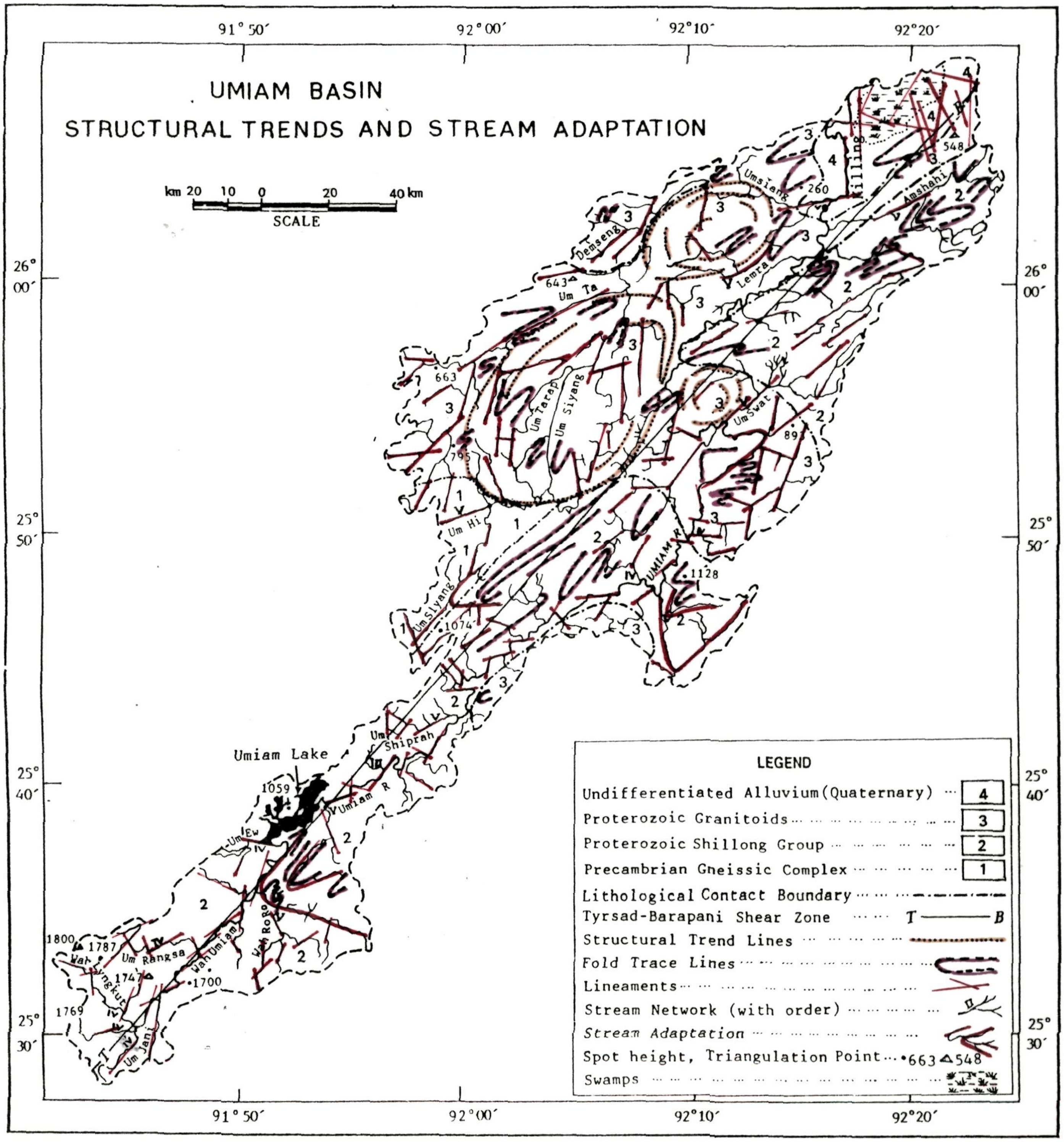
2. Asymmetrical to isoclinal folds, the trend of folds is also NE-SW, axial plane cleavage is subparallel to bedding. The amplitude of the fold varies from a few cm to several metre.

3. Broad open to asymmetric folds plunging from NNE to ENE.

The structural trends in the basin are depicted in Fig. (7). These structural trends include lineaments, fold form lines, fold axial traces and formational trend lines. These elements have largely controlled the geomorphic evolution of the basin.

The following lineaments depict signatures of reactivation as reflected by straight stream segments, shift in stream alignments and vigorous down cutting and associated seismicity - a manifestation of neotectonics or "Active Tectonics" of (Gregory and Schumm 1987). The alluvium forming the lowland in the terminal part of the basin has imprints of neotectonic activity along N-S and NW-SE lineaments indicating concealed basement discontinuities.

	Lithology	**Lineament**	**Nature**
1.	Alluvium	N-S NW-SE	Prominent Minor
2.	Plutons	N-S E-W NW-SE	Prominent Minor Rare
3.	Shillong Group	NE-SW NW-SE, N-S E-W	Prominent Minor Rare
4.	Gneissic Complex	NE-SW NW-SE N-S	Prominent Minor Rare



UMIAM BASIN
STRUCTURAL TRENDS AND STREAM ADAPTATION
km 20 10 0 20 40 km
SCALE
91° 50′
92° 00′
92°10′
92°20′
26° 00′
25° 50′
25° 40′
25° 30′
Umiam Lake
Demseng
Um Ta
Umsiang
Killing
Amshahi
Lemra
Um Tarap
Um Siyang
Um Swat
Um Hi
UMIAM R
Um Siyang
Um Shiprah
Umiam R
Um Ew
Wah Umiam
Um Rangsa
Wah Ropo
Um Jani
LEGEND
Undifferentiated Alluvium (Quaternary) 4
Proterozoic Granitoids 3
Proterozoic Shillong Group 2
Precambrian Gneissic Complex 1
Lithological Contact Boundary
Tyrsad-Barapani Shear Zone T B
Structural Trend Lines
Fold Trace Lines
Lineaments
Stream Network (with order)
Stream Adaptation
Spot height, Triangulation Point •663 △548
Swamps

Fig.(7)

The Gneissic Complex occurring along the left flank of the basin reveal tight fold envelopes with NE-SW to ENE-WSW axial traces showing gentle warping in vicinity of Nongpoh Pluton. The Shillong Group terrain depicts traces of open to tight folds with NE-SW and NW-SE axial trends. The Shillong Group as a whole has only minor open folds but, rare tight folds are also noticed along shear zones. However, the tight fold forms seen southwest of Barapani, northwest of Tarsa and between Amjonggaon and Nelli represent the folds of the "infracrustal" basement (Gneissic Complex). The dissection and deep denudation of the overlying Shillong Group has exposed the traces of these basement folds and the streams have adapted these traces (Fig. 7). It is a direct consequence of unloading of supracrustals so much so that the streams immediately "feel" the basement fractures as soon as their valley floor cut into the basement.

The Nongpoh Pluton also depicts tight fold forms with N-S and NE-SW axial trends reflecting the earliest fold geometry of the pre-migmatised parent rock. The Pluton conspicuously show curved trend lines indicating diapiric effects of the "rising" acid magmatic centres (Fig. 7).

TYRSAD-BARAPANI SHEAR ZONE

Tyrsad-Barapani shear zone is a prominent structural trend in the basin. It is a zone of subvertical dips (Plate-3) with local reversal, traced from Tyrsad in the southwest to Barapani in the northeast and continue further beyond Nelli. This zone is accompanied by shearing of the rocks. The shear planes mostly follow the axial planes of the folds. The shear zone is exposed in the G-S road cutting between Mawiong and Barapani Dam. The Sheared Quartz sericite schist and Sericite quartzite show minor drag folds in the road cutting. The carbonaceous slate/phyllite members of the Shillong Group exposed near Barapani Dam shows small scale shears, crushing - fracturing and minor faults.

This shear zone is discernible on satellite imagery and continues in northeast upto the fringe of Karbi-Anglong district of Assam and in the southwest beyond Tyrsad. The shear zone is a manifestation of deep seated basement controlled tectonic fracture, running along the axial part of the basin.

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CHAPTER - III

WEATHERING, MASS WASTING AND SOILS

WEATHERING, MASS WASTING AND SOILS

These three phenomena occur in nature in a sequence as part of "Circulation of Matter". Weathering is the initial phase in the denudational history of any landscape. The rocks must be weathered before the debris can be transported and erosion is very limited unless the agents of transport are carrying a load of debris.

Soil is the phase through which much of the rock waste of the lands must pass before it is ultimately removed. The movement of rock debris and soil on slopes is subjected to a large variety of processes, some of which act slowly but continuously like soil creep. However, process of mass wasting cause sudden movement of large masses of material followed by long period of quiescence.

WEATHERING

The inherent contrast in the underlying bedrock is brought into relief by process of weathering and erosion. Both weathering and erosion are strongly influenced by climate. A given set of climate and geological conditions causes the development of certain complex weathering and erosional processes. All landforms are to a greater or lesser extent the result of weathering (McCullagh 1978).

Weathering may be defined as the disintegration or decomposition of rocks insitu at or near the ground surface. It is primarily concerned with reduction of a rock mass to a form and size susceptible to erosion, which is accompanied by such agencies as mass movement, running water etc.

Soviet Geoscientist (Solovov 1987) recognises following four stages of weathering :

First stage : Initiation of physical weathering whereby the parent rocks change to coarse and fine grained detrital materials. Present day ongoing weathering sometimes terminates at this early stage under inclement environmental conditions and active denudation.

Second stage : It 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 carbonisation of primary minerals. The dominant secondary minerals produced belong to montmorillonite and nontronite groups. All the recent scree and surficial materials on slopes of mountainous terrain often reflect the second stage of weathering.

Third stage : It is characterised by further removal of alkaline and alkaline earth elements from the products of weathering. Consequently acidity sets in the zone of weathering. Under such conditions halloysite and kaolinite groups of secondary minerals are dominantly produced. The third stage of weathering is pronounced under conditions of slow or retarded denudation and relatively higher rainfall or wetting.

Fourth stage : It involves the formation of a residual allitic weathering crust enriched in iron and aluminoxides. Attainment of this stage is conditioned by presence of intensive chemical decomposition of primary minerals (rocks) coupled with very slow denudation in hot and humid conditions. The allite type of weathering is best represented by the red earths of the humid subtropical areas. The red colouration is due to the accumulation of ferric hydroxides in the residuum.

Out of the main rock forming minerals like quartz jasper, mica, amphibole, pyroxene, olivine etc., only quartz shows high resistance to chemical weathering. Moreover the mafic minerals are highly prone to chemical weathering. A very long geological time period is required for chemical weathering to be completed. As a result, appreciable quantities of unstable primary rock detritus and secondary clay minerals are often transported to the base level of erosion before they are reduced to free oxides. Therefore presence of rock fragments and their degree of weathering in sedimentary rocks is an important indicator of the weathering history of a terrain. Higher the incidence of rock fragments, closer the provenance of the detritus and lesser the time to which the parent rock suffered weathering processes. Similarly the degree of alterations of these fragments reveal the relative space time significance.

In extreme cases of weathering and very low natural denudation, wasteland is produced where anthropogenic activities degrade landscape beyond its resilient capabilities.

FACTORS CONTROLLING WEATHERING

The factors influencing weathering in an area are mainly temperature, rainfall, humidity, geology etc. The geologic factors more or less remain constant in an area over long period of time but, the other factors are time dependent. As a result, climate - temperature, humidity and rainfall exerts greater influence in the weathering processes.

The area experiences tropical monsoon climate and represent "selva climate process system" of Wilson (1968). The basin elevation varies from about 60m in the northeast to over 1900m in the southwest. The present climatic parameters show large variations due to this wide altitudinal differences. Broadly the basin shows three zones of climatic variations from the source area in the southwest to mouth area in the northeast (Table-3).

The basin area has three distinct seasons viz.,

(i) March to April (Summer Season)
(ii) May to Middle October (Rainy Season)
(iii) Middle October to February (Winter Season)

However, the rains spread over almost throughout the year with maximum precipitation during March - December. It is because the basin lies directly in the path of the southwest monsoon.

The high rainfall and the plateau nature of the area is

TABLE-3

CLIMATIC VARIATIONS IN THE BASIN

Area Parameter	**Southwestern Part Upper Shillong (Above 1700m)**	**Central Part Barapani station (100m-700m)**	**Northeastern Part Dharamtul-Chaparmukh stations (700m-60m)**	**Data Source**
RAINFALL(mm):				
Annual Mean	2148.30 (1962-1993)	2176.00 (1957-1988)	1900.00 (1971-1988)	Central Ground Water Board, Shillong.
TEMPERATURE(^{o}C):				
Annual Mean Maximum	20.70 (1962-1993)	24.50 (1960-1993)	29.30 (1971-1988)	Indian Agricultural Research Centre, Barapani
Annual Mean Minimum	12.80 (1962-1993	15.80 (1960-1993)	19.70 (1971-1988)	Indian Meteorological Department, Shillong.
RELATIVE HUMIDITY (%)				
Annual Mean Maximum	82.00 (1962-1993)	89.00 (1960-1993)	65.00 (1971-1988)	Meghalaya State Electricity Board, Shillong.
Annual Mean Minimum	69.00 (1962-1993)	76.40 (1960-1993)	44.00 (1971-1988)	

conducive to deep chemical weathering. Due to climate and altitude, the area 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 Plateau have helped in flushing out (Valeton 1972) the water soluble ions produced by chemical leaching along the flanks of the upland. This process is responsible for the formation of lateritic soils in large part of the basin.

The area experiences high rainfall (Table-3). 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 basin increases run-off along slopes causing sheet and gully erosion in the interfluve area of Umiam and Umsiang. Consequently, large quantities of material are constantly removed downslope thereby frequently exposing new bedrock to physical and chemical weathering.

Similarly, the area shows wide variations in temperature (Table-3). The high variation in temperature increases mechanical disintegration of rocks.

Humidity is related to rainfall and temperature, because of higher rainfall in the area, the humidity normally remains moderate to high (Table-3). As a result evaporation is slow. This indirectly helps in retaining the soil moisture for prolonged period. The overall effect is faster and prolonged chemical weathering.

Rock weathering has two general processes, operating in the area : 1) physical weathering, involving rock disintegration, without any change in mineralogical constitution, and 2) chemical weathering, involving complete or partial mineralogical reconstitution (alteration).

Chemical weathering is dominant phenomenon in humid areas as direct removal by "solution" is a more important factor in the reduction of the landscape than any other form of denudation (McCullagh 1978).

WEATHERING CHARACTERISTICS

The basin has the following broad lithological variations as per their spatial distribution :

1. The Gneissic Complex
2. The Shillong Group
3. The Khasi Greenstone
4. The Granitoid Plutons
5. Terrace Deposits

These five litho groups 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.

Gneissic Complex : The gneisses, by and large are the most competent rocks, occupying the left bank periphery of the basin.

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 blocks invariably show spheroidal weathering. The hummocky topography in the Gneissic terrain is due to accumulation of such boulders or remnants of it.

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

The Shillong Group : By far it is the predominant rock type in the area. The rocks are very well bedded and due to alternation of quartzite, phyllite and siltstone show differential weathering. The quartzites and phyllitic quartzite being more resistant to weathering, stand out in relief, while the siltstone and phyllites form subdued topography like "benches" and valley flats.

In areas where the beds have horizontal to subhorizontal disposition the physical weathering of rocks is much impeded except where the slopes have been destabilised by excavations. However, in areas where rocks have steeper or vertical dips the physical weathering is more pronounced (Plate-6), particularly in vicinity of Tyrsad-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 pulverised along "shears" and weathers out faster as slides of different scales and modes.

Chemically the rocks are not as receptive as 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 and around Shillong, Mawlai townships and Barapani ICAR research farm. Water seepage is a very common phenomenon visible along sharp cuttings or topographic break in 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 many a places. As a result the quartzite, phyllitic quartzite have lost their intergranular bonding strength and have become like "sands" and "silts". These altered rocks are being used as building materials

(Plate-6) :
Initiation of physical weathering due to intersection of bedding/schistosity and subhorizontal joints (upper right corner) in quartzite.

(Plate-7) : Landslide (slump) along slope profile (steep cuts) in soil after Khasi Greenstone.

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 Shillong Group of rocks is the presence of thin encrustations of goethite as laminae and dripstones. This is due to precipitation of Fe ions due to 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 rocks show variegated colouration (brown-maroon-orange).

The Khasi Greenstone : It occurs as minor linear impersistent lenses confined along the long axis of the basin. In contrast to gneisses, the Khasi Greenstone due to its massive nature produces bouldery outcrops. The size of boulders vary mostly between 10cm to 30cm, 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 area around Mawiong.

The Khasi Greenstone due to its basic/ultrabasic nature is more prone to chemical alterations and has weathered out fast producing a reddish-brown regolith and soil mantle (lateritic). 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 areal distribution of the parent rock.

The pine forest in the upper reaches of the basin 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.

Wherever the rock is sheared it has suffered brittle failure and occurs as a pulverised mass. Due to this 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.

Granitoid Pluton : They occur along the southwestern flank as well as the central part and to some extent towards the terminal part of the basin. The rock shows spheroidal weathering and bouldery-hummocky landforms. The boulders detach along the joint 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 k-felspar 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 have analogous domal expression but, they lack "baldness" and have thick weathered mantle supporting luxuriant vegetation cover. This contrast is mainly due to difference in climatic regimes.

The Terrace Deposits : These are the Quaternary sediments with restricted distribution in the upland part of the basin. But, the terminal part of the basin is by and large confined over these deposits.

These sediments in the terminal part of the basin comprise 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 further breakdown is a very slow process, consequently they persist unchanged in the zone of weathering.

But 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.

MASS WASTING

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 is the most important agency that sculpture and reduce the earth's surface. Sharpe (1938) made one of the first attempts to classify the various types of mass wasting.

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

LANDSLIDES

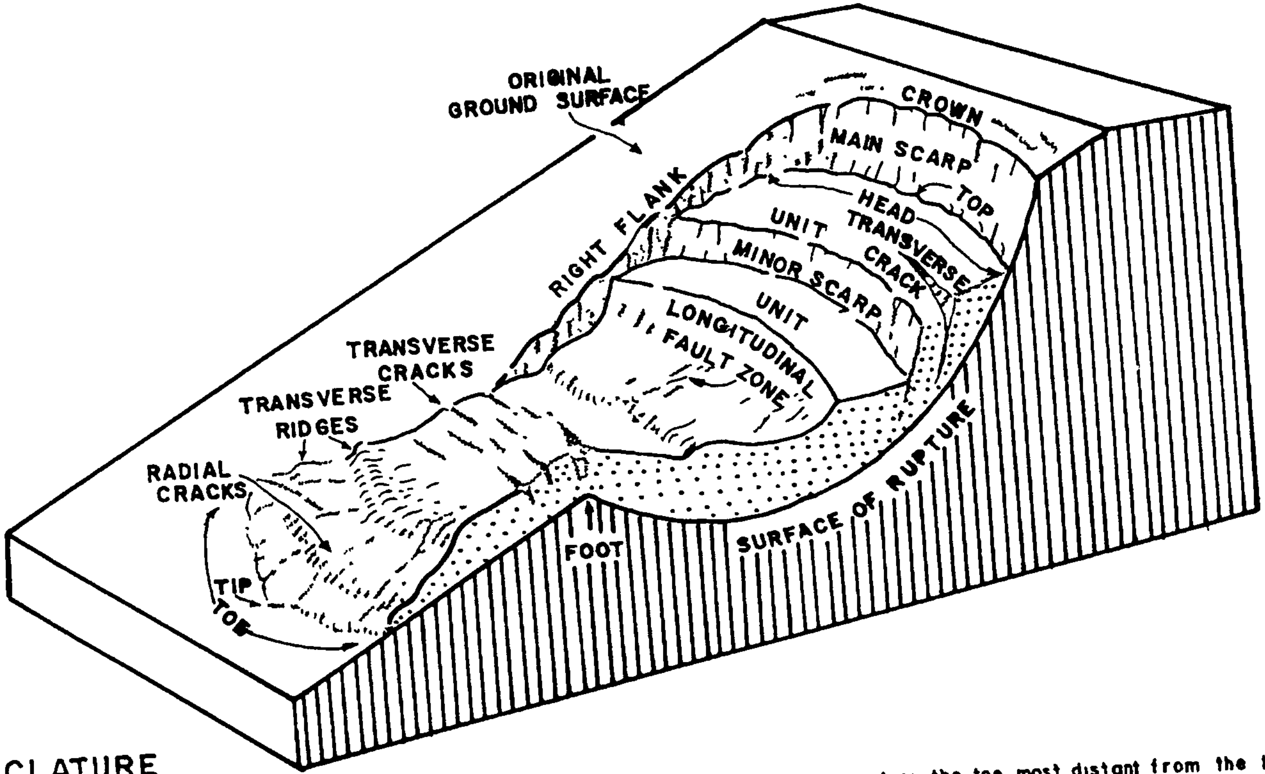
Landslides are of profound interest to the earth scientists, environmentalists and engineers. Landslide phenomenon is one of the most widespread and effective agent in sculpturing the earth's surface. A landslide unforeseen or improperly provided for, may destroy settlements, or engineering structures like roads, bridges, buildings, etc. or impair their usefulness. It may also bring sudden deaths to people who have trusted these structures.

Landslides denote downward and outward movement of slope forming materials, primarily composed of natural rocks, soil, artificial fills or combination of these materials. The nomenclature of different parts of a slide are shown in Fig. (8). The moving mass may proceed by anyone of the three following types of movements, or their combinations.

(a) Falling
(b) Sliding
(c) Flowing

Normally surficial creep, solifluction and avalanches

NOMENCLATURE OF THE PARTS OF A LANDSLIDE



NOMENCLATURE

MAIN SCARP- A steep surface on the undisturbed ground around the periphery of the slide, caused by movement of slide material away from the disturbed ground. The projection of the scarp surface under the disturbed material becomes the surface of rupture.

MINOR SCARP-A steep surface on the disturbed material produced by differential movements within the sliding mass.

HEAD- The upper parts of the slide material along the contact between the disturbed material and the main scarp.

TOP- The highest point of contact between the disturbed material and the main scarp.

FOOT- The line of intesection (Sometimes buried) between the lower part of the surface of rupture and the original ground surface.

TOE- The margin of disturbed material most distant from the main scarp.

TIP- The point on the toe most distant from the top of the slide.

FLANK- The side of the landslide.

CROWN- The material that is still in place, practically undisturbed, and adjacent to the highest parts of the main scarp.

ORIGINAL GROUND SURFACE- The slope that existed before the movement which is being considered took place If this is the surface of an older landslide that fact should be stated

LEFT AND RIGHT- Compass directions are preferable in describing a slide, but if right and left are used they refer to the slide as viewed from the crown.

Fig.(8)

are not considered as landslides (Varnes 1958). Various classifications of landslide are available, according to Ward (1945), classification of landslides should help an engineer to identify the different phenomena associated with the slides for appropriate remedial measures. Earth scientists, environmentalists or engineers need a classification to interpret the past and present trends of topography as revealed by their observations.

The most acceptable classification of landslides in vogue is given by Varnes (1958). The same is reproduced in Table (4) and nomenclature shown in fig.(9).

LANDSLIDES IN THE AREA :

Within the basin, the landslide prone zones are confined within the Shillong Group of rocks mainly. Landslides are more frequent where the developmental (constructional) activities have modified slope profiles, particularly making the profile segments steeper in sections (Plate-7). This makes the slopes unstable with a tendency to fall as and when the equilibrium is disturbed.

By and large, landslides are seen along the roads passing through the basin. The part of area falling within the Shillong agglomeration seldom shows landslides which is mainly because of the horizontal to subhorizontal disposition of Shillong Group of rocks and associated gentler slopes. However, along steeper slope segments particularly in vicinity of nalas, Table - 4

CLASSIFICATION OF LANDSLIDES
(after Varnes 1958)

TYPES OF MOVEMENT	TYPE OF MATERIAL			
	BEDROCK		SOILS	
FALLS	ROCKFALL		SOILFALL	
SLIDES: FEW UNITS	ROTATIONAL SLUMP	PLANAR BLOCK GLIDE	PLANAR BLOCK GLIDE	ROTATIONAL BLOCK SLUMP
SLIDES: MANY UNITS		ROCK SLIDE	DEBRIS SLIDE	FAILURE BY LATERAL SPREADING
	ALL UNCONSOLIDATED			
	ROCK FRAGMENTS	SAND OR SILT	MIXED	MOSTLY PLASTIC
FLOWS: DRY	ROCK FRAGMENT FLOW	SAND RUN; LOESS FLOW		
FLOWS: WET		RAPID EARTH FLOW	DEBRIS AVALANCHE	SLOW EARTH FLOW
		SAND OR SILT FLOW	DEBRIS FLOW	MUDFLOW
COMPLEX	COMBINATION OF MATERIALS OR TYPE OF MOVEMENT			

CLASSIFICATION OF LANDSLIDES (after Varnes 1958)

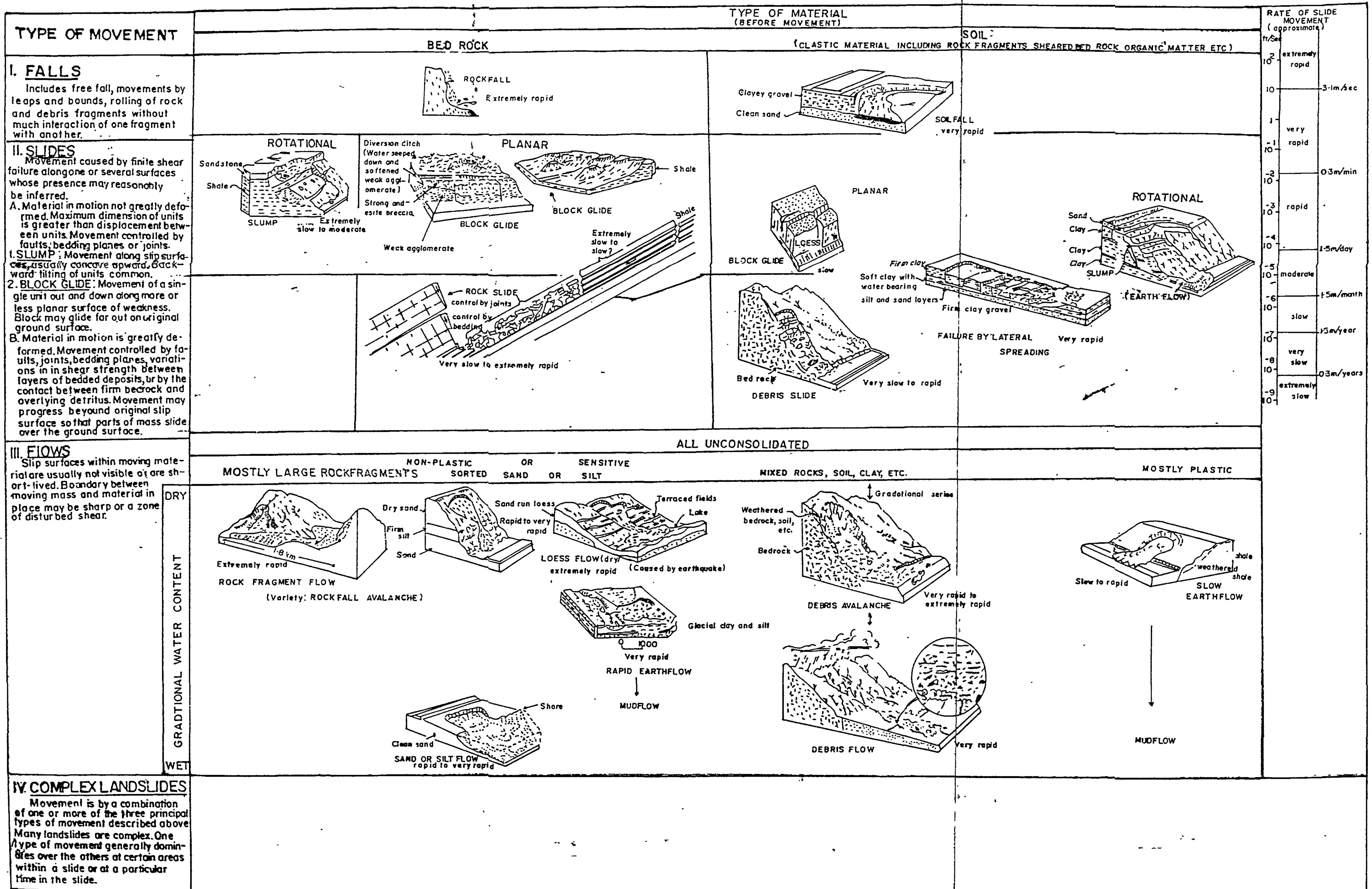


Fig. (9)

rare landslide incidences do occur. These nala sections are surface manifestations of structural weakness (c.f. Terrain analysis), rendering weak, the otherwise competent strata. During rains when the pore water pressure increases these 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. As such these landslides are one of the principal geohazards in the uplands.

Conspicuously the part of the area falling within the Shillong Master Plan i.e. between Marbisu in the southwest to Barapani in the northeast shows frequent incidences of landslides, particularly between Mawlai and Sumer. Incidentally all the active landslides of the area are encountered along National Highway No.40. The important landslides of the area are described below.

SLIDE NO. 1 : SLUMP

Location : Between km post 74-73, left side* of road (Shillong-Guwahati) between electric pole Nos.15 and 17.

The slide is in weathered and altered Shillong Group of rocks. The rocks are completely altered to soil of maroon to brown colour. The soil is homogeneous in nature, coarse to medium grained, loamy without any differentiated soil profile. The slide

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* Herein, side refers to in the direction of from Shillong to Guwahati.

has a width of 60m, height of crown is 10m and the slumped material has slope of 70^{o}- 75^{o}.

SLIDE NO. II : SLUMP

Location : Between km post 74-73, left side of Highway, in between electric pole Nos.46-48.

It is a debris slide on a old stabilised slide in highly weathered Khasi Greenstone. The profile section of the slide exposes the debris of an old slide - assorted boulders and blocks of 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 4-8 years old pine trees. The slumped material has slope of 75^{o}-80^{o} and shows transverse tensional cracks, the trace of slip surface is visible.

SLIDE NO. III : SLUMP

Location : Between km post 73 and 72, left side of road in between electric pole Nos. 61 and 62.

The longitudinal profile of slide is gently convex, about 50m long running parallel to the highway. The slide is on soil after weathered Khasi Greenstone. The crown height is 10m and the crown top has a slope of 10^{o}-15^{o},is deforested with a few remnants of old pine trees, 30-35 years old. The slumped material has very steep slope, over 75^{o} and is prone to frequent failures. The trace of slip surface is intermittently visible.

SLIDE NO. IV : DEBRIS SLIDE

Location : After Mawiong village, between 72-71 km post on left side 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 crown has slope of about 20^{o}, it is deforested and has few 8-12 years old pine trees.

SLIDE NO. V : SLUMP

Location : At 71 km post, left side of the highway.

The slide is on soil after sheared Khasi Greenstone. The width of slide is 90m and crown height is 10m. The top of crown has gentle slope of 15^{o} - 20^{o} and is deforested. It shows evidences of afforestation with 4-8 years old pine trees. The slumped material has steep slope of 75^{o} - 80^{o}.

SLIDE NO. VI : SLUMP

Location : Between km post 71-70, left side of highway.

The slide is on soil after weathered Khasi Greenstone. The width of slide is 40m and height of crown is 10m, while the height of free face is 3m. At crown an old stone line is seen indicating relict of an old slide now exposed in road cutting. The top of crown show 4-8 years old pine afforestation and has 15^{o}-20^{o} slope. The slope of slumped material varies from vertical to 70^{o}. Intermittently the trace of slip surface is visible.

SLIDE NO. VII : SLUMP

Location : Near Mawiong toll barrier, between km post 71-70, left side of the highway.

The slide is over highly weathered Khasi Greenstone and its soil profile exposes homogeneous red coloured loamy to clayey soil. The width of slide is 25m with crown height of 15m. The height of free face is about 3m. The top of crown has a slope of 15^{o} and show evidences of Jhumming activity. The top has now afforested pine trees, 8-12 years old. The slumped material has steep slope of 70^{o} - 80^{o}.

SLIDE NO. VIII : SLUMP

Location : Between 71-70 km post, about 300m away from slide VII, left side of highway.

This is a zone of four slides in a row spread over a cumulative length of 200m. The slides vary in width from 15m to 20m, with crown heights varying from 10m to 15m. The slides are over soil after Khasi Greenstone. The soil is loamy to clayey and of reddish brown colour. The top of crown has slope of 15^{o}-20^{o} and 4-8 years old pine afforestation. The slumped material has slope of 70^{o} to 80^{o}.

SLIDE NO. IX : SLUMP

Location : Between 70-69 km post, left side of the highway.

The slide is on soil after weathered Khasi Greenstone. The colour of soil is reddish brown. The slide has a width of

120m, crown height of 10m and height of free face 2m. The top of crown is deforested and has only a few shrubs and its slope is about 20. The slope of slumped material is steep (75^{o} - 80^{o}).

SLIDE NO. X : ROCK FALL AND ROCK SLIDE

Location : Between km post 68-67, left side of highway.

The slide is in phyllitic quartzite and phyllites of Shillong Group. The beds have vertical dips and have prominent joint parallel to bedding/foliation surface. The rock is sheared and has a zone of pulverised material at the central part of the slide. The width of slide is about 10m and height of free face is 20m. The top of free face has slope of 35^{o}- 40^{o} and is deforested rarely showing 4-8 years old pine trees.

SLIDE NO. XI : ROCK SLIDE

Location : Between 68-67 km post, right side of highway.

The slide is on sheared phyllitic quartzite, quartzite and phyllite of Shillong Group. The width of 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 about 20-25 years old while the dormant portion of the slide does not show pine trees older than 10-15 years indicating the dormancy period of the same order. The top of crown slope is about 45^{o} and the slumped material also has slope of 45^{o}.

SLIDE NO. XII : SLUMP

<u>Location</u> : About 30m away from slide XI, towards Barapani, on right side of road.

This appears to be a frequent slide spot and the slide has been provided with breast wall. The slide is in soil after Shillong Group of rocks, and has a width of 10m and crown height of 6m. The top of crown is afforested with pine trees of 8-12 years old. The trace of slip is not visible.

SLIDE NO. XIII : SLUMP

<u>Location</u> : Between km post 68-67, right side of the highway.

The slide is on soil after Shillong Group of rocks. The slide is active and has breached the breast wall. The width of slide is about 20m and crown height of 3m. At the top of crown,the slope is 20^{o}-25^{o} with pine trees, 25-30 years old. However, the flanks of slide has only 8-12 years old pine trees, indicating the dormancy period of flanks. The slumped material has slope of 65^{o} (Plate-8).

SLIDE NO. XIV : DEBRIS SLIDE

<u>Location</u> : Between 68-67 km post, right side of the highway.

The slide is on Shillong Group of rocks and appears to be quite active as its breast wall is broken at flanks. The width of slide is 45m and height of crown is 15m. The top of crown has gentle slope of $<40^{o}$ and the slope of slumped material is 75^{o}. The height of free face is 1m.

(**Plate–8**) : Landslide in phyllitic quartzite showing dormant patches (bottom left). Note age difference of pine trees.

SLIDE NO. XV : DEBRIS SLIDE

Location : Near km post 67, right side of highway.

The slide is in carbon phyllite of Shillong Group. The width of slide is 4m and height of crown is 10m. The top of crown has slope of 30^o and has pine trees 30-35 years old and the flanks have pine trees about 10-15 years old, indicating the order of dormancy of slide in flanks. The slumped material has slope of 75^o-80^o.

SLIDE NO. XVI : DEBRIS SLIDE

Location : Between km post 67-66, right side of highway.

The slide is in carbon phyllite of Shillong Group. The width is 25m, height of crown is 10m and height of free face is 1m.The top of crown has slope of 25^o-30^o and is forested with 25-30 years old pine trees. The flanks have pine trees about 10-15 years old and the slumped material has slope of 75^o.

SLIDE NO. XVII : ROCK GLIDE-ROCK FALL

Location : The slide is located between 67-66 km post, right side of road.

The slide is on sheared phyllitic quartzite of Shillong Group. The beds are thinly bedded with vertical dips showing minor folding. The width of slide is 20m and height of crown is 20m. The top of crown has slope of 30^o-35^o and is forested with pine trees, 15-20 years old, while the flanks have 8-12 years old pine trees.The slumped material at the toe has 70^o-75^o slope.

SLIDE NO. XVIII : SLUMP

Location : It is located between 67-66 km post, left side of highway.

The slide is on phyllitic quartzite, which is 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 slope of 30^{o} with pine trees, 30-35 years old. The slumped material at the toe has slope of 70^{o}.

SLIDE NO. XIX : DEBRIS SLIDE

Location : Opposite 66 km post.

The slide is on phyllitic quartzite and appears to be quite active with a breast wall. The width of slide is 15m and height of crown is also about 15m. The top of crown has sparse pine trees, 30-35 years old, and its slope is 45^{o}. The slumped material has slope of 75^{o}-80^{o}.

SLIDE NO. XX : DEBRIS SLIDE

Location : Between km post 66-65, left side of the highway.

The slide is on sheared phyllitic quartzite and is provided with a breast 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 slope of 45^{o} with 25-30 years old pine trees and the slumped material has slope of 75^{o}.

SLIDE NO. XXI : DEBRIS SLIDE

Location : Between km post 64-63, left side of highway.

The slide is in weathered quartzite. Its width is 10m and height of crown is 8m, the height of free face is 2.5m. The top of crown is deforested and has slope of 30^{o}, while the slope of slumped material is 75^{o}-80^{o}.

The aforesaid description of various slides reveal that the most common landslide are the "slump" type. The slides are mainly due to slope failure and slope instabilities induced by slope cuts along the highway. Deep weathering under tropical climatic conditions has reduced the slope cohesiveness making them vulnerable to slide and the deforestation has accentuated the slope instabilities further. It is abundantly clear that the active landslides in the basin are the result of anthropogenic activities and not due to "toe erosion" along drainage lines.

These landslides can not 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.

3. The slope cut faces should be rounded rather than making them sharp.

4. Breast wall and retaining walls to be made.

5. Benching and terracing of slopes.

6. Proper drainage galleries and drains to be provided.

7. Wire mesh or cribs to be provided in rock fall areas.

8. Slope profiles to be suitably modified in slide prone areas.

9. Vegetation cover along the highway areas not to be disturbed.

10 Total ban on agriculture, grazing and additional residential constructional activities along both sides of the highway and road networks.

SOILS

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

The soil types of the basin can broadly be classed into : Red loamy soil, Red sandy soil, Red gravelly soil and older alluvial soil (Fig.10). These soil types belong to the order Alfisols (Zonn 1986).

The dominant litho types in the area belong to the low grade metamorphosed Shillong Group represented by quartzite, phyllitic quartzite, phyllite and siltstone, intruded by thin linear lenses of Khasi Greenstone. The left bank peripheral part

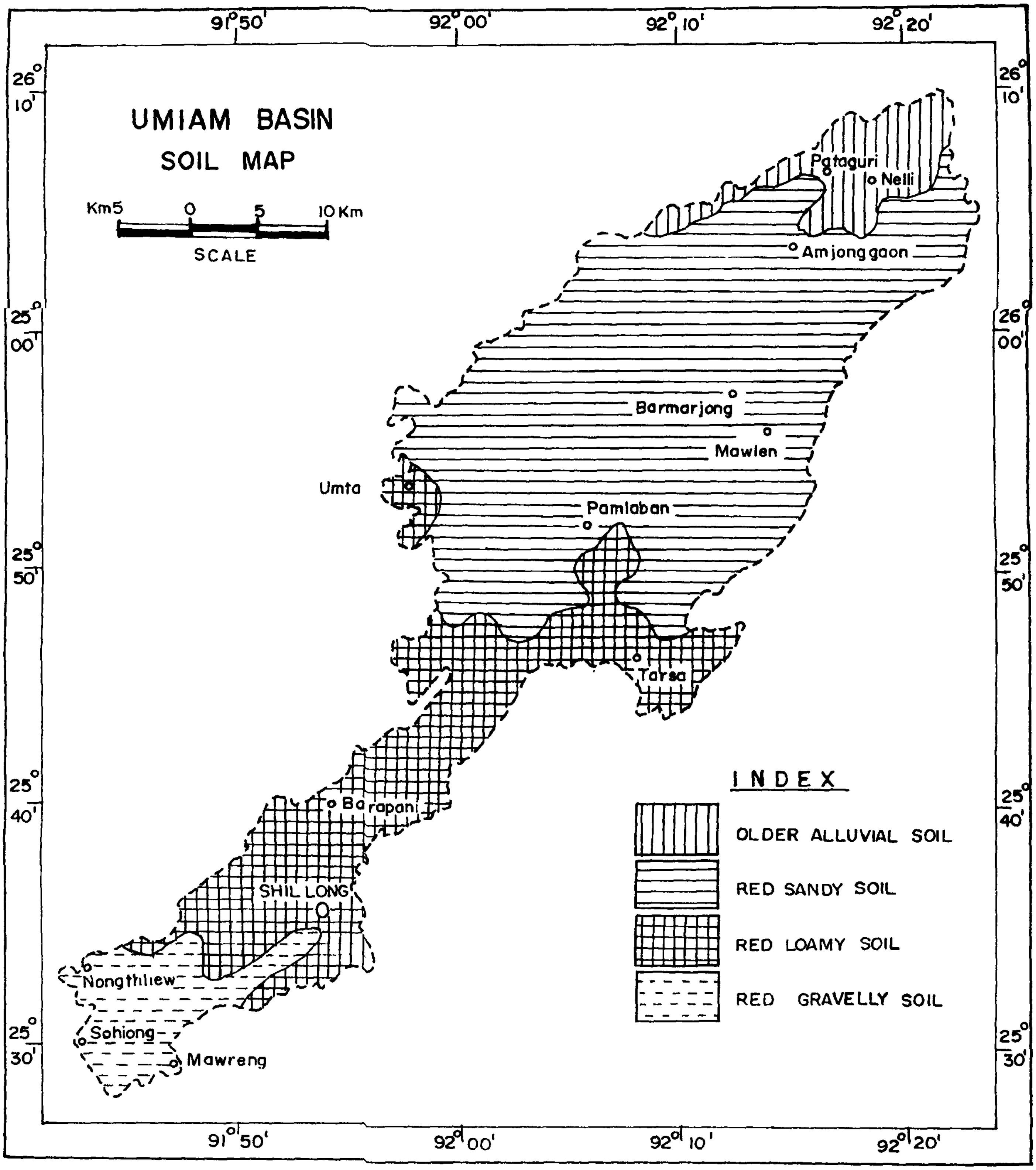
UMIAM BASIN
SOIL MAP
Km5 0 5 10 Km
SCALE
91°50'
92°00'
92°10'
92°20'
26° 10'
26° 00'
25° 00'
25° 50'
25° 40'
25° 30'
Pataguri
Nelli
Amjonggaon
Barmarjong
Mawlen
Umta
Pamlaban
Tarsa
Barapani
SHILLONG
Nongthliew
Sohiong
Mawreng
INDEX
OLDER ALLUVIAL SOIL
RED SANDY SOIL
RED LOAMY SOIL
RED GRAVELLY SOIL

Fig.(10)

of the basin has thin strip of gneisses. The central as well as terminal part of the basin has Granitoid Plutons.

The soil has predominantly formed by the insitu weathering of these rocks. They have variable colours both at surface and subsurface depending upon the degree of oxidation of Fe-Mg-Mn bearing mineral phases. The soils are strongly acidic throughout the solum (Nair and Chamuah 1988). The low pH and low base saturation indicate heavy leaching of bases under high rainfall conditions (Ram et al. 1984). However, the river valleys show transported soil profiles in limited areas.

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.

Soils over Gneissic Complex : The soil derived from the gneisses is mostly medium to fine textured. The soil profile is mostly thick and the soil 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 300cm.

It is gravelly at places due to the presence of abundant fragments of quartz. Due to the presence of evergreen forest, the top soil is rich in humus because of leaf litter. However, on steep slopes and on areas of "Jhum" activity 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 "A" and "B" *horizons*. In areas of low relief where the soil is developed on ledge/spur tops, having gentle and rolling topography, the soil profile does have differentiated "A" and "B" horizons.

Soils over Shillong Group : Soils derived from rocks of Shillong *Group are medium to fine textured. The depth of soil horizon* varies between 20cm to 200cm, with gravelly horizon locally. Due to continuous leaching the bases are leached out. In general the soil is homogeneous, granular, sandy, loamy to clayey, non sticky and non plastic but the predominant kind is sandy. The colour of soil varies from very dark grayish brown to yellow through brownish yellow and red. Due to the presence of evergreen forest, the top soil is rich in humus. Jhumming activity in the area has eroded much of the top soil to lower levels and at some areas the fertility of the soil has been reduced. The soil shows differentiated profile on gentler slopes only.

Soils over Khasi Greenstone : Soils over Khasi Greenstone is typically lateritic giving a reddish brown hue to the landscape around (plate-7). Due to the basic nature of the rock, 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. Its colour varies from yellowish red to red. The insitu soil profile varies in depth from 20cm to 200cm and shows homogeneous nature.

Soils over Granitoid Pluton : The soil derived from these Plutons are in general coarse to medium textured. It is dark brown to grey in colour with high percentage of quartz. The soil is highly leached 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 soil after the Mylliem Granitoid occurring at altitudes above 1500m is loamy. But, the soils after Kyrdem and Nongpoh Pluton which occur at altitudes below 1000m are clayey in nature.

Soils over Terrace Deposits : In general, these are transported soils (alluvial) deposited by running as well as standing waters (Bils-lakes and swamps). The thickness varies from 1m towards the uplands and exceeds 10m in lowlands. The terraces proximal to base of hills and pediments have thin aprons and fans of washed - off soils from the uplands. These terraces conspicuously have primary layering due to alternations of coarse and fine detritus. However, the upper part of the soil has lost its primary layering due to high incidence of anthropogenic activities (agricultural, settlements, tea plantation etc). The soil aprons flanking the pediments and hill slopes are by and large structureless and heterogeneous.

According to Prasad et al. (1980, 1981), steep slopes accelerate removal of soil separates, exchangeable cations through the various agencies like high intensity of rainfall, movement of animals and human beings. Soil properties as modified by topography in East Khasi Hills is given in Table (5).

A perusal of Table (5) indicates 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 get less time for settling due to heavy flow. This is the characteristic feature of soils throughout the entire Shillong Massif. Whenever the flow of the runoff sediment is slow, clay and organic fractions get accumulated in the valleys. Such a situation is not found in the area of study. But, Prasad et al. (op.cit) have reported accumulation of clay and organic carbon from Manipur valley.

A micronutrient studies of soils of East Khasi Hills carried out by Ram et al. (1984) indicates that the Zn and Cu are relatively higher at lower altitudes than at higher altitudes. But Mn shows higher values in lower altitudes (Table-6). This variation in micronutrient in the soil reflects the leaching differential in different altitudes.

It is abundantly clear that chemical weathering in the area has altered all lithotypes thereby enhancing the erodibility. The competent rocks like gneisses, granitoids and quartzite have become highly vulnerable to erosion due to leaching.

Table - 5

ALTITUDINAL VARIATION IN PHYSICO-CHEMICAL PROPERTIES OF SOILS
(after Prasad et al. 1980, 1981)

	Altitudes (above m.s.l.)			
	Above 1000m		**100 - 1000m**	
Soil Properties	**Upland**	**Lowland**	**Upland**	**Lowland**
Sand %	50.40 - 57.60 (54.40)	49.60 - 57.80 (53.80)	50.40 - 68.80 (56.90)	46.60 - 59.60 (54.30)
Silt %	27.40 - 34.80 (30.50)	31.40 - 34.80 (33.40)	16.40 - 24.40 (21.30)	24.00 - 32.00 (28.70)
Clay %	12.40 - 20.80 (15.10)	10.80 - 16.40 (12.80)	12.80 - 27.80 (20.80)	10.20 - 23.40 (17.10)
pH	4.70 - 5.40 (5.09)	4.70 - 5.35 (5.05)	4.35 - 5.45 (5.09)	4.85 - 5.60 (5.16)
Org. C. %	1.14 - 3.06 (2.12)	0.96 - 5.53 (3.24)	1.14 - 2.40 (1.81)	1.44 - 4.68 (3.07)
Exch. Ca+Mg (me/100 g)	3.99 - 5.15 (4.62)	3.57 - 5.36 (4.54)	3.27 - 7.04 (5.04)	3.97 - 9.87 (6.37)
C.E.C. (me/100 g)	6.25 - 9.25 (8.35)	8.00 - 14.50 (10.70)	7.00 - 10.00 (8.55)	7.50 - 15.75 (11.65)
Exch. Acidity (me/100 g)	0.35 - 3.70 (1.83)	0.88 - 3.12 (1.62)	0.24 - 5.75 (1.87)	0.35 - 3.03 (1.31)

(Figures within brackets denote average values).

Table - 6

SOIL MICRONUTRIENTS (ppm) VARIATION IN DIFFERENT ALTITUDES AND TOPOGRAPHY
(after Ram et al. 1984)

	Higher altitudes (1300-1900m)		Lower altitudes (100-1000m)	
Micronutrients	**Upland**	**Lowland**	**Upland**	**Lowland**
Total Zn	23.20 - 47.20 (30.90)	17.50 - 34.0 (27.30)	10.0 - 43.0 (30.40)	15.50 - 41.80 (30.20)
Total Cu	17.00 - 65.00 (44.50)	25.00 - 65.00 (42.00)	29.70 - 71.00 (50.30)	40.00 - 65.00 (51.90)
Total Mn	170.00 - 275.00 (222.10)	120.00 - 415.00 (282.20)	110.00 - 1230.00 (400.60)	105.00 - 770.00 (405.10)

(Figures within brackets denote average values)

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CHAPTER - IV

TERRAIN ANALYSIS

TERRAIN ANALYSIS

Terrain evaluation is the scientific basis for a rational and optional utilisation of land resources. It is useful to understand the nature of land degradation and the factors responsible for it. Terrain evaluation by quantitative geomorphic characterisation is a technique that provides spatial information products in the form of thematic maps and statistical data. This technique also helps in locating geohazards, if any. These products help planners to choose favourable locations for siting developmental schemes for agriculture, forests, hydropotential utilisation, industrialisation, pasture, settlements, urbanisation etc.

The geohazards and geomorphic risks cannot be avoided altogether, but, their recognition in the initial stages of planning help to adopt suitable precautionary measures within the ambit of benefit/cost analysis.

The methodology of preparation of these informatic products should be systematic, practicable and, as far as possible, simple so that, the practicing engineers, geographers geologists, and planners may understand and use them effectively.

Geomorphology has come a long way from the realm of descriptive approach (Smith 1935; Hammond 1964) to quantitative approach (Horton 1932, 1945; Schumm 1956; Strahler 1957, 1958; Leopold et al. 1964; Durry 1967; Zakrzewska 1967; and Doornkamp and King 1971). A numbers of geomorphic or morphometric attributes like Absolute Relief, Relative Relief, Dissection Index, Drainage Frequency, Drainage Density, Slope etc. are used for terrain characterisation, which is known as parametric approach of Terrain Evaluation (Nir 1957; Melton 1958; Van Lopik and Kolb 1959; Mabbutt 1968; Parry et al. 1968; Pal 1972; Singh 1974; Ollier 1977 and Hart 1986). Appreciation of quantitative techniques in geomorphology had been slow (Woldenberg 1985) but, the need to communicate with user agencies for benefit-cost analysis in land resource utilisation has gradually led emphasis on these techniques.

Absolute Relief (AR), Relative Relief (RR), Dissection Index (DI), Slope (SL), Drainage Frequency (DF) and Drainage Density (DD) are the different geomorphic parameters which have been analysed in the basin to differentiate physiographic characteristics and to prepare the various thematic maps. The parameters have been analysed from toposheets on 1:50,000 scale. The entire basin has been divided into 1613 grids of one sq.km each and all parameters are calculated for each grid.

The geomorphic parameters of the basin show manifestation of fragmental or remnantal configuration arising out of polycyclic denudation. The various geomorphic attributes of the basin are discussed below.

I. ABSOLUTE RELIEF (AR)

Absolute elevation in each grid has been computed from spot heights, triangulation points wherever available and from the maximum contour value passing through the grids (with contour interval 20m). The elevation within the basin varies from 60m in northeast to 1964m in southwest, the grid wise computed absolute heights, have been classified into 10 categories with a class interval of 200m ranging from less than 200m to over 1800m above m.s.l. (Table-7). The spatial distribution of these categories clearly depict a "staircased" physiography in the basin (Fig.11). These categories have been classed into five major groups for qualitative assessment (Table-7) and are discussed below. The distribution of these groups have shown strong geological control.

The highest elevation of 1964m above m.s.l. is located on Laitkor ridge, south of Shillong on the basin divide. The height categories of above 1800m and 1200-1400m covers only 2.096% (29.960sq.km) and 2.790% (39.877sq.km) respectively. The highest summits of the entire Shillong Massif lies in the above 1800m height category.

DISTRIBUTION PATTERN OF ABSOLUTE RELIEF

The different Absolute Relief categories reveal a peaked grid frequency distribution between 600m and 1200m categories.

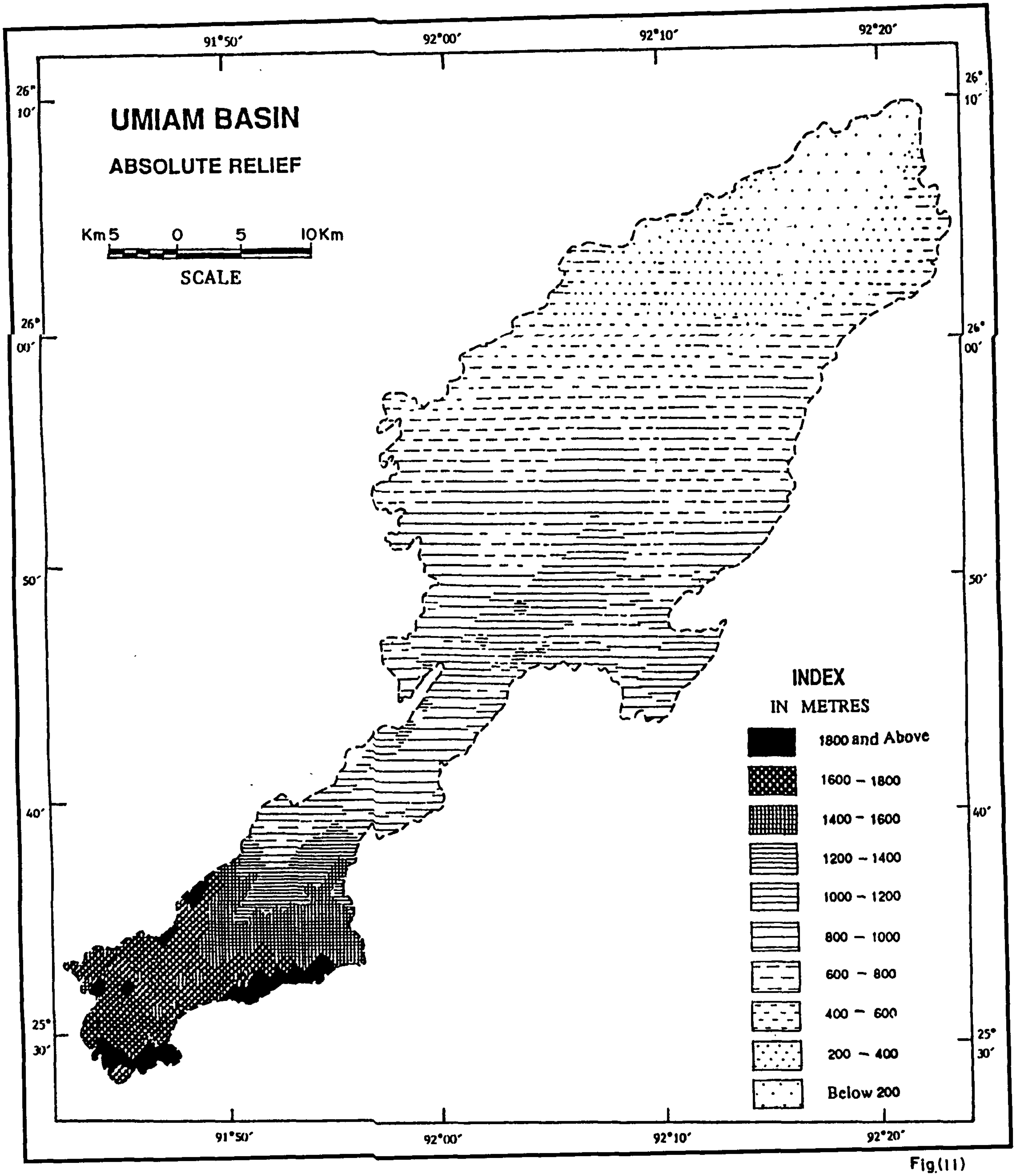
A perusal of Table-7 indicate that very high, high and low absolute relief group have insignificant spatial distribution (9.08%, 7.06% and 6.75% respectively). But, large part of the

TABLE-7

DISTRIBUTION OF ABSOLUTE RELIEF IN UMIAM BASIN

Absolute Relief Category (m)	Grid Frequency	Grid Frequency (%)	Area (sq.km)	Cumulative Area (sq.km)	Area (%)	Cumulative Area (%)	Major Absolute Relief Group
Above 1800	46	2.852	29.960	29.960	2.096	2.096	Above 1600m - Very high 129.775 sq.km (9.080%)
1600 - 1800	120	7.440	99.815	129.775	6.982	9.078	
1400 - 1600	65	4.030	61.030	190.805	4.269	13.347	1200m - 1600m - High 100.907 sq.km (7.068%)
1200 - 1400	46	2.852	39.877	230.682	2.790	16.137	
1000 - 1200	239	14.817	193.398	424.080	13.529	29.666	600m - 1200m - Moderately High 827.365 sq.km (57.88%)
800 - 1000	357	22.133	331.626	755.706	23.199	52.865	
600 - 800	333	20.645	302.341	1058.047	21.150	74.015	
400 - 600	140	8.679	128.828	1186.875	9.012	83.027	200m - 600m - Moderate 274.841 sq.km (19.23%)
200 - 400	154	9.547	146.013	1332.888	10.214	93.241	
Below 200	113	7.005	96.622	1429.510	6.759	100.000	Below 200m - Low 96.222 sq.km (6.75%)
TOTAL	1613	100.000	1429.510		100.000		

Range : 60m - 1964m Mean : 875.51m Median : 839.118 Mode : 771.831 Std. Dev. 450.97m Coeff. of var : 51.51



UMIAM BASIN
ABSOLUTE RELIEF
Km 5 0 5 10 Km
SCALE
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′
INDEX
IN METRES
1800 and Above
1600 – 1800
1400 – 1600
1200 – 1400
1000 – 1200
800 – 1000
600 – 800
400 – 600
200 – 400
Below 200

Fig.(11)

basin has moderate to moderately high absolute relief groups (57.88% and 19.23% respectively). The distribution of these groups is discussed below.

VERY HIGH ABSOLUTE RELIEF (ABOVE 1600m)

The terrain representing this group is confined to the southwestern part of the basin. It comprises Shillong Group of rocks mainly, flanked by Granitoid Plutons on three sides i.e., the Mylliem Pluton in the south, the South Khasi Pluton in the southwest and Nongrang Pluton in the north. The extreme height attained by this group is the result of uparching caused by rising acid magmatic centres (Plutons) as well as block movements along reactivated lineaments.

HIGH ABSOLUTE RELIEF (1200m-1600m)

It is represented by the Shillong Group of rocks and is confined around Shillong, and forms remarkable eastwest trending rock terraces. The Shillong Agglomeration and its peripheral sprawls are located over this group.

The terrain representing the very high and high absolute relief groups abundantly expresses the manifestation of pulses of rejuvenation as deduced from the "V" shaped distribution pattern (reentrants), cascading nature of different height categories within it.

The Plutons flanking these groups have not only uparched the overlying Shillong Group but have also acted as a competent barrier and retarded lateral basin expansion between Marbisu and Nongthliew. The uparching raised the elevation and enhanced the complimentary downcutting by stream channels.

MODERATELY HIGH ABSOLUTE RELIEF (600m-1200m)

It has the largest distribution and is mostly confined over the Nongpoh Pluton and to some extent over the Gneissic Complex, and Shillong Group particularly between Kyrdem and Nongpoh Plutons, in vicinity of Tarsa. By and large the Shillong Group depicts higher absolute relief categories than the Nongpoh Pluton suggesting northward "unloading" of the Shillong Group from over the Pluton. A prominent linear NE-SW trending trough (depression) representing 800m-1000m absolute relief category, runs from Mawlendep through Umden to southwest of Tarsa, corresponding to the Barapani Graben. Significantly the Umiam lake is confined in the southwestern part of this trough.

MODERATE ABSOLUTE RELIEF (200m-600m)

It is distributed over the Shillong Group as well as Nongpoh Pluton mainly around and north of Barmarjong. It does not show any preferred distribution to lithology but, marks the subdued landscape of the basin indicating considerable lowering of physiography in northeast direction.

LOW ABSOLUTE RELIEF (BELOW 200m)

It is least in extent (6.75%) and is completely confined in the terminal part of the basin representing the undifferentiated Quaternary sediments north of Amjonggaon. It forms part of the Umiam-Kopili-Brahmaputra bank oscillation flood plains. The lowest absolute relief category (less than 60m above m.s.l.) is prone to periodic flooding and is swampy.

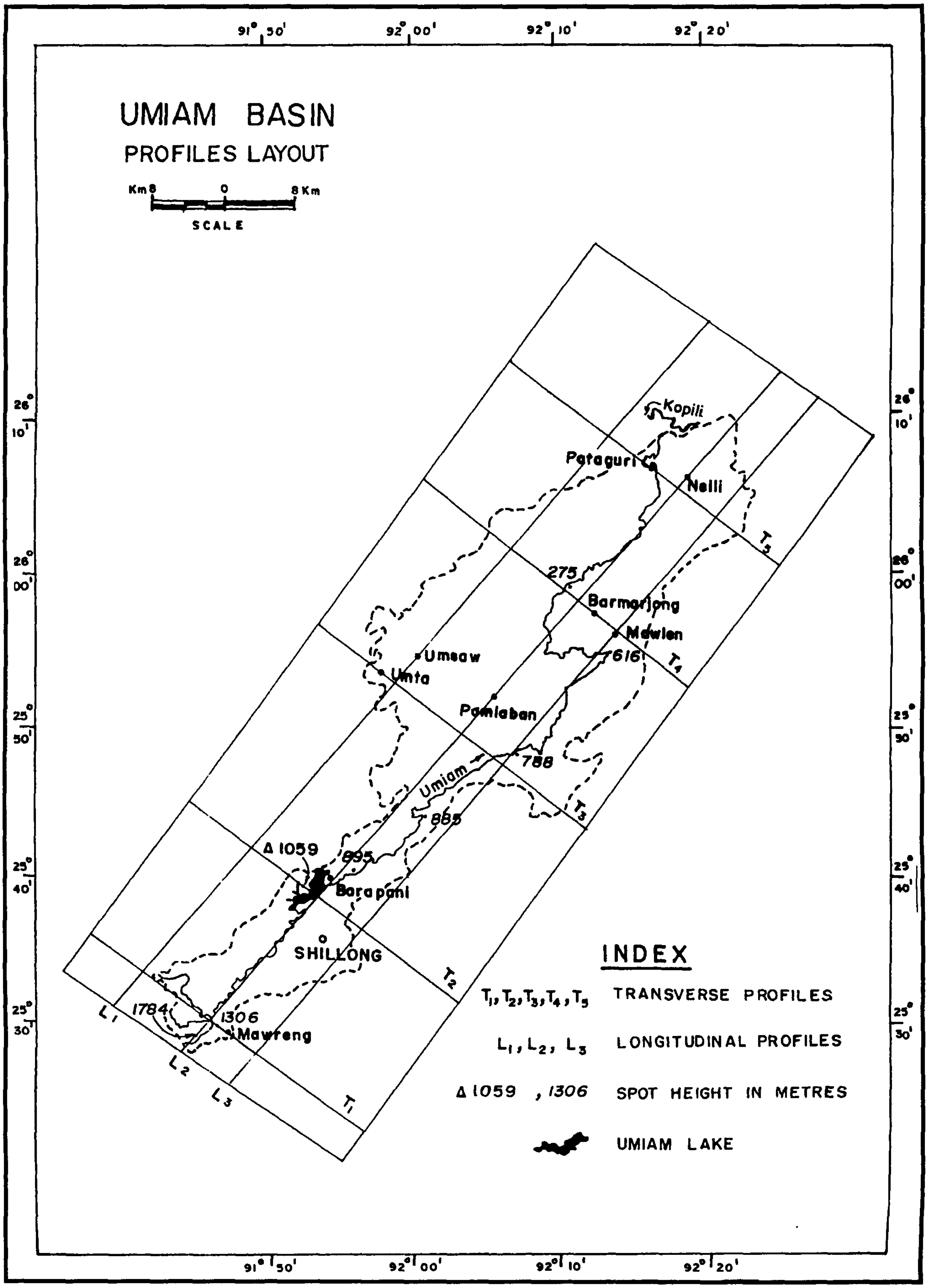
LANDSCAPE PROFILES

The absolute relief variation brings out the physiographic configuration appreciably when viewed with terrain profile. The "staircassed" or stepped physiography of the basin is evident from the landscape profiles. The terrain configuration is depicted by the longitudinal and transverse profiles drawn along the basin length and across it (Fig.12). Since the basin is "spear head" shaped pointing downstream, the section lines have been extended beyond the basin boundary to represent the entire terrain along the length and breadth of the basin.

LONGITUDINAL PROFILES

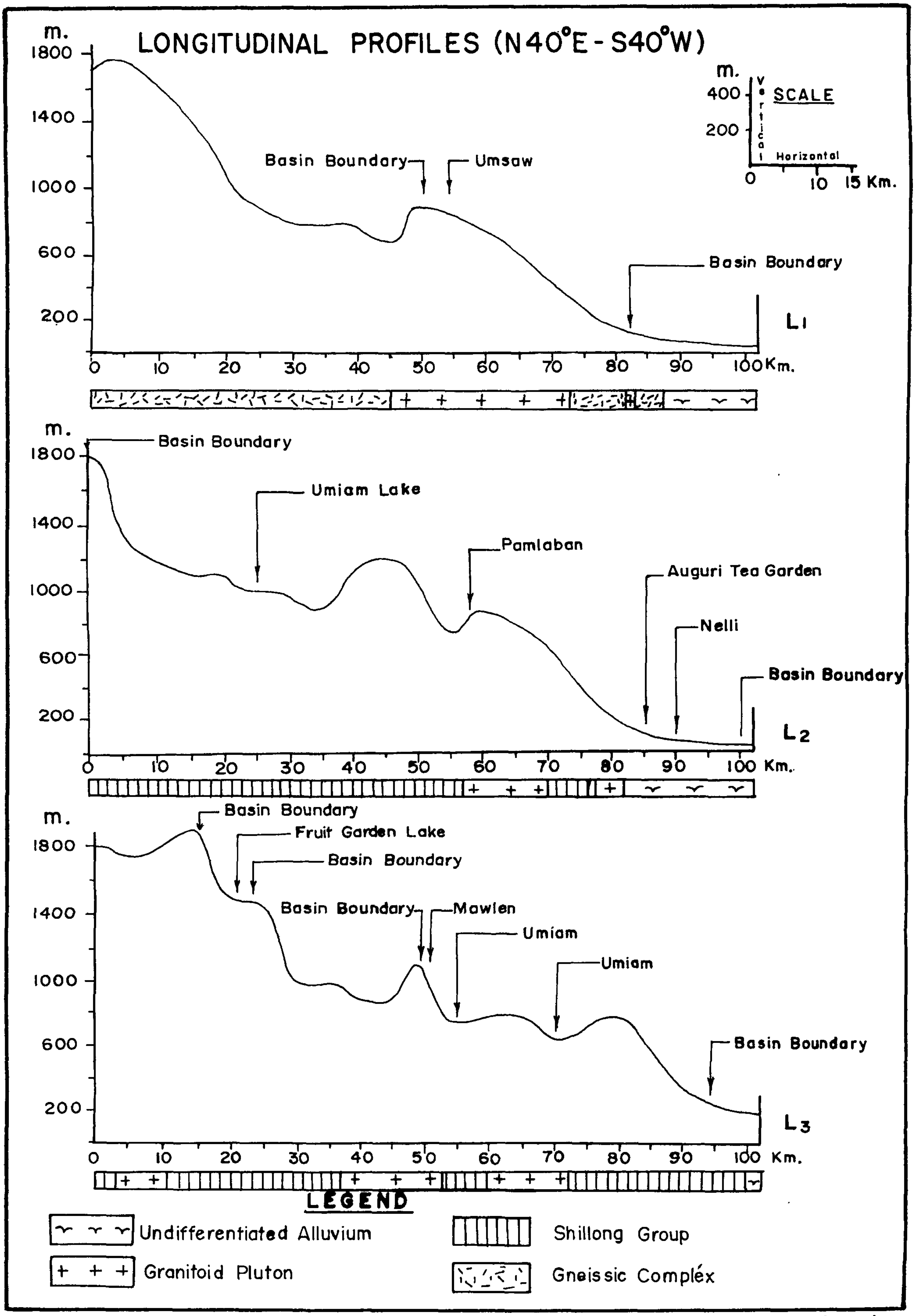
Three longitudinal profiles running N40°E - S40° W along the basin length from the source to the mouth have been drawn (Fig.13). The profile L1 passes through the left flank, L2 passes through the right flank and L3 passes through the axial part of the basin. The elevation at the southwestern end of the section lines varies from 1700m to 1800m above m.s.l. and at the northwestern end the elevation is less than 60m above m.s.l. There is a vertical fall of about 1800m in a total span of 100km.

The longitudinal profiles reveal a "eight step" landscape with micro steps in between from southwest to northeast



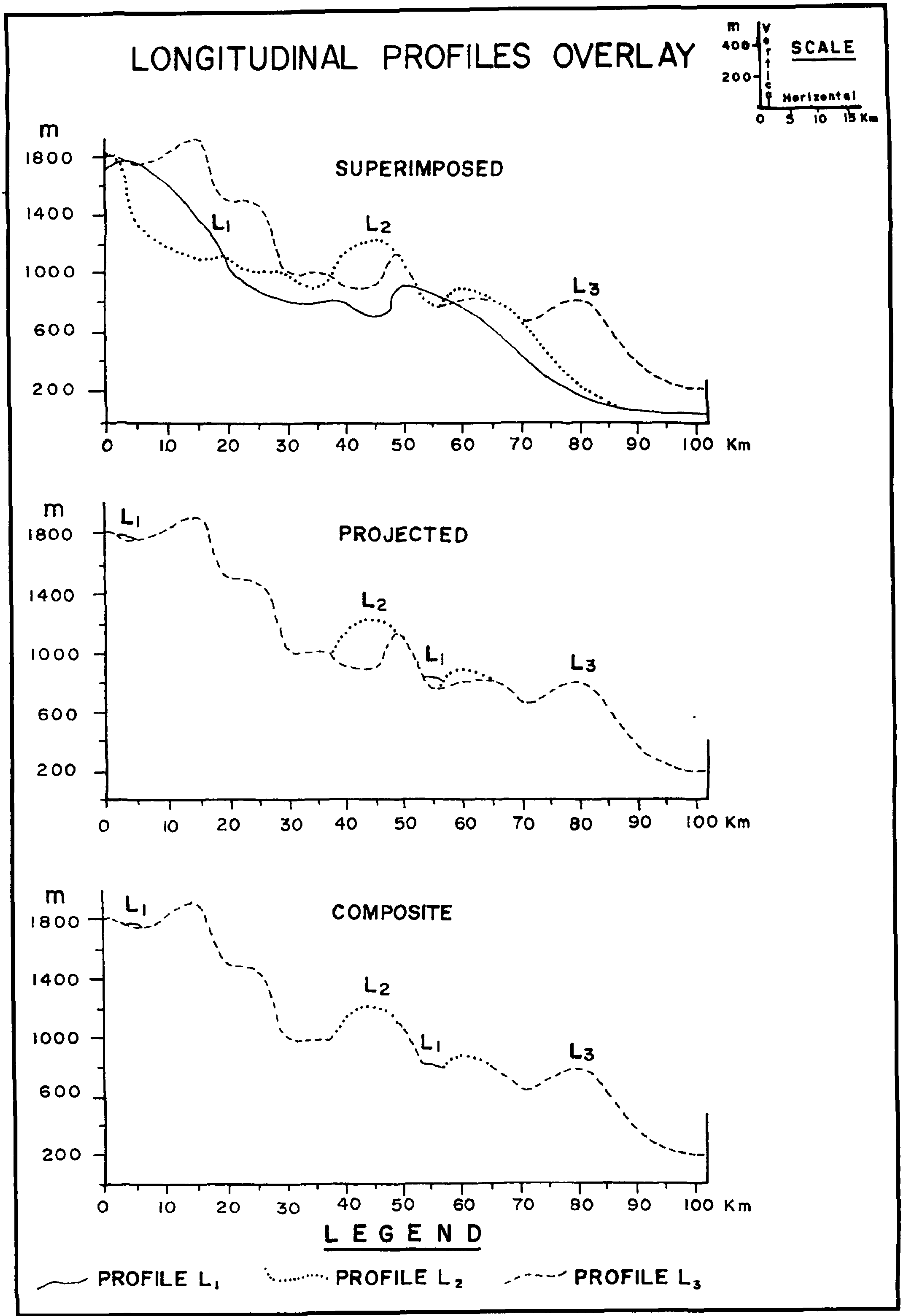
UMIAM BASIN
PROFILES LAYOUT
Km 8
0
8 Km
SCALE
91° 50'
92° 00'
92° 10'
92° 20'
26° 10'
26° 00'
25° 50'
25° 40'
25° 30'
Kopili
Pataguri
Nelli
275
Barmarjong
Mawlen
616
Umsaw
Umta
Pamlaban
788
Umiam
885
Δ 1059
895
Barapani
SHILLONG
1784
1306
Mawreng
T_1
T_2
T_3
T_4
T_5
L_1
L_2
L_3
INDEX
T_1, T_2, T_3, T_4, T_5 TRANSVERSE PROFILES
L_1, L_2, L_3 LONGITUDINAL PROFILES
Δ 1059 , 1306 SPOT HEIGHT IN METRES
UMIAM LAKE

Fig.(12)



LONGITUDINAL PROFILES (N40°E - S40°W)
m.
1800
1400
1000
600
200
SCALE
Vertical
Horizontal
0 10 15 Km.
400
200
Basin Boundary
Umsaw
Basin Boundary
L1
0 10 20 30 40 50 60 70 80 90 100 Km.
Basin Boundary
Umiam Lake
Pamlaban
Auguri Tea Garden
Nelli
Basin Boundary
L2
Basin Boundary
Fruit Garden Lake
Basin Boundary
Basin Boundary
Mawlen
Umiam
Umiam
Basin Boundary
L3
LEGEND
Undifferentiated Alluvium
Granitoid Pluton
Shillong Group
Gneissic Complex

Fig.(13)



LONGITUDINAL PROFILES OVERLAY
SCALE
m
400
200
Vertical
Horizontal
0 5 10 15 Km
SUPERIMPOSED
PROJECTED
COMPOSITE
m
1800
1400
1000
600
200
0 10 20 30 40 50 60 70 80 90 100 Km
L1
L2
L3
LEGEND
PROFILE L1
PROFILE L2
PROFILE L3

Fig.(14)

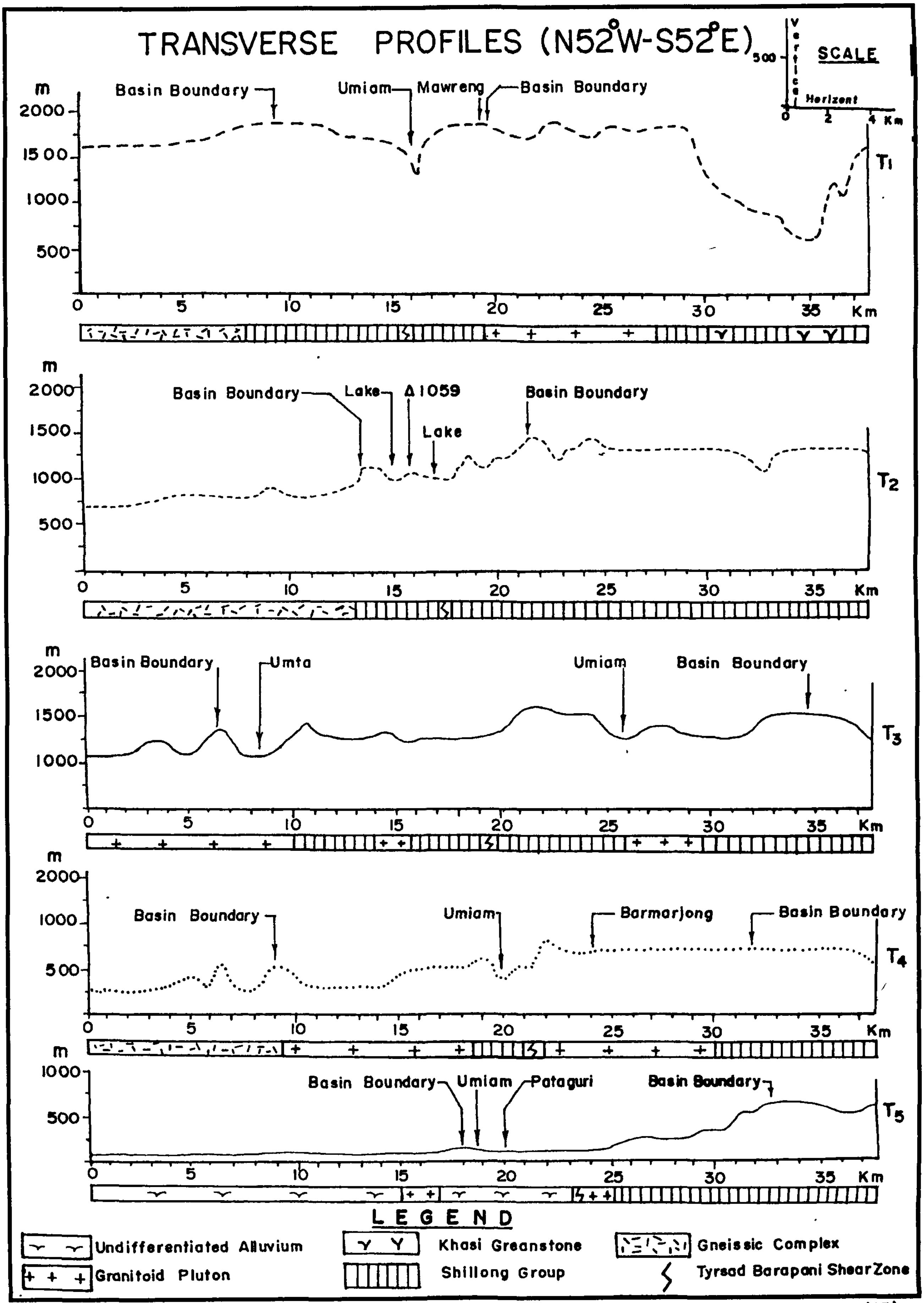
at following elevations above m.s.l. (1) 1900m, (2) 1800m, (3) 1700m, (4) 1500m, (5) 1200m, (6) 1000m, (7) 800m, and (8) less than 100m. The slopes of profile towards the source i.e. southwest is steeper than towards the northeast or the mouth of the basin. This multilevel landscape indicate a gradual unloading of physiography in the northeast as well as the terraced nature of the landscape. The "doming" suffered by Shillong Group terrain in vicinity of the exposed Plutons is conspicuously seen in the profiles.

The superimposed, projected and composite profiles are shown in the longitudinal profiles overlay (Fig.14). These profiles clearly show the multilevel terraced plateau configuration of the terrain and the "terraces" corresponding to peneplanation surfaces in the area.

TRANSVERSE PROFILES

Five transverse profiles T1, T2, T3, T4 and T5 aligned N52^{o} W-S52^{o} E, across the basin from source to mouth have been drawn (Fig.12). The general elevation varies from 1800m in the southwest along profile T1, to less than 60m in the northeast along profile T5 (Fig.15).

The multitier terraced plateau nature of the terrain is clearly evident from these cross profiles. The Umiam entrenchment in Shillong Group of rocks in vicinity of the Tyrsad-Barapani shear zone is remarkably conspicuous as a sharp "notch" cutting in profile T1 and the location of Umiam lake in a shallow trough



TRANSVERSE PROFILES (N52°W-S52°E)
SCALE
Vertical
Horizont
0 2 4 Km
500
m
2000
1500
1000
500
Basin Boundary
Umiam
Mawreng
Basin Boundary
T1
0 5 10 15 20 25 30 35 Km
Basin Boundary
Lake
Δ 1059
Lake
Basin Boundary
T2
Basin Boundary
Umta
Umiam
Basin Boundary
T3
Basin Boundary
Umiam
Barmarjong
Basin Boundary
T4
Basin Boundary
Umiam
Pataguri
Basin Boundary
T5
LEGEND
Undifferentiated Alluvium
Granitoid Pluton
Khasi Greanstone
Shillong Group
Gneissic Complex
Tyrsad Barapani ShearZone

Fig.(15)

TRANSVERSE PROFILE OVERLAY

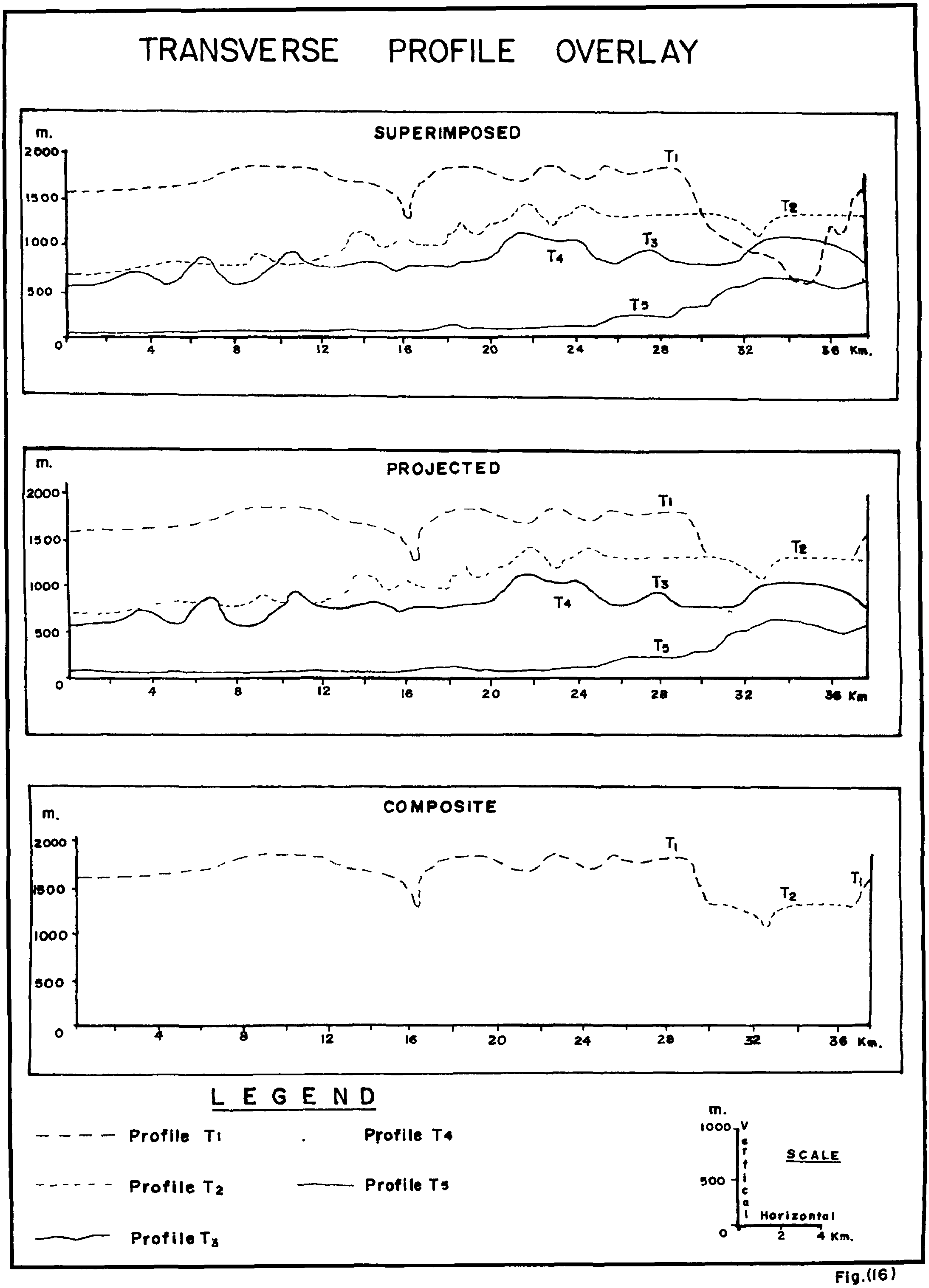


Fig.(16)

in profile T2.

The superimposed, projected and composite profiles are shown in the transverse profiles overlay (Fig.16). The overlay clearly depict the gradual northward lowering of the physiography in the successive profiles from T1 to T5. The terraced plateau nature of the terrain diminishes gradually from southwest to northeast. The sharp inflexion points commonly known as the Knick points on the profiles, where the relief also changes abruptly marks the effects of polycyclic rejuvenation episodes along reactivated basement structural discontinuities (lineaments).

II. RELATIVE RELIEF (RR)

Relative Relief in general denotes the actual variation of altitude 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 mean sea level. The idea of relative relief to understand landform evolution has been highlighted by Johnson (1933) and Smith (1935). Relative relief is also known as amplitude of available relief, drainage relief, local relief, relative altitude, topographic relief etc.

For the purpose of relative relief analysis, the height difference between the highest and lowest elevation within each grid is computed with a contour interval of 20m. The relative relief varies from 0m in the northeast to 520m southwest as well as northeast. The grid values are classified into six categories (Table-8) with a class interval of 100m, ranging

TABLE-8

DISTRIBUTION OF RELATIVE RELIEF IN UMIAM BASIN

Relative Relief Category (m)	Grid Frequency	Grid Frequency (%)	Area (sq.km)	Cumulative Area (sq.km)	Area (%)	Cumulative Area (%)	Major Relative Relief Group
Above 500	5	0.310	4.114	4.114	0.288	0.288	Above 500m - Very high 4.114 sq.km (0.29%)
400 - 500	16	0.992	15.024	19.138	1.051	1.339	300m - 500m - High 99.772 sq.km (6.98%)
300 - 400	91	5.642	84.748	103.886	5.929	7.268	
200 - 300	325	20.149	292.398	396.284	20.454	27.722	200m - 300m - Moderately High 292.398 sq.km (20.46%)
100 - 200	717	44.451	630.486	1026.770	44.105	71.827	100m - 200m - Moderate 630.486 sq.km (44.10%)
Below 100	459	28.456	402.740	1429.510	28.173	100.000	Below 100m - Low 402.740 sq.km (28.17%)
TOTAL	1613	100.000	1429.510		100.000		

Range : 0m - 520m Mean : 163.5m Median : 161.398 Mode : 125.030 Std. Dev. 90.82m Coeff. of var : 55.55

from less than 100m to more than 500m above m.s.l. The spatial distribution of these categories is shown in Fig.(17). The different relative relief categories reveal a decrease in grid frequency distribution with increase in relief above 100-200m category. However, the spatial distribution is highly irregular and clustered indicating segmented dissection of the terrain. For qualitative assessment these categories have been classed into five major groups (Table-8) and discussed below.

DISTRIBUTION PATTERN OF RELATIVE RELIEF

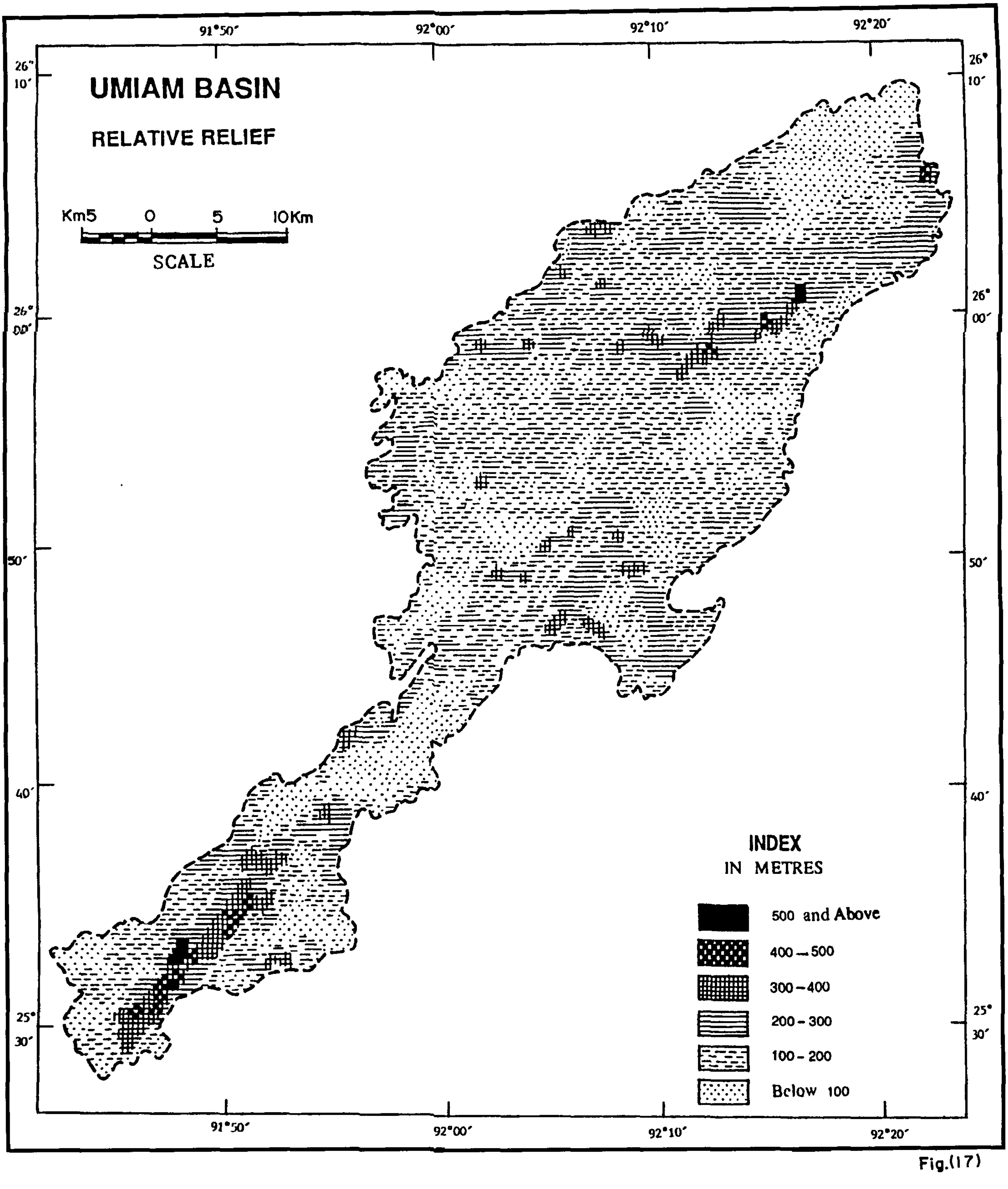
A perusal of Table (8) reveals that very high to high relief has insignificant areal distribution (0.29% and 6.98%) large part of the basin depict moderately high (20.46%) to moderate 44.10% relief and only 28.17% of the area has low relief.

VERY HIGH RELATIVE RELIEF (ABOVE 500m)

It cover a negligible area (0.29%) in the basin and is confined as isolated patches over Shillong Group. One such prominent patch occurs in the southwestern part of the basin, north of Mawreng in Umiam gorge section. Another patch occurs in the northeastern part of the basin, between Amjonggaon and Barmarjong. Such stray very high relative relief patches indicate localised vigorous downcutting perhaps in response to pulses of rejuvenation.

HIGH RELATIVE RELIEF (300m-500m)

It covers an insignificant area (6.98%) and is spread



UMIAM BASIN
RELATIVE RELIEF
Km5 0 5 10Km
SCALE
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′
INDEX
IN METRES
500 and Above
400 – 500
300 – 400
200 – 300
100 – 200
Below 100

Fig.(17)

over as clusters in the southwestern, central and northeastern part of the basin over the Shillong Group, Nongpoh and Kyrdem Plutons. These clusters over the Shillong Group occurring in the southwest between north of Mawreng and Shillong; in the central part south of Pamlaban; north and northeast of Barmarjong and in the northeastern fringe of the basin are collinear with the Tyrsad-Barapani shear zone cutting through the basin. Conspicuously, the clusters between north of Mawreng and Shillong occur in the Umiam gorge section indicating accelerated downcutting proximal to the shear zone. The clusters over the Pluton occur mostly along the country rock - Pluton interface. 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.

MODERATELY HIGH RELATIVE RELIEF (200m-300m)

This group covers 20.46% of the basin area. It is scattered throughout the basin but mainly confined over the Shillong Group and the Gneissic Complex. In the southwestern part, it mainly occurs between north of Mawreng to Mawlendeep. In the central part of the basin, it occurs mostly along the peripheral part of the Nongpoh and Kyrdem Plutons indicating overprinting of erosional cycles on the rejuvenated Precambrian peneplained surface.

MODERATE RELATIVE RELIEF (100m-200m)

By far, it is the most widely distributed group in the area (44.10%) occurring in clusters over all the lithotypes. However, in comparison to the Gneissic Complex and Shillong Group, the Plutons show maximum development of this group indicating lower incision in the Plutons. 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.

It is developed locally over Shillong Group indicating shallow dissection only, an imprint of late Quaternary erosion cycle under progress. It suggests that the terrain had supracrustals over it (Cretaceous - Tertiary cover sediments) and the Quaternary imprints on Shillong Group came into existence only after the unloading of these supracrustal.

LOW RELATIVE RELIEF (BELOW 100m)

This group covers 28.17% of the total area and occurs as large patches throughout the basin on all lithotypes. The prominent patches occur around Nongthliew-Sohiong-Mawreng-Shillong; Mawlendeep-Umden, Tarsa-Pamlaban, north of Umsaw-Mawlen-Barmarjong on the hard rock terrain. But the largest patch occur north of Amjonggaon over the Quaternary sediments.

The patches of this group over hard rock indicate remnants of older peneplanation or erosional surfaces under dissection by the ongoing Quaternary fluvial cycles.

III. DISSECTION INDEX (DI)

The absolute and relative relief of a mountainous terrain do not express adequately the sharpness of relief or extent of dissection. Nir (1957) computed "Dissection Index" as the ratio of two morphometric variables i.e., relative relief and absolute relief within a specific areal unit. He measured vertical distance from the erosion base to express the dynamic potential and relief energy of the area. According to Nir (op.cit), the dissection index indicates "the degree to which dissection has advanced". The value of the index can never exceed 1 (extreme case, vertical cliff at seashore) and cannot fall below 0 (complete absence of dissection).

In the basin, dissection index is computed for 1613 grids. The value varies from 0.0 to 0.83 and it has been classified into five categories (Table-9) with a class interval of 0.20, ranging from below 0.20 to above 0.80. The spatial distribution of these categories is shown in Fig.(18). For qualitative assessment, these five categories have been classed into three groups in conformity to the scale devised by Singh (1974).

DISTRIBUTION PATTERN OF DISSECTION INDEX

A perusal of Table (9) reveals that maximum grid frequency lie under the moderate and low groups covering 28.518% and 56.292% of the total frequency. It indicates the existence of peneplanation surfaces in the terrain with superimposition of

TABLE-9

DISTRIBUTION OF DISSECTION INDEX IN UMIAM BASIN

Dissection Index Category	Grid Frequency	Grid Frequency (%)	Area (sq.km)	Cumulative Area (sq.km)	Area (%)	Cumulative Area (%)	Major Dissection Index Group
Above 0.80	6	0.372	6.000	6.000	0.420	0.420	Above 0.80 - Very high 6.0 sq.km (0.42%)
0.60 - 0.80	101	6.262	95.110	101.110	6.650	7.070	0.4 - 0.80 - High 220.633 sq.km (15.43%)
0.40 - 0.60	138	8.556	125.523	226.633	8.780	15.850	
0.20 - 0.40	460	28.518	417.933	644.566	29.240	45.090	0.20 - 0.40 - Moderate 417.933 sq.km (29.24%)
Below 0.20	908	56.292	784.944	1429.510	54.910	100.000	Below 0.20 - Low 784.944 sq.km (54.91%)
TOTAL	1613	100.000	1429.510		100.000		

Range : 0.0 -0.83 Mean : 0.23 Median : 0.192 Mode : 0.166 Std. Dev. 0.18 Coeff. of var : 76.85

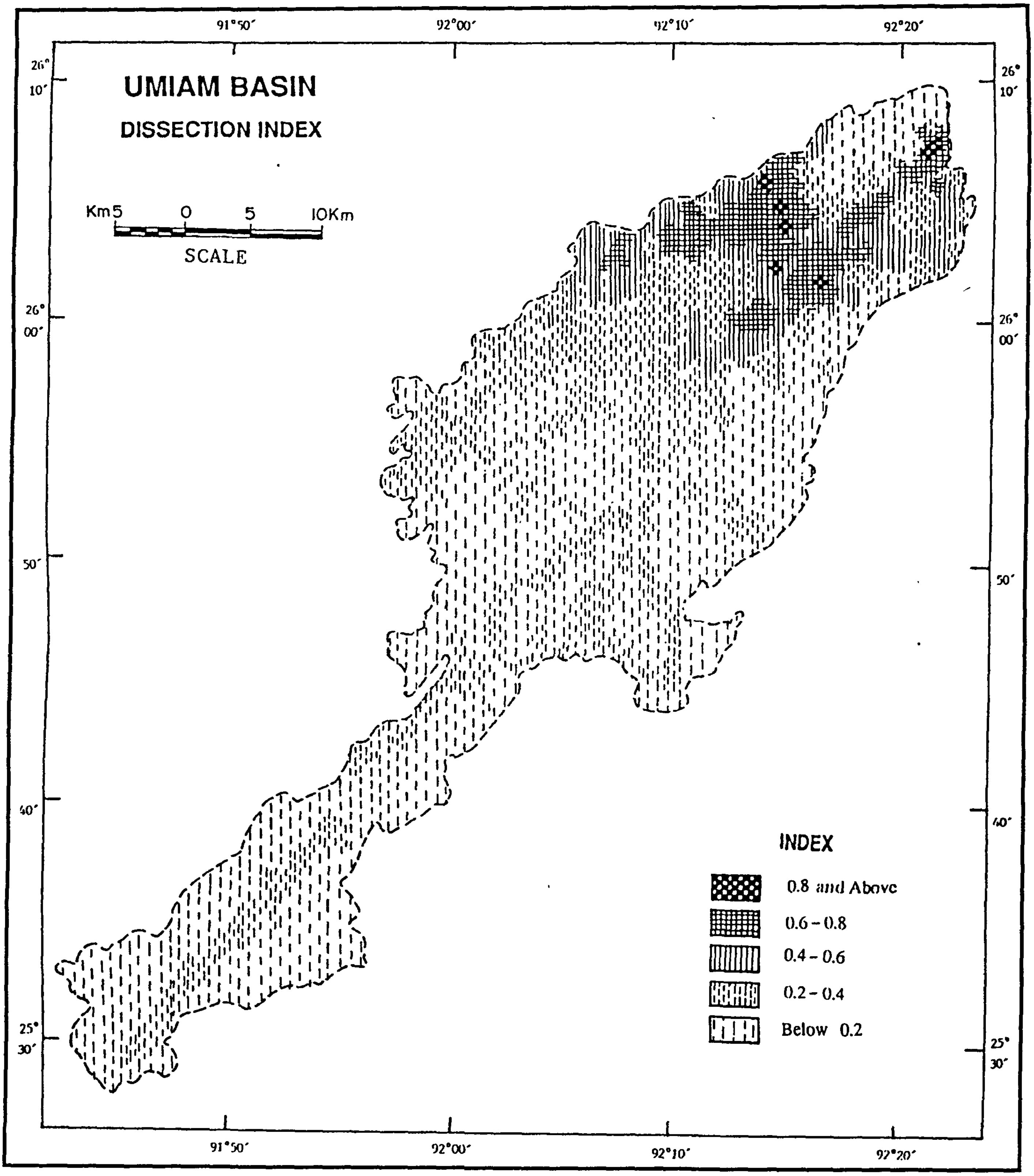

UMIAM BASIN
DISSECTION INDEX
Km5 0 5 10Km
SCALE
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′
INDEX
0.8 and Above
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
Below 0.2

Fig.(18)

fluvial cycles due to rejuvenation. The different dissection index groups are discussed below.

VERY HIGH (ABOVE 0.80)

It covers negligible area (0.42%) confined in the terminal part of the basin in and around Amjonggaon and east of Nelli as sporadic patches mainly over Nongpoh Pluton (extension). This Granitoid Pluton forms highly dissected hills bordering the Umiam-Kopili-Brahmaputra flood plains. The gradual northeastward unloading of the Pluton marks these sporadic centres of high dissection index, a result of vigorous periodic erosion of the Shillong Massif.

HIGH GROUP (0.40-0.80)

It is confined to the Nongpoh Pluton as well as Shillong Group in the northeastern part covering 15.43% of the area in the basin. The Nongpoh Pluton and the Shillong Group of rocks in this part of the basin show elongated hills and ridges which is a manifestation of repeated erosion of the upland. Conspicuously, this part has wide and intersecting stream valleys trending along reactivated N-S and NE-SW lineaments. These basement fractures have aided the effective erosion and segmented the upland into residual linear hills.

MODERATE (0.20-0.40)

It is spread over throughout the basin (29.24%) but, is more prominently distributed in the central and northeastern part of the basin particularly, over the Nongpoh and Kyrdem Plutons and the proximal Shillong Group around Tarsa. However, the Umiam gorge section between Marbisu and Shillong has a narrow linear zone of this group due to vigorous downcutting by Umiam in Shillong Group along the Tyrsad-Barapani shear zone.

The moderate dissection over the plutons and proximal Shillong Group between Umta-Tarsa and Amjonggaon depict the degree of incision since the stripping of the supracrustals and gradual unloading of topography consequent to it along weak zones like joints and fracture system.

LOW (BELOW 0.2)

By far, this is the predominant group in the basin occupying 54.91% area and is spread throughout the basin. However it is more conspicuous over the Shillong Group and the undifferentiated alluvium occurring in the northeastern fringe of the basin.

The low dissection index suggests that the stripping of Cretaceous-Tertiary cover sediments from over the Shillong Group is a recent phenomenon, a consequence of Quaternary erosional processes.

The moderate to high dissection index is localised and is the product of preferred vigorous erosion along weak zones. In general, the basin has retained the plateau configuration in areas underlain by Shillong Group of rocks due to low dissection - an imprint of Quaternary erosion cycle on the Pre-Cretaceous exhumed surface. The low dissection of the Post-Jurassic uplifted Massif to an elevation of 600m to 1800m above m.s.l. appears anomalous. It is due to the fact that the peneplained (Precambrian) Shillong Group terrain had supracrustals as the Gondwana Group as well as the Cretaceous-Tertiary cover sediments. The *Shillong Group could be exposed to erosion only after the* stripping of the supracrustals. Assuming a 5km conservative thickness (Mathur and Evans 1964; Anon 1974; Roy and Asthana 1989) of the supracrustals, their denudation was possible within the Quaternary period with an average rate of 7.5cm to 90cm per 1000 years (Khosla 1953; Wegman 1957; Schumm 1963). According to Gilluly (1955) and Menard (1961) the present rates of erosion are comparable to that of Cenozoic. However, locally, erosion rates could be as high as 1m to 4m per hundred years due to anthropogenic activities (Birnie 1993).

The longitudinal as well as transverse profiles (Fig. 13 & 15) reveal multilevel rejuvenated physiography, an episodic response to the tectonic movements and vertical block uplift of the Massif. Such episodic movements have changed the base level of the streams. Consequently, higher palaeo denudational rates are expected than at present. Moreover, relict glacial imprints found in the basin (c.f.Geomorphic Characteristics) mean higher denudational rate during Pleistocene glaciation period (Corbel 1959). Thus, the denudation of the supracrustals in the basin has certainly occurred not prior to Quaternary, perhaps, a Late Quaternary phenomenon. As a result, the Shillong Group (basement) has not suffered in general, higher dissection except along reactivated lineaments.

The undifferentiated alluvium occupying the lowlands at the terminal part of the basin is almost a relief less feature (more than 20m) except micro relief and monadnocks. This lowland is part of the Umiam-Kopili-Brahmaputra river oscillations in their flood plains. The microrelief features like microscarps, terraces and palaeolandslide-debris etc. are the signatures of Neotectonic movements in this part of the basin. The plate tectonic movements associated with the Himalayan-Patkai-Arakan-Yoma mobile belt causes high seismicity due to compensation of the strain energy along the criss-cross lineaments (basement fractures) in the Massif, resulting in Neotectonic movements in the basin. The multidated toposheets reveal change in elevation of spot heights in the basin. The 1966-67 spot heights show a rise upto 3m along the Umiam course with reference to 1910-11 heights indicating recent pulse of "rise" (Neotectonic movements), perhaps in response to the Great Assam Earthquake of 15th August 1950 with a magnitude of 8.7 (Anon 1950; Gupta et al. 1986; Gupta and Singh 1986). Thus the Massif has signatures of seismicity induced and/or isostatic vertical (uplift) movements. The result is frequent adjustment of streams to Active Tectonics (Gregory and Schumm 1987) which has its manifestations as localised higher dissection or development of gorge sections.

IV. **SLOPE (SL)**

Slopes are fundamental elements of the landscape (King 1962). Slope refer to the angle which any part of the earth's surface makes with horizontal. It is an element of the interface between lithosphere and either hydrosphere or atmosphere (Fairbridge 1968). Slopes have either aggradational forms or degradational forms. The aggradational forms are represented by alluvial, colluvial and talus slopes and the degradational slopes are represented by escarpments, interfluves, waterdivides of streams, surfaces directly eroded by streams and channels cut by streams.

According to Strahler (1950a) slopes reflect a steady state in the rate of supply of debris and rate of removal of debris. Slopes tend towards a constant angle which is related to the particular conditions of soil, bedrock, vegetation, climate and relief. The rate of erosion on a slope is a function of slope angle (Schumm 1956). Studies carried out by Strahler (1950b) showed that in the tectonically active southern California, slopes are relatively steep, generally more than 30^{o}. All long or steep slopes result from the operation of a variety of processes over a long period of time (Selby 1985).

Slope analysis is useful in deducing the evolutionary history of the terrain as well as in land resource utilisation planning. Slopes can be depicted as slope profiles or as average slope per unit area shown as maps particularly in highly dissected terrains (Monkhouse and Wilkinson 1980).

The slopes in the basin are the product of fluvial denudation and adjusted to the geometry of stream network systems.

ELEMENTS OF SLOPE

Slope are perceptible inclination visible on flanks of valleys and hills; plateau sections ridges, scarps, etc. Commonly, slopes are classified in terms of slope profile 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 gradient line orthogonal to topographic contours.

A slope profile may have a variety of forms. Geometrically, slopes may consist segments termed as "elements" (Fig.19a) which are concave upward, convex upward, straight or rectilinear and complex (Savigear 1956; Young 1964; McCullagh 1978). These forms also conforms to the 9-unit slope model of Dalrymple et al. (1968). The inflexion point or the point 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 various elements (Fig.19b). According to Frye (1959) and Fairbridge (1968), King's profile is usually not applicable in areas with non-stratified rock. However, King's profile is useful in qualitative analysis of slope profiles. The

ELEMENTS OF SLOPES (AFTER YOUNG 1964)

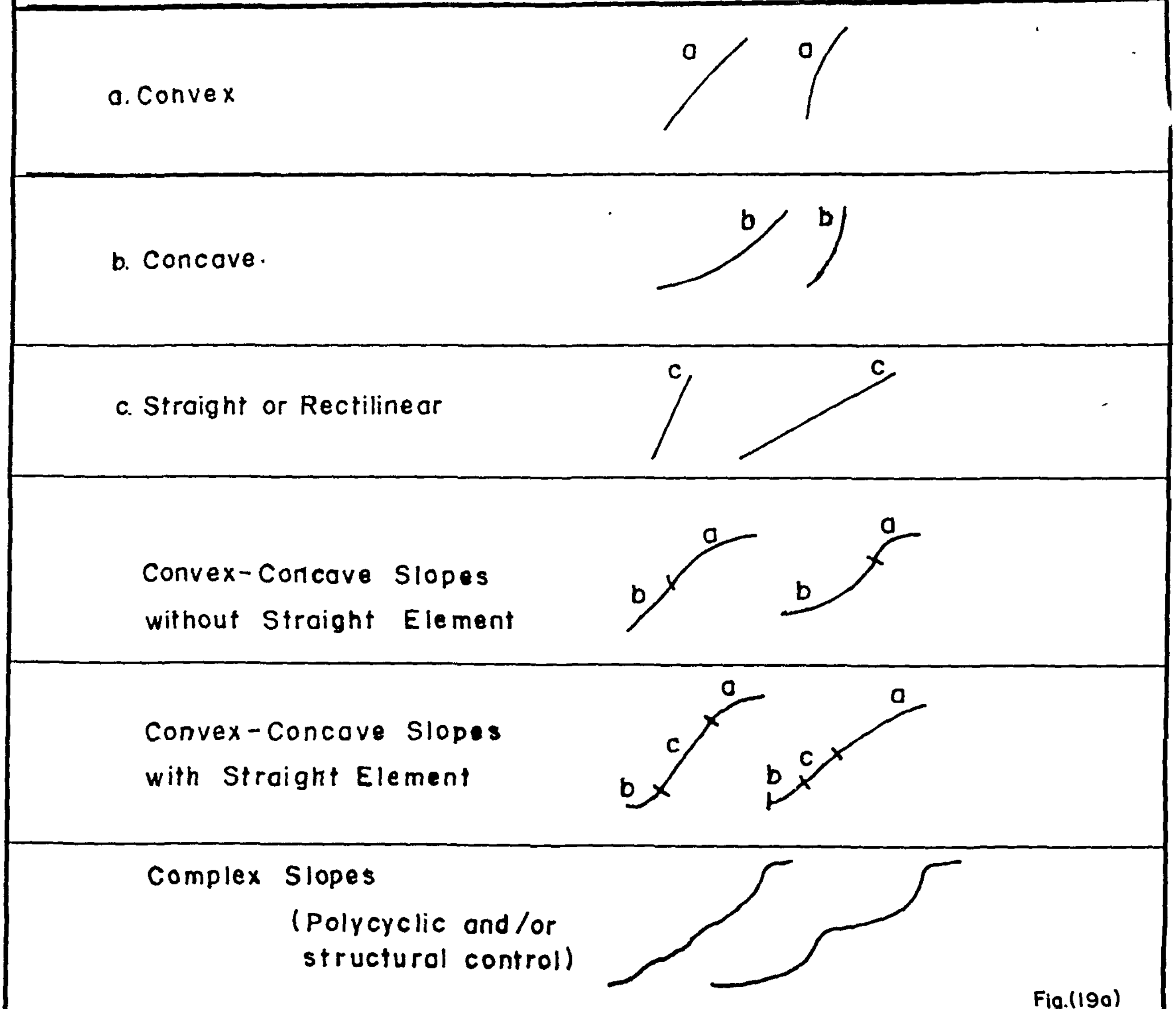


Fig.(19a)

ELEMENTS OF FULLY DEVELOPED HILLSLOPE (AFTER KING 1957)

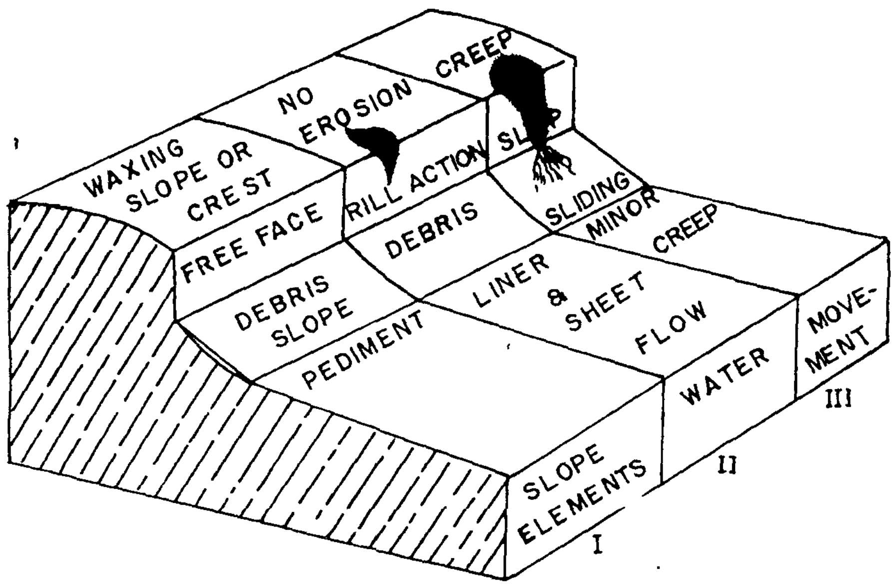


Fig.(19b)

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 stream or alluvial plains. It is produced by surface wash and its profile may approximate to an hydraulic curve.

Young (1972) has classified slopes into nine classes based on their inclination in degrees, as given below :

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	Precipitious
viii)	:	70 - 90	Almost Vertical
ix)	:	Over 90	Over Hanging

SIGNIFICANCE OF SLOPE ANALYSIS

The primary aim of slope analysis is to identify slope elements in an area. Since slope elements are the product of certain processes operating on the earth surface, their study helps in understanding the landform evolution in that particular area.

The manner in which contemporary processes and changes can influence slope form is of general interest in applied geomorphology. At the same time, there is increasing awareness of the practical value of slope studies with regard to proposed and existing developments in hilly areas (Chowdhury 1978). The aims of slope study can be summarized as follows :

(a) To assess the stability of different types of slopes under given conditions.

(b) To assess the possibility of landslides involving natural or existing man made slope.

(c) To analyse slips and landslides that have already occurred and to assist in the understanding of failure mechanisms and the influence of environmental factors.

(d) To enable the redesign of failed slopes, and the planning and design or preventive and remedial measures where necessary.

(e) To enable a study of the effect of exceptional loadings such as earthquake on slopes and embankments.

(f) To understand the development and form of natural slopes and the processes that have been responsible for the different natural features.

Slopes are ubiquitous elements of the land surface. They exert their influence on development of soil, loss of soil by soil erosion, mining operations, agricultural practices and development of communication network.

Since all these aspects are related to slope, a detailed analysis of slope of an area becomes essential for charting out a developmental plan for the area.

ANALYTICAL PROCEDURE

An exact way of representing slope is to give gradient along a line which can be done as follows :

(a) Drawing profiles on the basis of contours from maps.

(b) Measuring gradient directly in the field of hillsides by Abney Level.

(c) Channel gradient on the basis of contour and drainage maps.

However, such linear expression though exact, do not provide a spatial distribution of gradient in an area. The earth surface slopes in different directions with different values, so a linear expression does not give the true picture of slope in an area. Thus a spatial distribution of slope variation giving average slope is preferred over linear expressions though at the cost of exact slope values. Different methods are suggested for making slope maps Finsterwalder (1890); Wentworth (1930); Smith

(1935); Raisz and Henry (1937); Robinson (1948); Miller (1949); Calef (1950); Calef and Newcomb (1953); Strahler (1956); Miller and Summerson (1960); Cloves and Peters (1982) etc. Some methods are much laborious over others and have complicated calculations and the results obtained are not proportionately satisfactory to the labour involved. However, the method devised by Wentworth (1930) for "general and random" determination of average slope over an area from a contour map is quite satisfactory, and has been adopted for the slope analysis in the area.

The formula devised by Wentworth is given below :

Average Slope = Tan Θ = N x CI/3361

Where, N = Average no. of contour crossing in an area per sq.mile.

CI = Contour interval in feet

3361 = A constant figure

Zakrzewska (1967) modified Wentworth's above formula as given below :

Average Slope in degree = Tan Θ = V x N/0.6366 K*

Where, V = Vertical contour interval in metre or in feet.

N = No. of contour crossing per sq.km. or per sq.mile and,

K = Constant, 1000 for metric units and 5280 for feet and miles i.e. British units.

The basin has been divided into 1613 grids of one sq.km each and the number of contours crossing per sq.km . i.e. per grid is counted (contour crossing per side of the grid divided by four = contour crossings per grid). With the above modified Wentworth's formula, average slope per grid is computed (the

---

* 0.6366K becomes 636.6 for metric system (0.6366x1000) because 1 km=1000m. 0.6366 is the mean of all possible values of Sin Θ (where Θ is the horizontal angle between the contour and the grid line). 0.6366K becomes in f.p.s. (0.6366x5280) because 1 mile = 5280 feet.

value obtained by the formula is converted into degrees). These average slope values obtained have been classified into 8 categories (Table-10) with an interval of 5. These 8 categories are further classified into five qualitative groups (Table-10) as per Young's classification (Young 1972). The spatial distribution of these 8 categories is shown in Fig.(20). The slope within the basin varies from 0^{o} in the northeast to 37^{o} as isolated patch in Umiam gorge as well as south of Amjonggaon in the northeast.

DISTRIBUTION PATTERN OF SLOPE

The different slope categories show a peaked frequency distribution of slope between 10^{o} and 25^{o} categories.A perusal of Table (10) reveal very steep slope group has negligible areal extent (0.98%). At the same time gentle to moderate slope groups have insignificant areal distribution of 5.16% and 6.99% respectively. The steep to moderately steep slope groups have largest distribution in the basin, 29.44% and 57.43% respectively. The distribution of the various slope groups is discussed below.

VERY STEEP SLOPE (ABOVE 30^{o})

It occurs as isolated patches over Shillong Group of rocks and is confined in the Umiam gorge section between Marbisu and Mawlendep in the southwest and near Amjonggaon in the northeast. These isolated patches coincides with the trace of the Tyrsad-Barapani shear zone cutting through the basin. Such discrete steep slope patches indicate accelerated erosion in vicinity of the shear zone, a consequence of minor reactivation.

TABLE-10

DISTRIBUTION OF AVERAGE SLOPE IN UMIAM BASIN

Slope Category (^{o})	Grid Frequency	Grid Frequency (%)	Area (sq.km)	Cumulative Area (sq.km)	Area (%)	Cumulative Area (%)	Major Slope Group (^{o})
Above 35	3	0.185	3.000	3.000	0.210	0.210	Above 30^{o} 14.0 sq.km (0.980%) - Very steep
30 - 35	11	0.682	11.000	14.000	0.770	0.980	
25 - 30	90	5.580	83.198	97.198	5.820	6.800	20^{o} - 30^{o} 420.922 sq.km (29.44%) - Steep
20 - 25	377	23.373	337.724	434.922	23.625	30.425	10^{o} -20^{o} 820.966 sq.km (57.43%) - Moderately steep
15 - 20	575	35.648	513.963	948.885	35.954	66.379	
10 - 15	357	22.133	307.003	1255.888	21.476	87.855	5^{o} - 10^{o} 99.928 sq.km (6.99%) - Moderate
5 - 10	114	7.067	99.928	1355.816	6.990	94.845	
Below 5	86	5.332	73.694	1429.510	5.155	100.000	Below 5^{o} 73.694 sq.km (5.16%) - Gentle
TOTAL	1613	100.000	1429.510		100.000		

Range : 0.0 - 37.0 Mean : 16.81 Median : 17.354 Mode : 18.340 Std. Dev. 6.140 Coeff. of var : 36.52

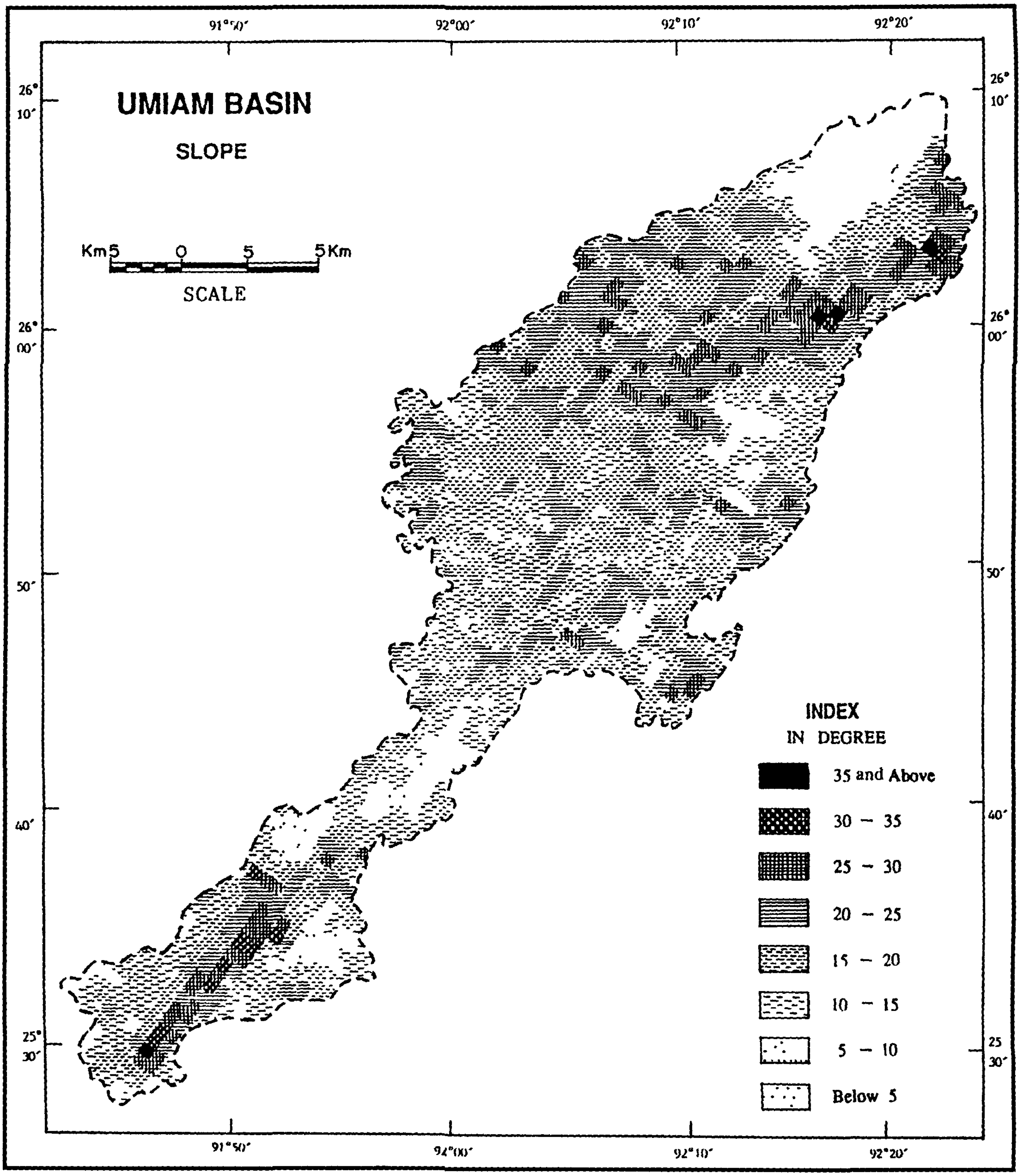

UMIAM BASIN
SLOPE
Km 5 0 5 5 Km
SCALE
INDEX
IN DEGREE
35 and Above
30 – 35
25 – 30
20 – 25
15 – 20
10 – 15
5 – 10
Below 5
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′

Fig (20)

STEEP SLOPE (20^{o} -30^{o})

In the southwestern part of the basin it occurs as linear patch along the Umiam gorge section over the Shillong Group while in the central and northeastern part of the basin 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 particularly southwest of Amjonggaon on the acid magmatic centre (c.f. Figs. 6 & 27) having domal expression (Hummocks). However beyond Amjonggaon the group on the Shillong Group coincides with the northeastern segment of the Tyrsad-Barapani shear zone such localised steep slopes are suggestive of instabilities of slopes and attendant vigorous erosion.

MODERATELY STEEP (10^{o} - 20^{o})

Over 50% of the basin (57.43%) is occupied by moderately steep slope group. The subhorizontally disposed Shillong Group predominantly show the 10^{o}-15^{o} category of slope while the Nongpoh Pluton predominantly depict 15^{o}-20^{o} slope category. Such slope differentiation is also due to the 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 from over it.

MODERATE (5^o - 10^o)

It is mainly developed as patches over Shillong Group as well as the southwestern fringe of undifferentiated alluvium bordering the uplands, around Pataguri-Nelli-Amjonggaon. The Shillong Agglomeration and Marbisu-Nongthliew terraced plateau remnants are located over this group. The linear "trough" from Mawlendep to southwest of Tarsa characteristically depicts this slope group indicating a rolling landscape over the Shillong Group. The intermontane valleys around Tarsa and Barmarjong also depict patches of moderate slope in association with gentle slope group indicating presence of terraced platforms on the upland.

GENTLE (BELOW 5^o)

By and large it is confined over the Quaternary terraces particularly in the terminal part of the basin, north of Amjonggaon. Isolated patches of this group have also developed over Shillong Group, around Barmarjong, Tarsa and Barapani areas. These localised occurrences indicate presence of "rock platforms" or benches on the uplands, the relicts of glacial imprints. The terminal part of the basin which is a lowland depict characteristically level terraces and high degree of anthropogenic activity. It forms the largest tract of land with lowest slopes in the entire basin, at one place, as such has a high potential of diverse landuse.

SLOPE DEVELOPMENT

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

The slopes in the area depicts all the three "forms" discreetly as well as in combination. The top of ridges usually have convex profiles but the ridge flanks show combination of all the three forms. By and large the convex and straight segment of the slope profiles in the area are erosional in nature while the concave slopes are depositional in nature. The natural slope profile is seen at places modified due to the interference of "man". The sections in the vicinity of developmental schemes show modified slope profile 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 jeopardised. The slope frequently fails due to rapid change in equilibrium conditions. This is the common feature seen along slope cuttings (Plate-9).

The slope profiles over Gneissic country are mostly concavo-convex. Slopes over Shillong Group and the Granitoid plutons show all the three slope elements, however, the bottom slopes are remarkably concave with low curvature, merging with rock platforms and pediments. Most of the lower concave segments are over palaeolandslides, debris and thick regolith lying in a

(Plate–9) :
Landslide in sheared Phyllitic quartzite due to steep cuts on slope profiles. Note bamboo fence improvisation for temporary protection.

(Plate–10) : Palaeolandslide lobe at the pediment hill slope interface on the uplands.

metastable condition over the rock platforms and pediments. These are lobate shaped fossilised landslides-debris flows of assorted and exotic regolith triggered by the major earthquakes of 1897 and 1950 in the region (Plate-10). Any anthropogenic modification on these metastable masses can accentuate the possibilities of their downslope translation and cause serious damages. Such lobate landforms proximal to rock platforms and pediments are potential geomorphic risks in this high rainfall and high seismic area.

It is evident 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.

V. DRAINAGE FREQUENCY (DF)

Drainage frequency and drainage density are the important index of degree of erosion in a terrain. It indicates the extent of adjustment of drainage net work to a given terrain in the cycle of erosion. The drainage net of Umiam basin is shown in Fig. (21).

Horton (1932, 1945) introduced drainage frequency as the number of stream segments per unit area.

Numerically, it is defined by the relation

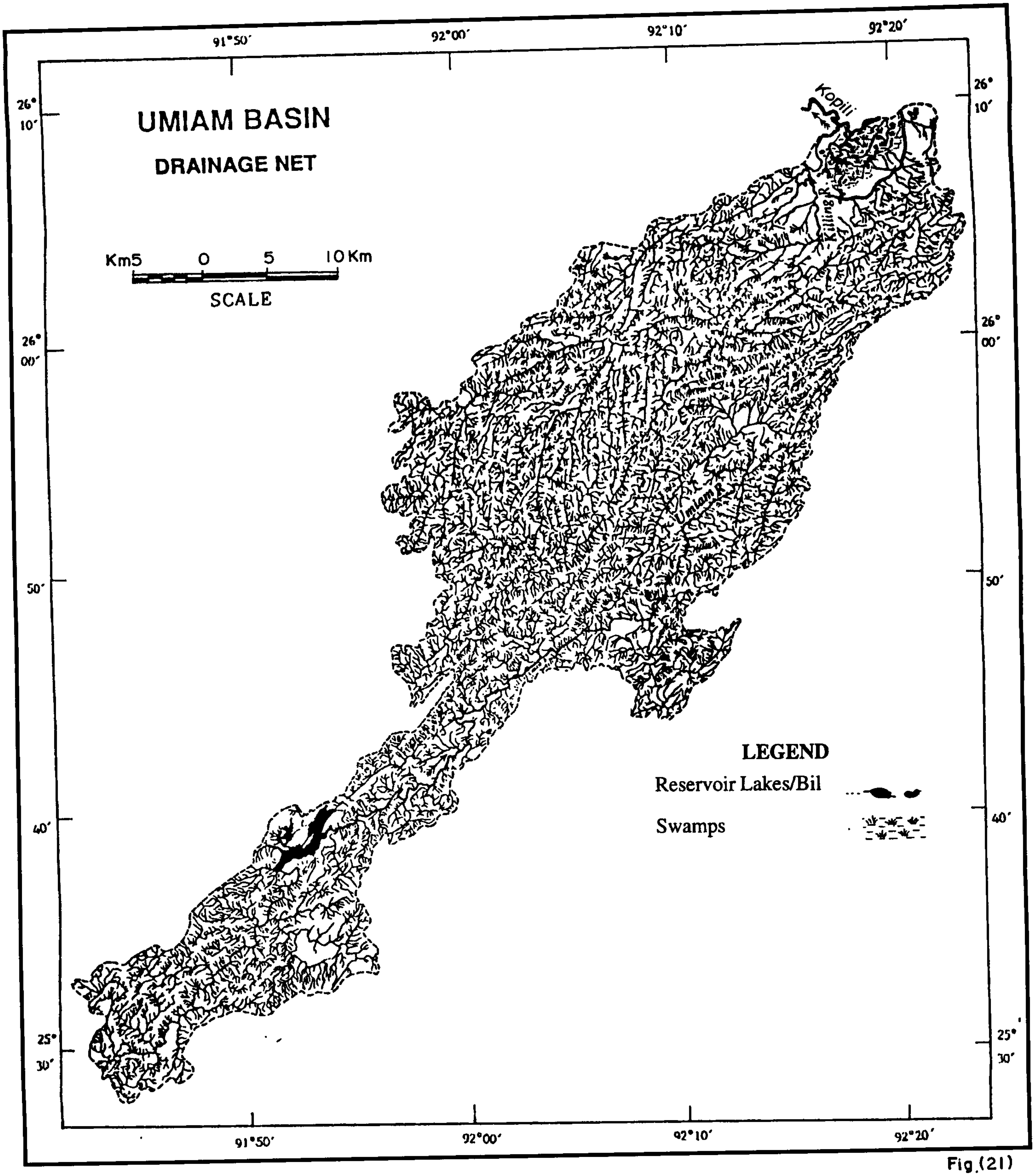
$$Fu = (N)u/Au$$

Where,

Fu = Drainage frequency in no/km^2

(N)u = Sum of total number of stream segments of all orders

Au = Total area of the drainage basin in sq.km



UMIAM BASIN
DRAINAGE NET
Km5 0 5 10 Km
SCALE
LEGEND
Reservoir Lakes/Bil
Swamps
Kopili
Killing R.
Umiam R.
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′

Fig.(21)

The expression Fu gives the average frequency of streams in the basin. The computed average drainage frequency of the basin is 5.24 nos. per sq.km. But, to know the variation of drainage frequency in the basin, the frequencies have been computed for each sq.km grid of the entire basin i.e. 1613 grids.

The drainage frequency within the basin varies from 0 in the terminal part to 16 nos. per sq.km scattered towards the northeastern part of the basin. The grid wise computed drainage frequencies are classified into six categories (Table-11) with a class interval of 3, ranging from below 3 nos. per sq.km to above 12 nos. per sq.km. The spatial distribution of these categories is shown in Fig.(22). These categories have been classed into five major drainage frequency groups (Table-11) and discussed below.

DISTRIBUTION PATTERN OF DRAINAGE FREQUENCY

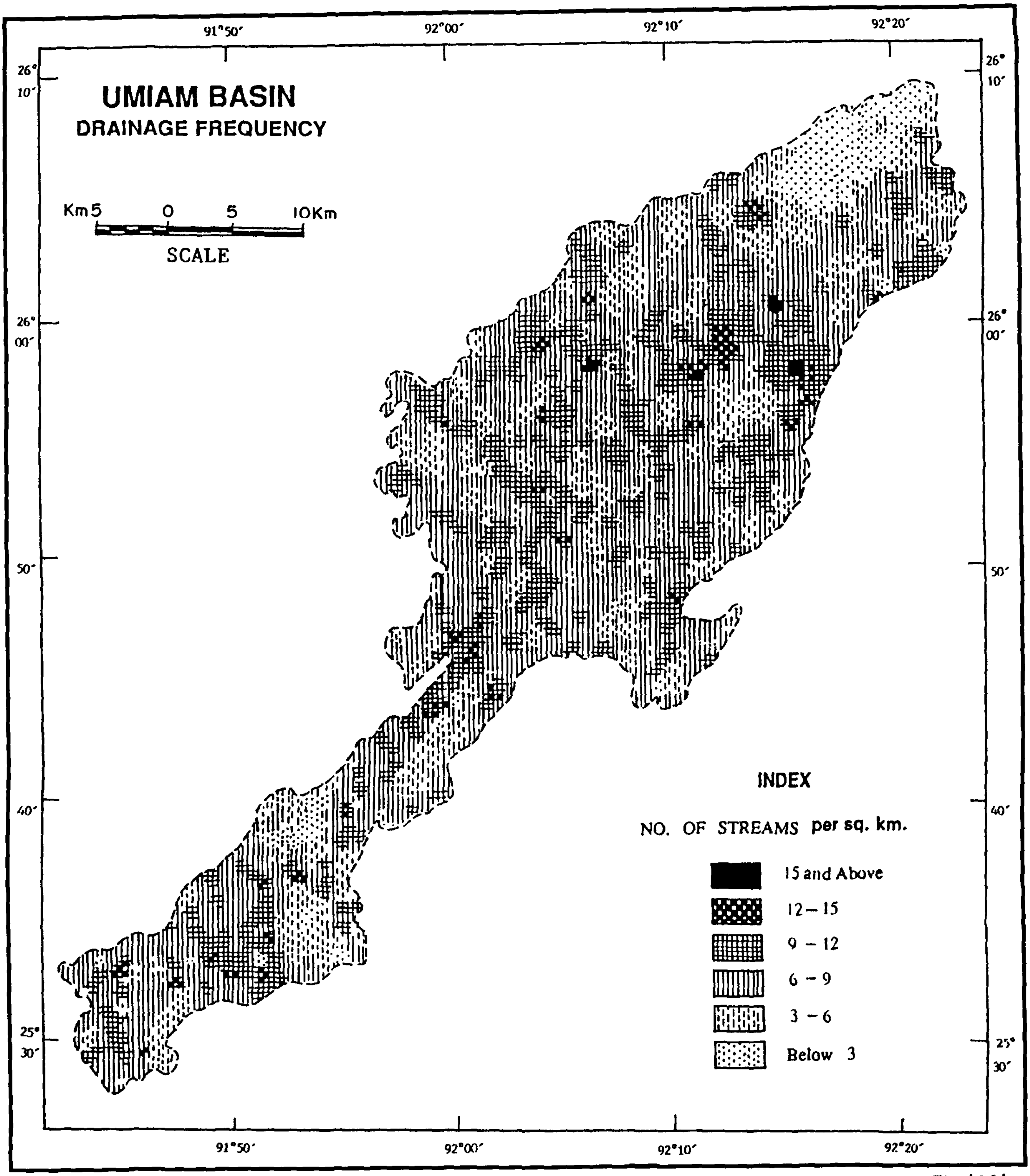
The different drainage frequency categories reveal a peaked grid frequency distribution between 3 nos. per sq.km and 12 nos. per sq.km drainage frequencies. A perusal of (Table-11) indicate that high and very low drainage frequency groups have insignificant distribution of 3.92% and 6.20% respectively in the basin. But, large part of the drainage basin has moderately high, moderate and low drainage frequencies, 24.95%, 43.87% and 21.06% respectively. The distribution of these groups is discussed below.

TABLE-11
DISTRIBUTION OF DRAINAGE FREQUENCY IN UMIAM BASIN

Drainage Frequency Category (nos/sq.km)	Grid Frequency	Grid Frequency (%)	Area (sq.km)	Cumulative Area (sq.km)	Area (%)	Cumulative Area (%)	Major Drainage Frequency Group	
Above 15	4	0.248	4.000	4.000	0.280	0.280	Above 12 nos./km^2- 56.062 sq.km (3.92 %)	High
12 - 15	57	3.534	52.062	56.062	3.642	3.922	9 - 12 nos./km^2 - 356.612 sq.km (24.95%)	Moderately High
9 - 12	389	24.117	356.612	412.674	24.946	28.868	6 - 9 nos./km^2 - 627.111 sq.km (43.87%)	Moderate
6 - 9	700	43.397	627.111	1039.785	43.869	72.737	3 - 6 nos./km^2 - 301.056 sq.km (21.06%)	Low
3 - 6	352	21.823	301.056	1340.841	21.060	93.797		
Below 3	111	6.881	88.669	1429.510	6.203	100.00	Below 3 nos./km^2 - 88.669 sq.km (6.20%)	Very low
TOTAL	1613	100.000	1429.510		100.000			

Range : 0-16 **Mean : 7.86** **Median : 8.476** **Mode : 8.511** **Std. Dev. 2.78** **Coeff. of var : 35.34**

The gridwise computed mean drainage frequency is higher than the computed average for the whole basin because the same stream segments get counted in all the grids traversed by them. But while computing the average for the whole basin, each segment is counted only once irrespective of the area traversed by it.



UMIAM BASIN
DRAINAGE FREQUENCY
Km 5 0 5 10 Km
SCALE
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′
INDEX
NO. OF STREAMS per sq. km.
15 and Above
12 – 15
9 – 12
6 – 9
3 – 6
Below 3

Fig. (22)

HIGH DRAINAGE FREQUENCY (ABOVE 12 nos/km^2)

It is scattered throughout the basin in discrete patches, largely clustered in the Shillong Group and sporadically over the Nongpoh Pluton west of Barmarjong. Inspite of being part of very high rainfall region, very low areal distribution (3.92%) of this group of drainage frequency suggests presence of higher secondary permeability and lower concentrated flow or lower channelisation in the hand rocks.

MODERATELY HIGH DRAINAGE FREQUENCY (9-12 nos/km^2)

This group occurs as large patches over all the lithologies except the undifferentiated alluvium. Conspicuously the peripheral part of the acid magmatic centres within the Nongpoh Pluton show concentration of patches of this group. Patches of these groups show preferred N-S and NW-SE alignments. The NW-SE trends are predominant and are oblique to the formational trends indicating presence of strong cross structural elements (lineaments) which have influenced evolution of drainage lines in the basin. The concentration of patches of this group around Nongpoh Pluton indicate development of drainage lines along diapirism induced topographic rise and channelisation of run off along structural lines.

MODERATE DRAINAGE FREQUENCY (6-9 nos/km^2)

This has the largest distribution in the basin (43.87%) and is spread over event through out over the Shillong Group and Nongpoh Pluton. The spatial distribution of this group (Fig.22) does not show any influence of lithology or structure.

LOW DRAINAGE FREQUENCY (3-6 nos/km^2)

It occurs as patches throughout the basin and is developed on Shillong Group as well as Nongpoh Pluton. The patches over Shillong Group are comparatively larger than on the pluton. The Shillong Agglomeration and Mawlendep-Barapani area are located over these large patches on Shillong Group. The patches of this group are aligned in N-S and NE-SW direction. The N-S alignments are oblique to the regional trend of the formations indicating presence of strong N-S structural elements (lineaments) in the basin. The N-S trends are more pronounced over the Nongpoh Pluton than over the Shillong Group perhaps representing persistence of the pre-migmatisation trends of the Gneissic Complex, in the Nongpoh Pluton. The sporadic N-S trends over Shillong Group particularly around Tarsa and northeast of Amjonggaon suggests the control of basement (Gneissic Complex) on the evolution of drainage lines over the Shillong Group terrain where the stream channels have cut through the remnants of Shillong Group and have touched the underlying Gneissic basement.

VERY LOW DRAINAGE FREQUENCY (BELOW 3 nos/km^2)

It has insignificant distribution in the basin. These are by and large confined over the undifferentiated alluvium at the terminal part of the basin i.e., north of Amjonggaon. However, sporadic minor patches occur over the hard rocks in the southwestern part near Marbisu, Shillong and Mawlendep, in the central part near Tarsa and northeast of Umta; and in the northeastern part of the basin each of Amjonggaon. The low drainage frequency over the alluvium signifies high infiltration low run off i.e., low channelisation, consequently lesser development of stream networks. But, the low drainage frequency in the uplands comprising hard rocks reflect high infiltration through secondary permeability i.e., joints fractures defining lineaments in the basin.

Thus the spatial distribution of the various drainage frequency groups in the basin reflect strong influence of structural elements than the lithological variation in the drainage evolution. The localised patches of lower drainage frequency categories in the uplands is indicative of high groundwater recharge through secondary permeability. As such the intermontane valleys and lowland depressions in vicinity of such patches would have high groundwater potential in the hard rocks.

DRAINAGE DENSITY (DD)

It is the ratio between the cumulative channel lengths of channel segments of all orders and the area of the basin. Horton (1945) introduced this parameter to express the closeness of spacing of channels.

Numerically it is defined by the expression

$$Dd = (EL)u/Au$$

Where Dd = Drainage density in km/km^2
(EL) u = Sum of total lengths of streams of all order in km
Au = Area of the basin in sq.km

The expression Dd signifies the average drainage density of streams in the basin. Theoretically the value should always come more than unity. The computed average drainage density of the basin is 3.82 km per sq.km. But to know the variation of drainage density in the basin, the densities have been computed per sq.km grid for the entire basin. The drainage density within the basin varies from 0 in the southwest near Barapani and near Pataguri-Nelli in the northeast, to 8.5 in the central part of the basin near Barmarjong. The grid wise drainage densities have been classified into 5 categories (Table-12) with a class interval of 2 km per sq.km, ranging from below 2 km per sq.km to above 8.5 km per sq.km. Their spatial distribution is shown in Fig.(23). These categories are referable to qualitative drainage density groups of Singh (1974) viz., Very High, High, Moderate, Low and Very Low (Table-12).

DISTRIBUTION PATTERN OF DRAINAGE DENSITY

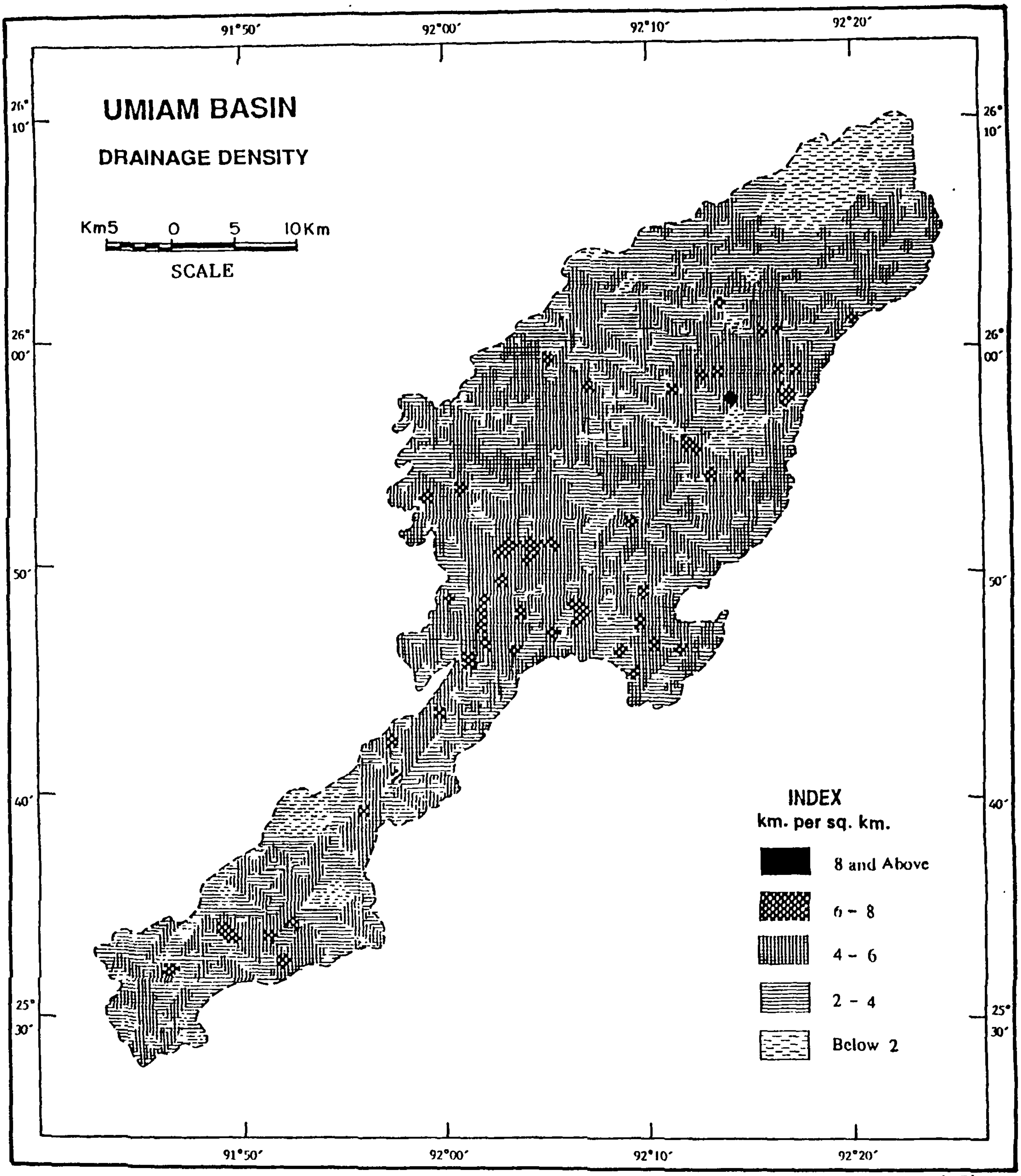
The different drainage density categories reflect a peaked grid frequency distribution between 2 km per sq.km to 6 km per sq.km drainage densities accounting for 88.468% of the grids in the basin. A perusal of (Table-12) reveal that very high and high groups have insignificant area, 0.062% and 3.782% respectively in the basin. Similarly the very low group has limited spatial distribution (7.688%). But large part (1273.034sq.km) of the basin has high and moderate groups distributed in it. The distribution of the various groups is discussed below.

TABLE-12

DISTRIBUTION OF DRAINAGE DENSITY IN UMIAM BASIN

Drainage Density Category (km/km^2)	Grid Frequency	Grid Frequency (%)	Area (sq.km)	Cumulative Area (sq.km)	Area (%)	Cumulative Area (%)	Major Drainage Density Group
Above 8	1	0.062	1.000	1.000	0.070	0.070	Above 8 nos/km^2 - Very high 1.000 sq. km (0.07 %)
6 - 8	61	3.782	60.045	61.045	4.200	4.270	6 - 8 km/km^2 - High 60.045 sq.km (4.20 %)
4 - 6	763	47.303	705.700	766.745	49.367	53.637	4 - 6 km/km^2 - Moderate 705.700 sq.km (49.37%)
2 - 4	664	41.165	567.334	1334.079	39.687	93.323	2 - 4 km/km^2 - Low 567.334 sq.km (39.69%)
Below 2	124	7.688	95.431	1429.510	6.676	100.000	Below 2 km/km^2 - Very low 95.431 sq.km (6.67%)
TOTAL	1613	100.000	1429.510		100.000		

Range : 0-8.5 **Mean : 4.052** **Median : 4.363** **Mode : 5.058** **Std. Dev. 1.314** **Coeff. of var : 32.44**



UMIAM BASIN
DRAINAGE DENSITY
Km5 0 5 10Km
SCALE
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′
INDEX
km. per sq. km.
8 and Above
6 - 8
4 - 6
2 - 4
Below 2

Fig.(23)

VERY HIGH DRAINAGE DENSITY (ABOVE 8 km/km^2)

It occurs over Shillong Group as an insignificant patch (1.0sq.km) confined northeast of Barmarjong. This isolated patch of very high drainage density reflects presence of very localised resistant lithology within the Shillong Group.

HIGH DRAINAGE DENSITY (6-8km/km^2)

This group occurs as minor patches mostly in the southwestern and central part of the basin predominantly scattered over the Shillong Group with subordinate distribution over Nongpoh Pluton. The patches over the Shillong Group have four broad clusters from southwest to northeast viz., (1) south of Shillong, (2) between Barapani and Umden, (3) between Tarsa and Pamlaban, (4) around Barmarjong. These clusters incidentally fall in deforested terrain (c.f. Fig.30) suggestive of higher channelisation of run off due to deforestation. The patches show alignments in conformity to the regional NE-SW trends, of the formations as well as oblique NW-SE trends also. The oblique trends signify the joints-fractures control over the development of the drainage lines.

MODERATE DRAINAGE DENSITY (4-6km/km^2)

It is the major group occupying almost 50% of the basin area (705.70sq.km) 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 basin which characteristically has terraced plateau landforms has relatively lesser development of this group than the Nongpoh Pluton. This mild contrast indicate that the upper reaches of the basin has relatively higher permeability than the lower reaches.

LOW DRAINAGE DENSITY (2-4km/km^2)

This group has the second largest distribution occupying 567.334sq.km of the basin. 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.

VERY LOW DRAINAGE DENSITY (BELOW 2km/km^2)

This group is mainly distributed over the undifferentiated alluvium confined in the northeastern part of the basin, beyond Amjonggaon. Its minor sporadic patches are seen in the hard rock terrain comprising Shillong Group as well as Nongpoh Pluton and the Genissic Complex. Incidences of such discrete patches is more over Shillong Group than the pluton or the Gneisses. These isolated patches mark the depressions or intermontane valleys like near Sohiong, Marbisu, Shillong, Maw-lendep-Barapani-Umden, Tarsa, Mayang, Barmarjong etc. These depressions represent structural weak zones in the basin i.e. either fault systems, joint fracture systems or reactivated lineaments as a result zones of relatively high permeability in the hard rock terrain.

The spatial distribution of drainage density groups influence of structural control in the evolution of drainage lines in the basin. It corroborate the inference drawn from the drainage frequency distribution in the basin. Moreover, the deforested areas have yielded higher incidences of very high to high drainage densities i.e. higher channelisation of run off in comparison to forest covered areas in the basin.

CORRELATION OF PARAMETERS

The interrelation between the different morphometric parameters is measured by Karl Pearson's co-efficient of correlation. The correlation matrix is given in (Table-13). The correlation is tested at t(0.1), t(0.05) and t(0.01) level of significance and classified into weak, moderate and strong correlation (Table-14).

This correlation is compatible with the spatial distribution of geomorphic attributes in the different geomorphic domains (c.f. Fig.27). The degree of dependency of each parameter is given in (Table-15). It is seen that the variation in absolute relief has almost no effect on RR, DF, DD and SL but, DI show low dependency on AR. It indicates that the areas of high elevations have low dissection index resulting in the preservation of plateau characters in the terrain. The relative relief controls DI to some extent and SL is highly dependent on RR. It is also seen that drainage density and drainage frequency are mutually highly interdependent. Similarly slope is highly dependent on RR. It is evident from the (Table-15) that SL, DD,

TABLE-13

CORRELATION MATRIX OF GEOMORPHIC ATTRIBUTES

	AR	**RR**	**DF**	**DI**	**DD**	**SL**
AR	1.000	0.226	0.219	0.511	0.139	0.095
RR		1.000	0.279	0.505	0.219	0.729
DF			1.000	0.057	0.783	0.429
DI				1.000	0.045	0.460
DD					1.000	0.369
SL						1.000

Remarks – **AR** : Absolute Relief, **RR** : Relative Relief, **DF** : Drainage Frequency,
DI : Dissection Index, **DD** : Drainage Density, **SL** : Average Slope

TABLE-14

NATURE OF CORRELATION OF GEOMORPHIC ATTRIBUTES

Parameter	POSITIVE CORRELATION			NEGATIVE CORRELATION		
	Weak (t 0.1)	**Moderate (t 0.05)**	**Strong (t 0.01)**	**Weak (t 0.1)**	**Moderate (t 0.05)**	**Strong (t 0. 01)**
AR	-	-	RR, DF, DD, SL	-	-	DI
RR	-	-	AR*, DF, DI, DD, SL	-	-	-
DF	-	DI	AR*, RR, DD, SL	-	-	-
DI	DD	DF	RR, SL	-	-	AR*
DD	DI	-	AR*, DD, DF, SL	-	-	-
SL	-	-	AR*, RR, DF, DI, DD	-	-	-

Remarks : Based on coefficient of correlation

* Spurious correlation

TABLE-15

DEGREE OF DEPENDENCY OF GEOMORPHIC ATTRIBUTES

	DEPENDENT PARAMETER						
Independent Parameter	**Negligible L-10 %**	**Very low 10% - 20%**	**Low 20%-30%**	**Moderate 30%-40%**	**Moderately high 40%-50%**	**High 50%-60%**	**Very high G-60%**
AR	RR, DF, DD, SL	-	DI	-	-	-	-
RR	AR*, DF, DD	-	DI	-	-	SL	-
DF	AR*, RR, DI	SL	-	-	-	-	DD
DI	DF, DD	-	AR*, RR, SL	-	-	-	-
DD	AR*, RR, DI	SL	-	-	-	-	DF
SL	AR*	DF, DD	DI	-	-	RR	-

Remarks : based on values of R^2 (coefficient of determination)

* Spurious dependency
L = Less than, G = Greater than

DF and RR are exclusively interdependent in the terrain. No single parameter has controlled the development of other parameters significantly which is typical character of plateaus. However, due to local geological inhomogeneity like reactivated lineaments - rejuvenation, the parameters do depict sharp dependencies over small segments of the terrain.

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CHAPTER - V

WATERSHED CHARACTERISTICS AND MORPHOMETRY

WATERSHED CHARACTERISTICS AND MORPHOMETRY

The most important of all geologic processes is the action of running water. Streams are the most active agents of denudation on land. The role of running water in shaping the surficial features on the landmass has been qualitatively and quantitatively studied by geologists, geographers and hydrologic engineers.

The physical changes produced in the landscape by running water are known as fluvial processes. It extends from the point where the precipitation first hits the ground to where it reenters the sea (Cloves and Peters 1982) as part of the hydrologic cycle, through streams of all shapes and sizes commonly known as drainage net.

The drainage net includes minor rills, ephemeral channels etc., and its details are dependent on scale of toposheets used to trace the channels. The fluvial processes from source to sea in a drainage net are either depositional or erosional, ultimately progressively dissecting and degrading the higher lands. The fluvial processes produce various types of valleys and interfluvial ridges depending upon the stage of development of the river, on the lithology and the structure of the area drained by the stream network. Large part of the earths surface represents erosional landforms produced through channel erosion by drainage network (Strahler 1950a) or drainage system.

The magnitude and nature of fluvial processes are best studied when analysed for the complete area of a drainage net also known as drainage basin or catchment. A drainage basin in geomorphology and hydrology is a region drained by a particular stream or by a river system comprising perennial, seasonal, intermittent, periodical, episodic and ephemeral channels (Fairbridge 1968). A drainage network also functions as a process response system where channel characteristics are best indicators of geomorphic sensitivity within the drainage basin. The drainage basin provides clearly a definable landunit, delineated by topographic divides that isolate it from adjacent catchment. River basins provide meaningful physical boundaries for integrating environment and human relationships with development (Cunningham 1986). A need is being increasingly recognised globally for coordinating and integrating approaches to natural resource utilisation (Downs et al. 1991) and which is achieved through the "total catchment management" or TCM (Martin and Lockie 1993). Such an approach calls for collecting information on catchment characteristics.

UMIAM RIVER SYSTEM :

Umiam basin covers an area of 1429.510 sq.km with a perimeter of 315.75km. Its elevation varies from more than 1900m in the source area to less than 60m above m.s.l. at the mouth. The length of the basin is 94.63km and its maximum width is 32.50km. The trunk channel is a 7th order stream known as Wah Umiam in the upper reaches, as Umiam or Bagra in the middle reaches and Killing in the lower reaches, before joining the Kopili River near Dharamtul (near Noa bil).

The drainage network analysis has been carried out to evaluate the basin characteristics. Various morphometric parameters of the component basins have been computed to characterise the basin.

BASIC BASIN CHARACTERISTICS :

The drainage net (Fig.21) of Umiam is with reference to 1:50,000 scale toposheets. The system of ordering of channel segments as proposed by Horton (1945) and modified by Strahler (1952b) is followed here. The Umiam drainage net has 120 component basins (Fig.24) with order varying from 3rd to 6th, and 923 nos. 1st order and 160 nos. 2nd order streams directly draining into the trunk stream from 295.344sq.km of interfluves. The basic features of component basin are summarised in Table (16). The component Basin Nos. 1 to 43 (43 nos) are located on the right bank of Umiam and 44 to 120 (77 nos) are located on the left bank of Umiam. Order wise breakup of the component basins is given below.

3rd order basins	-	66 nos.
4th order basins	-	39 nos.
5th order basins	-	14 nos.
6th order basins	-	1 no.
Total	-	120 nos.

The component Basin Nos. 36 to 43 and 119 & 120 confined towards the terminal part of the drainage network are

TABLE -16

COMPONENT BASIN CHARACTERISTICS

Sl. No.	Comp. Basin Number	Comp.Basin Name	Basin Lithology	U	Au (sqkm)	Pu (km)	Lb (km)	Hh (m)	Hl (m)	Z (m)
1	2	3	4	5	6	7	8	9	10	11
1	73	- -	PG	3	0.450	2.25	0.95	640	360	280
2	113	- -	GC	3	0.650	3.25	1.00	360	180	180
3	88	- -	PG	3	0.742	3.50	1.25	810	600	210
4	11	- -	SG	3	0.788	3.00	1.30	980	880	100
5	89	- -	PG	3	0.842	3.75	1.25	800	560	240
6	102	- -	GC	3	0.875	4.50	1.60	960	820	140
7	97	- -	PG	3	0.917	4.25	1.70	400	60	340
8	46	- -	SG	3	1.144	5.00	1.75	1720	1200	520
9	14	- -	SG40%,PG60%	3	1.181	5.50	2.00	1075	840	235
10	99	- -	PG	3	1.188	5.50	2.20	280	60	220
11	31	- -	SG	3	1.275	6.00	1.60	591	180	411
12	76	- -	PG	3	1.413	5.25	1.55	400	212	188
13	103	- -	GC	3	1.425	6.00	2.20	960	760	200
14	66	- -	PG	3	1.438	5.00	1.85	840	640	200
15	65	- -	SG	3	1.469	5.00	1.70	1120	760	360
16	13	- -	SG50%,PG50%	3	1.519	5.00	1.70	1075	840	235
17	8	- -	SG	3	1.589	5.75	2.20	1060	900	160
18	52	- -	SG	3	1.619	6.00	1.90	1240	980	260
19	39	- -	PG70%,UA30%	3	1.650	7.50	2.30	200	60	140
20	82	- -	GC	3	1.706	6.00	1.80	920	780	140
21	59	- -	SG	3	1.706	7.50	2.25	1180	840	348
22	22	- -	PG	3	1.750	6.50	2.40	880	700	180
23	57	- -	SG	3	1.769	7.24	2.45	1180	840	340
24	74	- -	PG	3	1.788	4.00	1.60	760	275	485
25	92	- -	PG	3	1.817	6.25	1.90	540	340	200

Contd. Table-16

1	2	3	4	5	6	7	8	9	10	11
26	78	- -	PG	3	1.833	5.75	2.25	340	80	260
27	40	- -	PG25%,UA75%	3	1.833	6.00	2.00	246	60	186
28	110	- -	PG	3	1.892	6.50	2.20	720	360	360
29	71	- -	PG	3	2.050	7.75	3.10	840	540	300
30	116	- -	GC	3	2.083	7.00	1.70	312	65	247
31	28	- -	PG	3	2.094	7.00	2.15	820	580	240
32	83	- -	GC	3	2.138	7.50	2.00	887	700	187
33	36	- -	PG70%,UA30%	3	2.200	6.75	2.25	280	55	225
34	79	- -	PG	3	2.300	8.75	3.55	362	80	282
35	16	- -	PG	3	2.356	7.50	1.80	1200	820	380
36	27	- -	PG	3	2.438	7.75	2.65	860	580	280
37	54	Um Muh	SG	3	2.463	7.00	1.95	1020	900	120
38	25	- -	PG	3	2.556	7.50	2.90	760	618	142
39	53	- -	SG	3	2.569	9.00	2.70	1020	900	120
40	48	Um Wahpynthon	SG	3	2.650	7.25	2.85	1700	1100	600
41	69	- -	PG	3	2.656	7.50	2.05	840	583	257
42	37	- -	PG80%,UA20%	3	2.825	9.50	3.00	300	55	245
43	115	- -	GC	3	2.831	7.50	2.50	720	84	636
44	75	- -	PG	3	3.525	8.00	2.70	700	260	440
45	96	- -	PG	3	3.600	9.00	3.25	447	64	383
46	101	- -	GC	3	3.863	11.00	3.05	1056	840	216
47	20	- -	SG	3	3.880	10.00	2.75	1160	760	400
48	77	- -	PG	3	3.958	11.25	4.35	417	100	317
49	12	- -	SG40%,PG60%	3	3.962	11.75	2.70	1075	860	215
50	95	- -	PG	3	4.417	14.00	3.05	447	64	383
51	93	Uempri	PG75%,GC25%	3	4.456	10.50	3.00	460	129	331
52	62	Um Latar	SG	3	4.613	11.75	3.85	1212	820	392
53	109	- -	PG	3	5.131	13.00	5.80	720	420	300
54	17	- -	PG	3	5.163	11.50	3.40	1200	780	420
55	68	- -	PG65%,SG35%	3	5.256	13.75	4.55	980	583	397
56	24	- -	PG50%,SG50%	3	5.375	14.50	6.00	893	620	273
57	60	- -	SG	3	5.381	11.50	3.55	1235	820	415
58	18	Phud Umshing	PG50%,SG50%	3	5.419	10.25	3.90	1180	760	420
59	38	- -	PG80%,UA20%	3	6.100	12.50	4.30	300	60	240
60	43	- -	PG50%,UA50%	3	6.325	14.75	5.50	548	55	493

Contd. Table-16

1	2	3	4	5	6	7	8	9	10	11
61	2	Um Shaw Shaw	SG	3	6.344	14.00	5.00	1842	1234	608
62	49	Um Wahjit	SG	3	6.581	14.00	4.90	1826	1080	746
63	105	- -	PG90%,GC10%	3	7.025	17.00	6.10	884	700	184
64	94	Hema	PG75%,GC25%	3	7.144	12.00	4.90	460	67	393
65	70	- -	PG	3	7.838	18.75	7.45	940	563	377
66	3	Um Ban	SG90%,PG10%	3	7.900	16.00	5.40	1964	1195	769
67	15	- -	SG40%,PG60%	4	2.406	8.00	2.20	1040	840	200
68	33	- -	SG	4	2.763	7.00	3.15	580	120	460
69	118	- -	PG75%,GC25%	4	3.094	7.25	2.35	400	80	320
70	86	- -	PG	4	3.719	8.00	2.15	900	680	220
71	7	- -	SG	4	4.019	10.25	3.65	1360	900	460
72	56	- -	SG	4	4.319	9.00	2.45	1202	840	362
73	72	- -	PG	4	4.544	13.25	4.35	820	540	280
74	119	- -	PG85%,UA15%	4	4.658	14.00	5.05	411	60	351
75	4	- -	SG	4	5.213	11.50	3.50	1780	1060	720
76	63	- -	SG	4	5.281	11.50	4.00	1180	800	380
77	107	- -	PG	4	5.342	13.50	3.50	945	640	305
78	42	Banpara	PG50%,UA50%	4	5.825	10.25	3.75	540	60	480
79	117	- -	PG90%,GC10%	4	5.942	10.50	3.60	340	80	260
80	81	- -	SG90%,GC10%	4	5.950	15.50	4.20	1235	851	384
81	64	Khalu Langri	SG	4	5.963	12.25	3.20	1180	760	420
82	106	- -	PG95%,GC5%	4	6.138	12.00	4.20	945	680	265
83	30	- -	SG	4	6.231	13.00	4.40	840	240	600
84	87	- -	PG	4	6.813	12.00	3.40	921	640	281
85	10	- -	SG	4	6.856	11.75	2.70	1147	877	270
86	58	- -	SG	4	7.006	14.00	4.55	1160	840	320
87	9	- -	SG	4	7.025	14.00	3.60	1147	900	247
88	51	Um Ew	SG	4	7.450	13.50	5.00	1740	1000	740
89	32	Marlak	SG	4	7.794	15.50	4.85	741	126	615
90	120	- -	PG90%,UA10%	4	7.830	13.75	5.20	411	60	351
91	112	Um Da	PG95%,GC5%	4	7.992	14.75	6.25	580	220	360
92	41	Dadra	PG95%,UA5%	4	8.017	17.00	4.00	600	60	540
93	29	- -	SG	4	9.081	16.50	4.60	860	260	600
94	98	Piyomi	PG	4	9.425	13.00	4.75	425	60	365
95	21	Um Sader	PG	4	9.538	16.50	3.90	1080	720	360

Contd. Table-16

1	2	3	4	5	6	7	8	9	10	11
96	50	- -	SG	4	9.600	15.13	6.25	1851	1040	811
97	44	Wah Umphaniet	SG	4	9.988	17.20	5.20	1820	1400	420
98	61	- -	SG	4	10.950	15.00	4.25	1235	820	415
99	1	Um Jani	SG	4	11.775	16.50	4.60	1861	1400	461
100	91	- -	PG	4	13.906	23.50	7.00	775	340	435
101	114	Langso Bhur Bhur	GC	4	14.942	17.00	5.45	680	100	580
102	108	Um Tarap	PG	4	16.469	25.00	8.50	945	560	385
103	80	- -	GC70%,SG30%	4	16.513	19.25	6.00	1120	851	269
104	47	Um Ramgsaw	SG	4	19.217	20.75	7.10	1836	1140	696
105	45	Wah Lyngkut	SG	4	26.044	28.75	8.15	1855	1306	549
106	104	Umhi	PG90%,GC10%	5	14.342	20.00	4.60	940	700	240
107	55	Um Shiprah	SG	5	22.456	30.50	9.95	1350	960	390
108	6	Phud Umshing	SG	5	23.250	24.00	8.20	1640	900	740
109	85	Um Thana	PG45%,GC5%,SG50%	5	23.919	25.25	6.20	1114	680	434
110	90	- -	PG	5	24.292	29.00	6.45	921	480	441
111	84	Um Shiyaw	SG90%,GC10%	5	34.413	34.50	9.70	1212	671	541
112	23	Um Lji	PG	5	36.756	31.75	7.30	1100	620	480
113	67	Um Bi	SG60%,PG40%	5	37.938	39.00	11.10	1180	600	580
114	100	Lemra	PG95%,UA5%	5	38.750	40.00	14.95	775	60	715
115	19	Um Let	SG90%,PG10%	5	43.088	33.00	7.15	1209	760	449
116	34	Um Thalong	SG	5	45.733	45.50	9.20	857	80	777
117	5	Wah Ro Ro	SG	5	46.681	35.00	9.45	1962	981	981
118	35	Amshai	SG	5	51.683	43.50	13.55	731	60	671
119	26	Um Swat	SG65%,PG35%	5	52.113	42.50	12.60	860	620	240
120	111	Um Ta	PG85%,GC15%	6	115.381	80.00	23.50	977	283	694
Interfluve Area (295.344 sqkm.)										
Umiam Basin			**SG 60%, PG 30%, GC 5%, UA 5%**	**7**	**1429.510**	**315.75**	**94.63**	**1964**	**55**	**1909**

Remarks. GC = Gneissic Complex, PG = Granitoid Pluton,
SG = Shillong Group, UA = Undifferentiated Alluvium

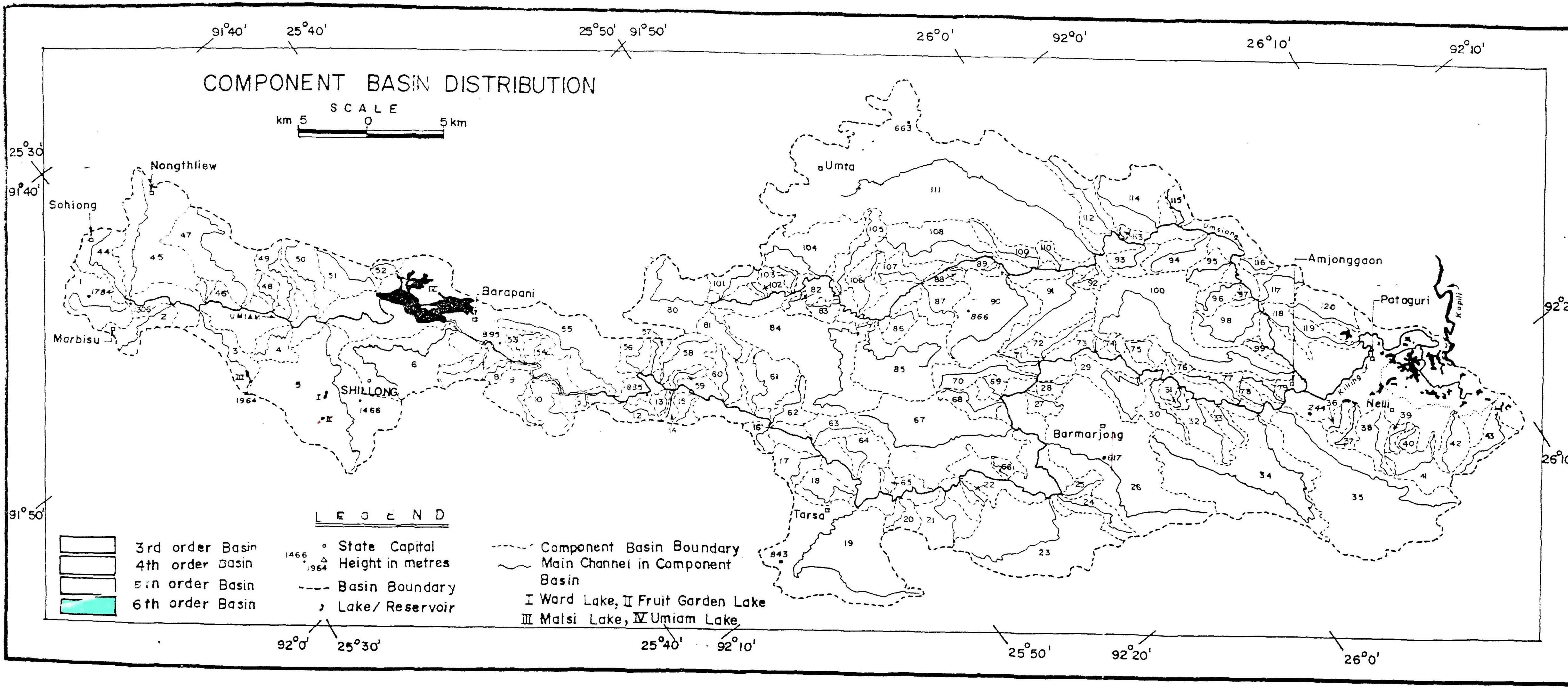
COMPONENT BASIN DISTRIBUTION
SCALE
km 5 0 5 km
LEGEND
3rd order Basin
4th order Basin
5th order Basin
6th order Basin
State Capital
Height in metres
Basin Boundary
Lake/ Reservoir
Component Basin Boundary
Main Channel in Component Basin
I Ward Lake, II Fruit Garden Lake
III Malsi Lake, IV Umiam Lake
Nongthliew
Sohiong
Marbisu
UMIAM
Barapani
SHILLONG
Umta
Tarsa
Barmarjong
Umsiong
Amjonggaon
Patoguri
Kopili
Killing
Nelli
91°40'
25°40'
25°50'
91°50'
26°0'
92°0'
26°10'
92°10'
92°20'
25°30'

Fig.(24)

under active anthropogenic modification covering an area of 110.626sq.km with a perimeter of 49.25km.

The component basins have wide variation in area and perimeter. Order wise minimum and maximum area (Au) and perimeter (Pu) of component basins are given in Table (17 & 18).

The 3rd order basins show area variation upto 17.56 times and perimeter variation upto 8.34 times. The 4th order basins have area variation upto 10.80 times and perimeter upto 4.12 times. The 5th order basins show area variation upto 3.63 times and perimeter upto 2.28 times. The Granitoid terrain has highest numbers of 3rd order basins. At the same time these basins have relatively smaller area and perimeter than their counterparts over the Shillong Group. Such distinction indicates easy erodibility of Shillong Group by the stream networks.

Conspicuously the component basins initially do not show influence of geostructures in their development. However, the basins above 2.50sq.km area depict strong elongation in N-S and E-W directions oblique to formational trends. Such preferred orientations indicate influence of Active Tectonics (Gregory and Schumm 1987) in basin development.

The geology of the basin has significantly controlled the development of different component basins. The basin length (Lb) and basin relief (Z) show wide variations. The order wise minimum and maximum basin length and basin relief are given in Tables (19 & 20).

TABLE-17

BASIN ORDER WISE MINIMUM-MAXIMUM AREA (sq.km) OF COMPONENT BASINS

Order	Minimum Area	Component Basin No.	Bank of Umiam	Maximum Area	Component Basin No.	Bank of Umiam
3	0.450	73	left	7.900	3	right
4	2.406	15	right	26.044	45	left
5	14.342	104	left	52.113	26	right
6	-	-	-	115.381	111	left
3	Mean : 2.97	Median : 2.33	Mode : 1.70	Std. dev.: 2.02	Coeff. Var. 68.16	
4	Mean : 8.23	Median : 6.90	Mode : 5.75	Std. dev.: 4.93	Coeff. Var. 59.93	
5	Mean :35.36	Median :36.00	Mode :37.50	Std. dev.:13.72	Coeff. Var. 38.81	

TABLE-18

BASIN ORDER WISE MINIMUM-MAXIMUM PERIMETER (km) OF COMPONENT BASINS

Order	Minimum Perimeter	Component Basin No.	Bank of Umiam	Maximum Perimeter	Component Basin No.	Bank of Umiam
3	2.25	73	left	18.75	70	left
4	7.00	33	right	28.75	45	left
5	20.00	104	left	45.50	34	right
6	-	-	-	80.00	111	left
3	Mean : 8.48	Median : 7.39	Mode : 6.76	Std. dev.: 3.80	Coeff. Var. 44.82	
4	Mean :14.55	Median :13.82	Mode :13.18	Std. dev.: 4.77	Coeff. Var. 32.75	
5	Mean :35.00	Median :35.00	Mode :35.00	Std. dev.: 7.56	Coeff. Var. 21.60	

TABLE-19

BASIN ORDER WISE MINIMUM-MAXIMUM LENGTH (km) OF COMPONENT BASINS

Order	Minimum Basin length	Component Basin No.	Bank of Umiam	Maximum Basin length	Component Basin No.	Bank of Umiam
3	0.95	73	left	7.45	70	left
4	2.15	86	left	8.50	108	left
5	4.60	104	left	14.95	100	left
6	-	-	-	23.50	111	left

3	Mean : 2.88	Median : 2.57	Mode : 2.25	Std. dev.: 1.44	Coeff. Var. 50.14
4	Mean : 4.63	Median : 4.38	Mode : 4.22	Std. dev.: 1.57	Coeff. Var. 33.96
5	Mean : 9.64	Median : 9.60	Mode : 9.00	Std. dev.: 2.64	Coeff. Var. 27.40

TABLE-20

BASIN ORDER WISE MINIMUM-MAXIMUM BASIN RELIEF (m) IN COMPONENT BASINS

Order	Minimum Basin Relief	Component Basin No.	Bank of Umiam	Maximum Basin Relief	Component Basin No.	Bank of Umiam
3	100	11	right	769	3	right
4	200	15	right	811	50	left
5	240	104	left	981	5	right
6	-	-	-	694	111	left

The 3rd order basins have basin length variation upto 7.80 times and basin relief variation upto 7.69 times. The 4th order basins have basin length variation upto 3.95 times and basin relief upto 4.10 times. The 5th order basins have basin length variation upto 3.25 times and basin relief upto 4.10 times.

It is evident from above analysis that the largest variation in basic basin characteristics is shown by low order basins i.e. the 3rd order basins. The higher order basins depict consistent basic basin characters suggestive of their more stabilised nature in the terrain. At the same time the left bank component basins have largest variation in basic characters in contrast to the right bank component basins.

GRADIENT OF UMIAM :

The total length of Umiam from its headwaters in the southwest to its (mouth) confluence with Kopili is 151.01km and suffers a fall of 1806m from source to mouth. The average gradient of Umiam along its course from headwaters - Um Jani (component Basin No.1) to Mouth is given in Table (21). The longitudinal profiles of Umiam based on 1910-21 database and 1964-68 database is shown in Fig.(25a & 25b).

The gradient of Umiam is not uniform and is broken into broad segments with varying gradients. On the basis of variation in gradient, the Umiam course is divided into 7 segments (Table-21), each segment has characteristic expression. The 1st segment

TABLE-21

GRADIENT ALONG UMIAM COURSE

Sl. No	Stream Segment	Length (km)	Cumulative length (km)	Elevation (m) Max.	Elevation (m) Min.	Fall m	Average Gradient (^{O})	Remarks
1.	Headwaters (component Basin No.1) to Wah Lyngkut confluence.	8.26	8.26	1861	1306	555	3^{O} 50'38"	Gorge Section
2.	Wah Lyngkut confluence to Wah Ro Ro confluence.	16.00	24.26	1306	981	325	1^{O} 09'49"	Gorge Section
3.	Wah Ro Ro confluence to Lake intake.	7.50	31.76	981	960	21	0^{O} 09'38"	Gentle narrow valley
4.	Lake intake to Dam.	5.25	37.01	960	960	0	0^{O} 00'00"	Umiam Lake
5.	Dam to confluence with component. basin no. 69.	69.50	106.51	960	583	377	0^{O} 18'39"	Gentle broad valley
6.	Component basin no. 69 confluence to Amshai Nadi confluence.	24.50	131.01	583	60	523	1^{O} 13'22"	Narrow valley
7.	Amshai Nadi confluence to mouth.	20.00	151.01	60	55	5	0^{O} 00'52"	Alluvial Plain
	TOTAL	151.01				1806		

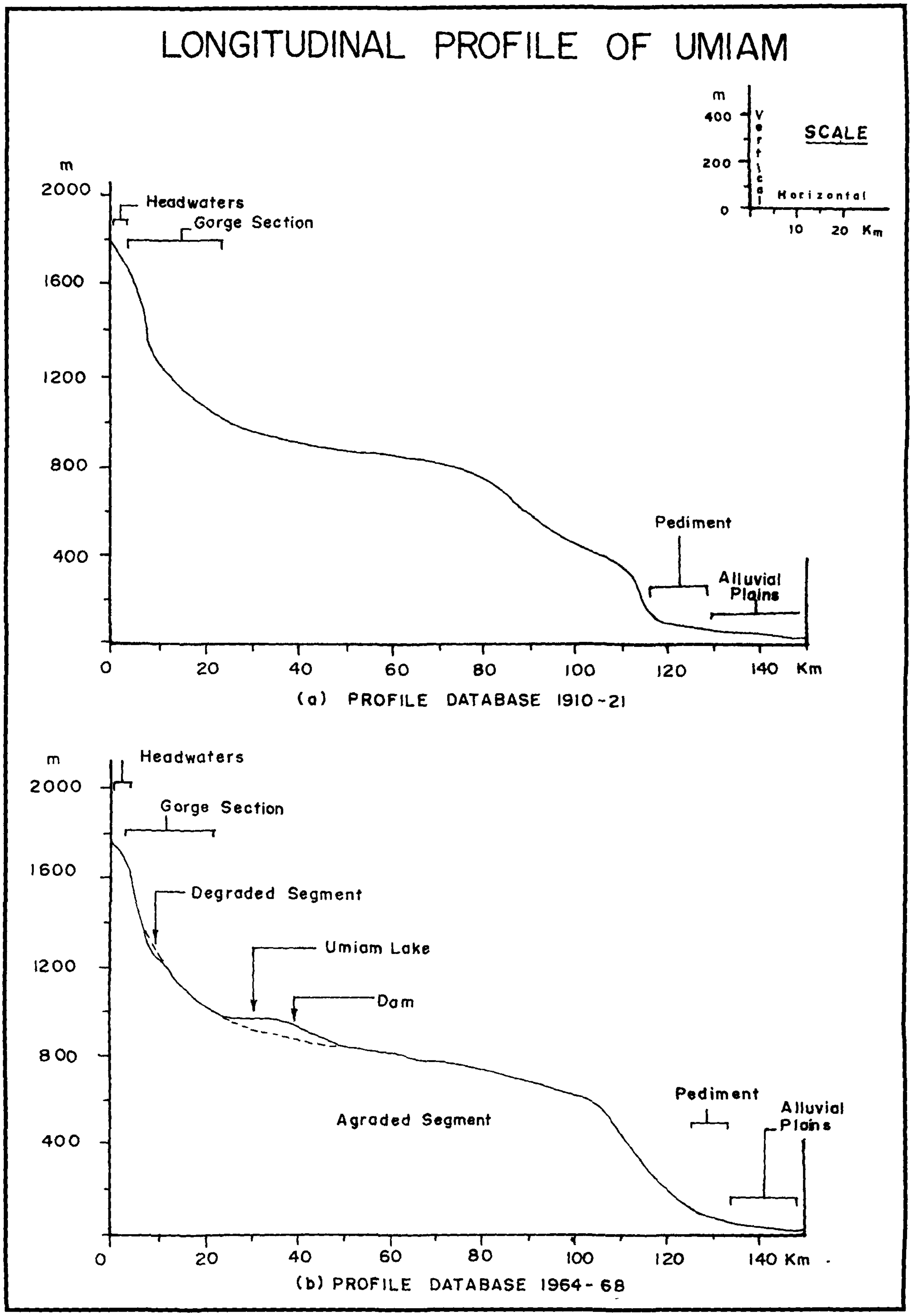
LONGITUDINAL PROFILE OF UMIAM
m
400
200
0
Vertical
Horizontal
10
20 Km
SCALE
m
2000
1600
1200
800
400
Headwaters
Gorge Section
Pediment
Alluvial Plains
0
20
40
60
80
100
120
140 Km
(a) PROFILE DATABASE 1910-21
m
2000
1600
1200
800
400
Headwaters
Gorge Section
Degraded Segment
Umiam Lake
Dam
Agraded Segment
Pediment
Alluvial Plains
0
20
40
60
80
100
120
140 Km
(b) PROFILE DATABASE 1964-68

Fig.(25)

upto Wah Lyngkut confluence forms a magnificent gorge section with steepest gradient (>3^{o}). It here undercuts (Fig.25a & 25b) the profile (degraded segment) due to high hydraulic energy. The next segment upto Wah Ro Ro confluence is also a gorge section but with relatively lower gradient (>01^{o}) indicating decrease in hydraulic energy. The gradient further decreases (>09') in the next segment upto Umiam lake intake and the river course changes from gorge to a gentle narrow valley. It opens up into a broad depression from here onwards forming the 4th segment over which the river is dammed to form the Umiam lake. Downstream of the lake, the gradient steepens (>18') and defines the 5th segment which depicts gentle broad valley course upto the confluence of component Basin No. 69. In the 6th segment, the gradient suddenly steepens (>01^{o}) and the river course forms narrow valley upto the Amshai Nadi confluence and it marks a major "inflexion" point on the profile. The last segment is downstream of Amshai Nadi confluence upto the mouth of Umiam (Plate-11) and forms the pediment - alluvial plain configuration with flattened gradient (<01'). The Umiam course has maximum gradient variations over the Shillong Group.

The longitudinal profile of the Umiam (Fig.25a & 25b) show "stepped" or "cascading" nature in conformity to the general terraced and stepped physiography of the terrain (c.f. Fig.13 & 14). The general concavity from source to mouth of Umiam is missing indicating that the river is not graded althrough. The "steps" in the longitudinal profile of Umiam are the signatures

(Plate–11) : Confluence of Umiam with Kopili River. Note the heavy silt lode (dark colour) in Umiam River and, the Holocene stabilised terrace plains supporting settlements.

of repeated uplift along weak zones producing convexities in the profile. It indicates continuing adjustment of river to "Active Tectonics" (Adams 1980; Russ 1982; Burnett and Schumm 1983; Gregory and Schumm 1987). A comparison of Fig. (25a) and Fig.(25b) indicate that the lake segment of Umiam has become aggraded due to damming of the river in 1965 (data base 1964-68). It is because the Umiam lake acts as a local base level in this part of the basin with almost zero down cutting at present. These hydraulic changes are the manifestation of man's manipulation in stream regimen (Langbein and Leopold 1964; Stall and Yang 1970; Ruhe 1971; Gregory et al. 1985). Such localised hudraulic changes in the Umiam profile are not related to "Active Tectonics".

DRAINAGE PATTERN

It refers to the spatial relationship among streams or rivers. The pattern which stream forms are determined by inequalities of surface slope, rock resistance, geologic structure and history of the area (Zernitz 1932; Feldman et al. 1968).

The drainage network in the Umiam basin show following five types of drainage pattern (Fig.26).

(a) Annular
(b) Parallel
(c) Subparallel
(d) Dendritic
(e) Subdendritic

(a) **ANNULAR PATTERN** : It is a ring like pattern indicating presence of maturely dissected Plutons. This pattern

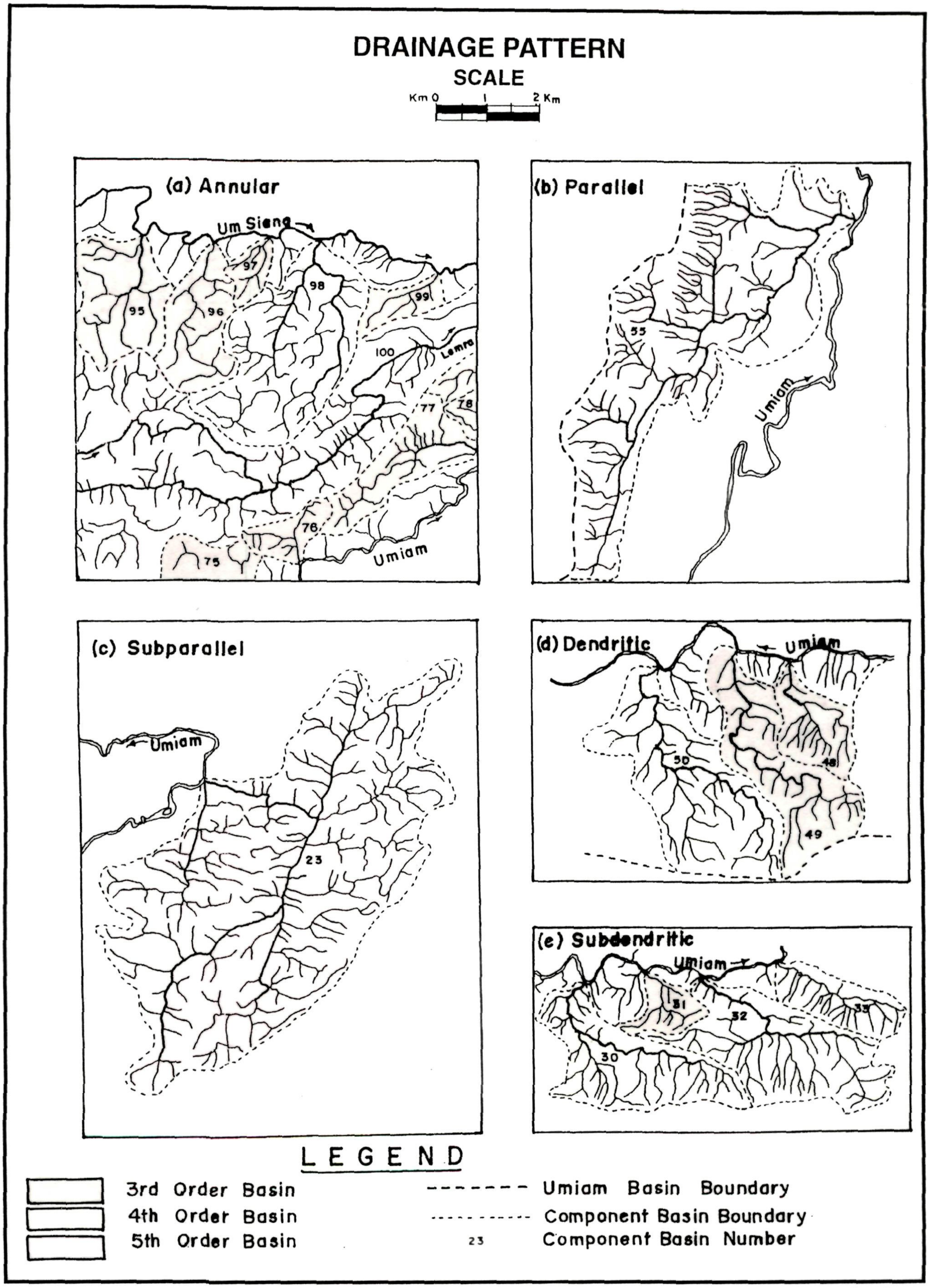
DRAINAGE PATTERN
SCALE
Km 0
1
2 Km
(a) Annular
Um Sieng
97
98
95
96
99
100
Lemra
77
78
76
75
Umiam
(b) Parallel
55
Umiam
(c) Subparallel
Umiam
23
(d) Dendritic
Umiam
50
48
49
(e) Subdendritic
Umiam
31
32
33
30
LEGEND
3rd Order Basin
4th Order Basin
5th Order Basin
Umiam Basin Boundary
Component Basin Boundary
23 Component Basin Number

Fig.(26)

is typically represented by the component Basin Nos. 75, 76, 77, 78 and 95, 96, 97, 98, 99, 100 (Fig.26a) over the Nongpoh Pluton in the northeastern part of the basin. The component basin nos. 96, 97, 98 are over one of the acid magmatic centres in the Nongpoh Pluton. According to Zernitz (op.cit) the annular pattern develops most perfectly where the erosion of the dome exposes the "rimming" country rocks. This holds true in the case of Nongpoh Pluton. The northward cascading topography has unloaded the Shillong Group envelope from over the Pluton. As a result the stream segments have adapted the structural trends in the Plutons. The curved courses of stream segments represent the ghost structures of the migmatised Gneissic Complex- the parent rock of the Plutons.

The "rings" are associated with 1st and 2nd order radial stream segments developed along joints and fracture systems. The curvature of stream segments indicate their adjustment to the warps suffered by the gneissosity by the rising (diapiric) Plutons during acid magmatism (Proterozoic).

(b) **PARALLEL PATTERN** : The parallel pattern consists of parallel arrangement of stream segments. It reflects strong structural control by joints and fractures and is typically found in glaciated terrains. This pattern is typically depicted by component basin no. 55 over the Shillong Group (Fig.26b) in the upper reaches of the basin. The component basin no. 55 lies northwest of the narrow linear glacio-fluviatile valley (c.f.

Fig. 27). The parallel pattern of stream channels indicate indirect evidence of glacially fluted slopes in the component basin adjacent to the glacio-fluviatile valley.

(c) **SUB PARALLEL PATTERN** : It is modified version of parallel pattern. It lacks the general regular parallelism of the streams and often show orthogonal bending in direction. The regional schistosity/gneissosity, complex folding and faulting usually control the development of this pattern (Zernitz 1932).

The component basin no 23 over the Nongpoh Pluton depicts this pattern (Fig.26c) characteristically in the central part of the basin. In this part of the basin the granitoid does not show warping of structural trends in the parent rock i.e. the gneisses. It suggests that this part of the Gneissic Complex remained passive during migmatisation and anatexis related acid magmatism. So the regional slope, regional structural trends and joints-fractures in the Granitoids have controlled the development of drainage lines. The master stream in the basin is deeply entrenched in the bedrock aligned along the lineaments suggesting reactivation of lineaments.

(d) **DENDRITIC PATTERN** : This pattern is characterised by irregular branching, like a tree, of stream segments. It is mainly developed where the bedrocks offer uniform resistance to erosion in horizontal direction. The component basin nos. 48, 49 and 50 depicts the dendritic pattern (Fig.26d) developed over *the horizontaly to subhorizontaly disposed Shillong Group of* rocks in the southwestern part of the basin. The master streams in these component basins have small entrenched straight segments oblique to the formational trends indicative of the influence of lineaments (joints-fractures) in the drainage evolution. However, the general dendritic pattern still prevails. But the master streams or the higher order streams loose the dendritic pattern as the structural control takes over the development of the drainage lines.

(e) **SUBDENDRITIC PATTERN** : It is a modification of typical dendritic drainage pattern showing rhythmically arranged low order segments. The slope of the terrain significantly control the development of this pattern. The component basin nos. 30, 31, 32 & 33 developed over the Shillong Group of rocks in the northeastern part of the basin, depict this pattern (Fig.26e). The influence of structure - lineaments is too pronounced here as seen by relatively longer straight segments of master streams than in the dendritic pattern of component basin nos. 48, 49 & 50. The cascading longitudinal profiles of the basin (Fig.13) as well as that of the Umiam river (Figs.25a & 25b) suggest a continuous northward "unloading" of physiography due to which the basement structures have become prominent in influencing the development of drainage lines in the northeastern part than in the southwestern part of the basin (Fig.7).

DRAINAGE ANALYSIS

Drainage analysis by quantitative methods is useful for characterising a terrain. Morphometry is a quantitative technique employed world over for drainage analysis and has evolved into a distinct discipline known as Quantitative Geomorphology (Horton 1932; Horton 1945; Strahler 1950a; 1950b; 1952a; 1952b; Schumm 1956; Strahler 1957; Morisawa 1958; Strahler 1958; Chorley 1959; Scheidegger 1961; Chow 1964; Leopold et al. 1964; Strahler 1964; Chorley 1966; King 1966; Zakrzewska 1967; Singh 1969; Doornkamp and King 1971; Pal 1972; Pal 1973; Singh 1974; Dixit 1976; Soni 1984; Hart 1986; Singh 1991; Mithra and Rao 1993). Drainage analysis is a way to understand evolution of landforms. The landforms and geomorphological processes are increasingly analysed by numerical methods so that the deductions and inferences drawn have the universal interpretation compatibility and reproducibility. As such over the years the qualitative interpretation has changed to vigorous quantitative interpretation and various morphometric attributes have been numerically defined.

All 120 component basins of the Umiam river system have been analysed by evaluation of the following 29 morphometric parameters. Evaluation of these parameters have helped delineating areas with geomorphic risks and geohazards.

MORPHOMETRIC PARAMETERS EVALUATED

Sl.No.	Parameter/Element	Symbol	Units	Dimension
(A) DRAINAGE NETWORK				
1.	Stream Order	u	Enumerative	O

Contd.

Sl.No.	Parameter/Element	Symbol	Units	Dimension
2.	Order of the Basin	U	Enumerative	O
3.	Number of Stream of Order u	Nu	Enumerative	O
4.	Total Number of Streams within Basin of Order u	(EN)u	Enumerative	O
5.	Bifurcation Ratio	Rb	Enumerative	O
6.	Average Bifurcation Ratio	$\overline{Rb}$	Enumerative	O
7.	Weighted Mean Bifurcation ratio	$\overline{Rbw}$	Enumerative	O
8.	Total Stream Length of Order u	Lu	km	L
9.	Total Stream Length within Basin of Order u	(EL)u	km	L
10.	Mean Stream Length of Order u	$\overline{Lu}$	Enumerative	O
11.	Stream Length Ratio	$\overline{Rl}$	Enumerative	O
(B)	<u>BASIN GEOMETRY</u>			
12.	Basin Area	Au	km^2	L^2
13.	Basin Perimeter	Pu	km	L
14.	Basin Length	Lb	km	L
15.	Basin Circulatory Ratio	Rc	Enumerative	O
16.	Basin Elongation Ratio	Re	Enumerative	O
17.	Form Factor	Ff	Enumerative	O
18.	Rotundity Factor	Rf	Enumerative	O
19.	Compaction Coefficient	Cc	Enumerative	O
(C)	<u>ATTRIBUTES OF INTENSITY OF DISSECTION</u>			
20.	Drainage Frequency	Fu	nos./km^2	L^{-2}
21.	Drainage Density	Du	km/km^2	L^{-1}
22.	Texture	Tu		
23.	Constant of Channel Maintenance	Kc	km^2/km	L
(D)	<u>ATTRIBUTES INVOLVING HEIGHTS</u>			
24.	Height of Highest Point on Watershed	Hh	m	L
25.	Height of Basin Mouth	Hl	m	L
26	Total Basin Relief	Z	m	L
27.	Relief Ratio	Rz	Enumerative	O
28.	Relative Relief of Basin	Rr	Enumerative	O
29.	Ruggedness Number	Rn	Enumerative	O

STREAM SEGMENT ORDERING (u)

The relative magnitude of a segment of a stream channel is a hierarchy determined by arrangement of tributaries with respect to the main trunk stream. The system of ordering channel segments proposed by Horton (1945) and modified by Strahler (1952b) is followed here. In the present study, toposheets on 1:50,000 scale have been used and all the segments of order "u" are counted to yield the total number "Nu" of the stream order "u". The order wise stream segments in different component basins is given in Table (22). Order wise minimum and maximum total stream segments (EN)u is given in Table (23).

Conspicuously the minimum and maximum total stream segments do not show correspondence to area or perimeter of the 3rd order basins. However, the total stream segments of 4th & 5th order basins do have correspondence with the basin size and perimeter. In general the 3rd order basins have disproportionate size with respect to (EN)u indicating enlargement of basin by rapid downcutting as well as headward erosion.

BIFURCATION RATIO (Rb)

It is the ratio between the total number of streams of one order to that of next higher order in a drainage basin and is given by Rb= Nu/Nu+1.

It is an index of degree of integration as to how far the lower order segments join the next higher order channel segment in a basin. According to Strahler (1964) the Rb ratios

TABLE -22

COMPONENT BASIN CHARACTERISTICS

Sl. No.	Comp. Basin Number	U	Nu: N1	N2	N3	N4	N5	N6	N7	ΣNu	Rb: Rb1	Rb2	Rb3	Rb4	Rb5	Rb6	$\bar{Rb}$	$\bar{Rbw}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	73	3	5	2	1	0	0	0		8	2.50	2.00	0.00	0.00	0.00	0.00	2.25	2.35
2	113	3	5	2	1	0	0	0		8	2.50	2.00	0.00	0.00	0.00	0.00	2.75	2.35
3	88	3	6	2	1	0	0	0		9	3.00	2.00	0.00	0.00	0.00	0.00	2.50	2.73
4	11	3	4	2	1	0	0	0		7	2.00	2.00	0.00	0.00	0.00	0.00	2.00	2.00
5	89	3	5	2	1	0	0	0		8	2.50	2.00	0.00	0.00	0.00	0.00	2.25	2.35
6	102	3	5	2	1	0	0	0		8	2.50	2.00	0.00	0.00	0.00	0.00	2.25	2.35
7	97	3	6	2	1	0	0	0		9	3.00	2.00	0.00	0.00	0.00	0.00	2.50	2.73
8	46	3	6	2	1	0	0	0		9	3.00	2.00	0.00	0.00	0.00	0.00	2.50	2.73
9	14	3	6	2	1	0	0	0		9	3.00	2.00	0.00	0.00	0.00	0.00	2.50	2.73
10	99	3	5	2	1	0	0	0		8	2.50	2.00	0.00	0.00	0.00	0.00	2.25	2.35
11	31	3	9	4	1	0	0	0		14	2.25	4.00	0.00	0.00	0.00	0.00	3.13	2.74
12	76	3	9	3	1	0	0	0		13	3.00	3.00	0.00	0.00	0.00	0.00	3.00	3.00
13	103	3	7	2	1	0	0	0		10	3.50	2.00	0.00	0.00	0.00	0.00	2.75	3.13
14	66	3	8	3	1	0	0	0		12	2.67	3.00	0.00	0.00	0.00	0.00	2.84	2.76
15	65	3	10	3	1	0	0	0		14	3.33	3.00	0.00	0.00	0.00	0.00	3.17	3.25
16	13	3	7	2	1	0	0	0		10	3.50	2.00	0.00	0.00	0.00	0.00	2.75	3.13
17	8	3	8	2	1	0	0	0		11	4.00	2.00	0.00	0.00	0.00	0.00	3.00	3.54
18	52	3	7	2	1	0	0	0		10	3.50	2.00	0.00	0.00	0.00	0.00	2.75	3.13
19	39	3	6	2	1	0	0	0		9	3.00	2.00	0.00	0.00	0.00	0.00	2.50	2.73
20	82	3	11	2	1	0	0	0		14	5.50	2.00	0.00	0.00	0.00	0.00	3.75	4.84
21	59	3	8	2	1	0	0	0		11	4.00	2.00	0.00	0.00	0.00	0.00	3.00	3.54
22	22	3	6	2	1	0	0	0		9	3.00	2.00	0.00	0.00	0.00	0.00	2.50	2.73
23	57	3	10	2	1	0	0	0		13	5.00	2.00	0.00	0.00	0.00	0.00	3.50	4.40
24	74	3	7	2	1	0	0	0		10	3.50	2.00	0.00	0.00	0.00	0.00	2.75	3.13
25	92	3	8	3	1	0	0	0		12	2.67	3.00	0.00	0.00	0.00	0.00	2.84	2.76

Contd. Table-22

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
26	78	3	7	2	1	0	0	0		10	3.60	2.00	0.00	0.00	0.00	0.00	2.75	3.13
27	40	3	10	3	1	0	0	0		14	3.33	3.00	0.00	0.00	0.00	0.00	3.17	3.25
28	110	3	14	4	1	0	0	0		19	3.50	4.00	0.00	0.00	0.00	0.00	3.75	3.61
29	71	3	13	3	1	0	0	0		17	4.33	3.00	0.00	0.00	0.00	0.00	3.67	4.06
30	116	3	8	3	1	0	0	0		12	2.67	3.00	0.00	0.00	0.00	0.00	2.84	2.76
31	28	3	5	2	1	0	0	0		8	2.50	2.00	0.00	0.00	0.00	0.00	2.25	2.35
32	83	3	13	2	1	0	0	0		16	6.50	2.00	0.00	0.00	0.00	0.00	4.25	5.75
33	36	3	8	3	1	0	0	0		12	2.67	3.00	0.00	0.00	0.00	0.00	2.84	2.76
34	79	3	11	2	1	0	0	0		14	5.50	2.00	0.00	0.00	0.00	0.00	3.75	4.84
35	16	3	11	3	1	0	0	0		15	3.67	3.00	0.00	0.00	0.00	0.00	3.34	3.52
36	27	3	9	4	1	0	0	0		14	2.25	4.00	0.00	0.00	0.00	0.00	3.13	2.74
37	54	3	10	3	1	0	0	0		14	3.33	3.00	0.00	0.00	0.00	0.00	3.17	3.25
38	25	3	14	2	1	0	0	0		17	7.00	2.00	0.00	0.00	0.00	0.00	4.50	6.21
39	53	3	9	3	1	0	0	0		13	3.00	3.00	0.00	0.00	0.00	0.00	3.00	3.00
40	48	3	14	3	1	0	0	0		18	4.67	3.00	0.00	0.00	0.00	0.00	3.84	4.35
41	69	3	9	3	1	0	0	0		13	3.00	3.00	0.00	0.00	0.00	0.00	3.00	3.00
42	37	3	8	3	1	0	0	0		12	2.67	3.00	0.00	0.00	0.00	0.00	2.84	2.76
43	115	3	7	2	1	0	0	0		10	3.50	2.00	0.00	0.00	0.00	0.00	2.75	3.13
44	75	3	12	3	1	0	0	0		16	4.00	3.00	0.00	0.00	0.00	0.00	3.50	3.79
45	96	3	13	2	1	0	0	0		16	6.50	2.00	0.00	0.00	0.00	0.00	4.25	5.75
46	101	3	14	2	1	0	0	0		17	7.00	2.00	0.00	0.00	0.00	0.00	4.50	6.21
47	20	3	21	5	1	0	0	0		27	4.20	5.00	0.00	0.00	0.00	0.00	4.60	4.35
48	77	3	19	2	1	0	0	0		22	9.50	2.00	0.00	0.00	0.00	0.00	5.75	8.56
49	12	3	14	3	1	0	0	0		18	4.67	3.00	0.00	0.00	0.00	0.00	3.84	4.35
50	95	3	11	4	1	0	0	0		16	2.75	4.00	0.00	0.00	0.00	0.00	3.38	3.06
51	93	3	11	2	1	0	0	0		14	5.50	2.00	0.00	0.00	0.00	0.00	3.75	4.84
52	62	3	21	6	1	0	0	0		28	3.50	6.00	0.00	0.00	0.00	0.00	4.75	4.02
53	109	3	18	3	1	0	0	0		22	6.00	3.00	0.00	0.00	0.00	0.00	4.50	5.52
54	17	3	27	4	1	0	0	0		32	6.75	4.00	0.00	0.00	0.00	0.00	5.38	6.37
55	68	3	15	5	1	0	0	0		21	3.00	5.00	0.00	0.00	0.00	0.00	4.00	3.46
56	24	3	35	4	1	0	0	0		40	8.75	4.00	0.00	0.00	0.00	0.00	6.38	8.21
57	60	3	25	4	1	0	0	0		30	6.25	4.00	0.00	0.00	0.00	0.00	5.13	5.92
58	18	3	17	4	1	0	0	0		22	4.25	4.00	0.00	0.00	0.00	0.00	4.13	4.20
59	38	3	20	6	1	0	0	0		27	3.33	6.00	0.00	0.00	0.00	0.00	4.67	3.90
60	43	3	15	2	1	0	0	0		18	7.50	2.00	0.00	0.00	0.00	0.00	4.75	6.68

Contd. Table-22

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
61	2	3	15	2	1	0	0	0		18	7.50	2.00	0.00	0.00	0.00	0.00	4.75	6.68
62	49	3	26	3	1	0	0	0		30	8.67	3.00	0.00	0.00	0.00	0.00	5.84	7.98
63	105	3	32	7	1	0	0	0		40	4.57	7.00	0.00	0.00	0.00	0.00	5.79	4.98
64	94	3	23	4	1	0	0	0		28	5.75	4.00	0.00	0.00	0.00	0.00	4.89	5.48
65	70	3	33	6	1	0	0	0		40	5.50	6.00	0.00	0.00	0.00	0.00	5.75	5.58
66	3	3	29	5	1	0	0	0		35	5.80	5.00	0.00	0.00	0.00	0.00	5.40	5.68
67	15	4	16	4	2	1	0	0		23	4.00	2.00	2.00	0.00	0.00	0.00	2.67	3.38
68	33	4	20	6	2	1	0	0		29	3.33	3.00	2.00	0.00	0.00	0.00	2.78	3.15
69	118	4	15	5	2	1	0	0		23	3.00	2.50	2.00	0.00	0.00	0.00	2.50	2.78
70	86	4	22	5	2	1	0	0		30	4.40	2.50	2.00	0.00	0.00	0.00	2.97	3.85
71	7	4	19	5	2	1	0	0		27	3.80	2.50	2.00	0.00	0.00	0.00	2.77	3.37
72	56	4	27	7	2	1	0	0		37	3.86	3.50	2.00	0.00	0.00	0.00	3.12	3.67
73	72	4	18	5	2	1	0	0		26	3.60	2.50	2.00	0.00	0.00	0.00	3.05	3.22
74	119	4	15	5	2	1	0	0		23	3.00	2.50	2.00	0.00	0.00	0.00	2.50	2.78
75	4	4	30	7	2	1	0	0		40	4.29	3.50	2.00	0.00	0.00	0.00	3.26	4.01
76	63	4	33	8	2	1	0	0		44	4.13	4.00	2.00	0.00	0.00	0.00	3.38	3.99
77	107	4	27	9	3	1	0	0		40	3.00	3.00	3.00	0.00	0.00	0.00	3.00	3.00
78	42	4	15	6	2	1	0	0		24	2.50	3.00	2.00	0.00	0.00	0.00	2.50	2.58
79	117	4	27	6	2	1	0	0		36	4.50	3.00	2.00	0.00	0.00	0.00	3.17	4.44
80	81	4	33	7	2	1	0	0		43	4.71	3.50	2.00	0.00	0.00	0.00	3.40	4.34
81	64	4	31	7	3	1	0	0		42	4.43	2.33	3.00	0.00	0.00	0.00	3.25	3.92
82	106	4	28	8	2	1	0	0		39	3.50	4.00	2.00	0.00	0.00	0.00	3.17	3.51
83	30	4	36	12	2	1	0	0		51	3.00	6.00	2.00	0.00	0.00	0.00	3.67	3.60
84	87	4	35	8	2	1	0	0		46	4.38	4.00	2.00	0.00	0.00	0.00	3.46	4.19
85	10	4	31	7	2	1	0	0		41	4.43	3.50	2.00	0.00	0.00	0.00	3.31	4.12
86	58	4	44	9	2	1	0	0		56	4.89	4.50	2.00	0.00	0.00	0.00	3.80	4.70
87	9	4	27	6	2	1	0	0		36	4.50	3.00	2.00	0.00	0.00	0.00	3.17	4.06
88	51	4	29	6	2	1	0	0		38	4.83	3.00	2.00	0.00	0.00	0.00	3.28	4.33
89	32	4	41	9	2	1	0	0		53	4.56	4.50	2.00	0.00	0.00	0.00	3.69	4.43
90	120	4	23	5	2	1	0	0		31	4.60	2.50	2.00	0.00	0.00	0.00	3.03	4.01
91	112	4	39	8	2	1	0	0		50	4.88	4.00	2.00	0.00	0.00	0.00	3.63	4.59
92	41	4	29	10	4	1	0	0		44	2.90	2.50	4.00	0.00	0.00	0.00	3.30	2.90
93	29	4	56	10	3	1	0	0		70	5.60	3.33	3.00	0.00	0.00	0.00	4.47	5.12
94	98	4	45	10	2	1	0	0		58	4.50	5.00	2.00	0.00	0.00	0.00	3.83	4.48
95	21	4	39	9	3	1	0	0		52	4.33	3.00	3.00	0.00	0.00	0.00	3.44	4.00

Contd. Table-22

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
96	50	4	35	9	2	1	0	0		47	3.89	4.50	2.00	0.00	0.00	0.00	3.46	3.91
97	44	4	47	11	3	1	0	0		62	4.27	3.67	3.00	0.00	0.00	0.00	3.65	4.09
98	61	4	47	10	2	1	0	0		60	4.70	5.00	2.00	0.00	0.00	0.00	3.90	4.64
99	1	4	56	16	2	1	0	0		75	3.50	8.00	2.00	0.00	0.00	0.00	4.50	4.32
100	91	4	62	11	4	1	0	0		78	5.64	2.75	4.00	0.00	0.00	0.00	4.13	5.09
101	114	4	72	15	3	1	0	0		91	4.80	5.00	3.00	0.00	0.00	0.00	4.27	4.77
102	108	4	77	18	3	1	0	0		99	4.28	6.00	3.00	0.00	0.00	0.00	4.43	4.54
103	80	4	60	17	3	1	0	0		81	3.53	5.67	3.00	0.00	0.00	0.00	4.07	3.93
104	47	4	88	27	7	1	0	0		123	3.26	3.86	7.00	0.00	0.00	0.00	4.71	3.58
105	45	4	105	28	5	1	0	0		139	3.75	5.60	5.00	0.00	0.00	0.00	4.78	4.15
106	104	5	64	17	5	2	1	0		89	3.77	3.40	2.50	2.00	0.00	0.00	2.92	3.57
107	55	5	101	27	8	2	1	0		139	3.74	3.38	4.00	2.00	0.00	0.00	3.28	3.65
108	6	5	87	19	4	2	1	0		113	4.58	4.75	2.00	2.00	0.00	0.00	3.33	4.44
109	85	5	105	22	4	2	1	0		134	4.77	5.50	2.00	2.00	0.00	0.00	3.57	4.73
110	90	5	108	25	7	3	1	0		144	4.32	3.57	2.33	3.00	0.00	0.00	3.31	4.05
111	84	5	158	35	9	2	1	0		205	4.51	3.39	4.50	2.00	0.00	0.00	3.73	4.26
112	23	5	165	39	10	2	1	0		217	4.23	3.90	5.00	2.00	0.00	0.00	3.78	4.18
113	67	5	167	38	9	2	1	0		217	4.40	4.22	4.50	2.00	0.00	0.00	3.78	4.35
114	100	5	162	35	6	2	1	0		206	4.63	5.83	3.00	2.00	0.00	0.00	3.87	4.74
115	19	5	178	46	11	3	1	0		239	3.87	4.18	3.67	3.00	0.00	0.00	3.68	3.91
116	34	5	195	45	8	3	1	0		252	4.33	5.63	2.67	3.00	0.00	0.00	3.90	4.48
117	5	5	162	39	9	3	1	0		214	4.15	4.33	3.00	3.00	0.00	0.00	3.62	4.11
118	35	5	168	43	11	3	1	0		226	3.91	3.91	3.67	3.00	0.00	0.00	3.62	3.89
119	26	5	235	58	14	3	1	0		311	4.05	4.14	4.67	3.00	0.00	0.00	3.97	4.08
120	111	6	472	95	26	5	2	1		601	4.97	3.65	5.20	2.50	2.00	0.00	3.66	4.73
Interfluve Area (295.344 sqkm.)			923	166	--	-	-	2	1	1092								
Umiam	**Basin**	**7**	**5769**	**1314**	**305**	**78**	**16**	**3**	**1**	**7486**	**4.39**	**4.31**	**3.91**	**4.88**	**5.33**	**3.00**	**4.30**	**2.68**

TABLE-23

BASIN ORDER WISE MINIMUM-MAXIMUM TOTAL STREAMS (EN)u IN COMPONENT BASINS

Order	Minimum (EN)u	Component Basin No.	Bank of Umiam	Maximum (EN)u	Component Basin No.	Bank of Umiam
3	7	11	right	40	24	right
				40	70	left
				40	105	left
4	23	15	right	139	45	left
	23	118	left			
	23	119	left			
5	89	104	left	311	26	right
6	-	-	-	601	111	left

3	Mean : 16.82	Median : 15.26	Mode : 14.55	Std. dev.: 9.68	Coeff.Var. 57.54
4	Mean : 52.44	Median : 46.11	Mode : 44.00	Std. dev.:26.09	Coeff.Var. 49.75
5	Mean :196.43	Median :214.29	Mode :226.92	Std. dev.:67.39	Coeff.Var. 38.81

TABLE-24

BASIN ORDER WISE VARIATION IN BIFURCATION RATIOS

Order	Rb1	Rb2	Rb3	Rb4	Rb5	Rb6
3	2.00-9.50	2.00-7.00	-	-	-	-
4	2.50-5.64	2.00-8.00	2.00-7.00	-	-	-
5	3.74-4.77	3.38-5.83	2.00-5.0	2.00-3.00	-	-
6	4.97	3.65	5.20	2.50	2.00	-
Umiam Basin	4.39	4.31	3.91	4.88	5.33	3.00

varies from 3.0 to 5.0 for watersheds in which the geostructures do not distort the drainage pattern. The computed Rb of all component basins is given in Table (22). A perusal of the table reveal following pattern of variation in Rb ratios in basins of different orders (Table-24).

It is seen from above that the 3rd and 4th order basins and low order stream segments show large variation in Rb ratios indicating their "youth stage" of development. However the 5th and 6th order component basins tend to acquire the Rb ratios compatible with that of the Umiam basin as a whole (Table-24) and have relatively stabilised net.

The left bank component basins have comparatively higher Rb ratios than the right bank basins indicating more branching of channel segments in left bank of Umiam. It means more headward erosion or higher rates of denudation in the left bank.

The mean bifurcation ratio is given by $\bar{Rb}$=Rb1+Rb2+... Rbn/n and weighted mean bifurcation ratio is given by $\bar{Rbw}$ = Rb1 (N1+N2) + Rb2(N2+N3) + ... + Rbu(Nu+Nu+1)/N1+2N2+2N3+..... Nu+1). These ratios eliminate spurious or localised aberrations in channel networks and are more representative of bifurcation ratios of the component basins as a whole. The mean and weighted mean bifurcation ratios are given in Table (22). An analysis of the Table reveal following pattern in the different component basins vis-a-vis the Umiam Basin (Tables-25 & 26).

TABLE-25

BASIN ORDER WISE VARIATION IN MEAN BIFURCATION RATIOS

Order	Minimum $\overline{Rb}$	Component Basin No.	Bank of Umiam	Maximum $\overline{Rb}$	Component Basin No.	Bank of Umiam
3	2.00	11	right	6.38	24	right
4	2.50	42 118 119	right left left	4.78	45	left
5	2.92	104	left	3.97	26	right
6	-	-	-	3.66	111	left
Umiam Basin	-	-	-	4.30	-	-

3	Mean : 3.59	Median : 3.43	Mode : 2.89	Std. dev.: 1.05	Coeff. Var. 29.38
4	Mean : 3.53	Median : 3.52	Mode : 3.52	Std. dev.: 0.62	Coeff. Var. 17.58
5	Mean : 3.43	Median : 3.46	Mode : 3.48	Std. dev.: 0.26	Coeff. Var. 7.51

TABLE-26

BASIN ORDER WISE VARIATION IN WEIGHTED MEAN BIFURCATION RATIOS

Order	Minimum $\overline{Rbw}$	Component Basin No.	Bank of Umiam	Maximum $\overline{Rbw}$	Component Basin No.	Bank of Umiam
3	2.00	11	right	8.56	77	left
4	2.58	42	right	5.12	29	right
5	3.57	104	left	4.74	100	left
6	-	-	-	4.73	111	left
Umiam Basin	-	-	-	2.68	-	-

3	Mean : 4.02	Median : 3.65	Mode : 3.00	Std. dev.: 1.52	Coeff. Var. 37.86
4	Mean : 3.99	Median : 4.08	Mode : 4.23	Std. dev.: 0.75	Coeff. Var. 18.73
5	Mean : 4.21	Median : 4.30	Mode : 4.38	Std. dev.: 0.45	Coeff. Var. 10.72

The mean and weighted mean bifurcation ratios of the left bank component basins is higher than the right bank basins. The values of $\bar{Rb}$ and $\overline{\overline{Rbw}}$ less than 3 and higher than 5 (c.f. Strahler 1964) have been considered in this study as anomalous indicating higher branching of lower order channel segments i.e. rapid headward erosion. Such vigorous erosion in this hard rock terrain is responsible for stripping of the supracrustals and lowering of topography as a consequence. The component basins with Rb and Rbw values outside the limit of 3-5 represent fragile basins under heavy degradation.

STREAM LENGTH (Lu)

The stream lengths Lu and total stream lengths (EL)u in each component basin is given in Table (27). The highest variation in stream lengths is shown by low order basins as well as low order stream segments. The variation of stream lengths vis-a-vis Umiam basin as a whole is given in Tables (28 & 29).

The above analysis reveal that the highest total stream segments (EL)u occur in left bank component basins. It is also observed that low order basins show highest variation in (EL)u. The basin wise variation is given.

The component basins with (EL)u values of mean+1 std. dev. have been considered anomalous i.e.,. these basins have enlarged their drainage lines through efficient headward erosion. Incidentally such basins also depict entrenched or well incised valleys indicating heavy erosion. The following component

TABLE -27

COMPONENT BASIN CHARACTERISTICS

Sl. No.	Comp. Basin Number	U	<--- Lu ---> L1	L2	L3	L4	L5	L6	L7	(ΣLu)
1	2	3	4	5	6	7	8	9	10	11
1	73	3	2.25	0.25	0.200	0.00	0.00	0.00	0.00	2.700
2	113	3	2.00	0.75	0.250	0.00	0.00	0.00	0.00	3.000
3	88	3	3.00	0.50	0.200	0.00	0.00	0.00	0.00	3.700
4	11	3	2.50	1.00	0.200	0.00	0.00	0.00	0.00	3.700
5	89	3	3.00	0.75	0.200	0.00	0.00	0.00	0.00	3.950
6	102	3	2.50	0.75	0.500	0.00	0.00	0.00	0.00	3.750
7	97	3	2.50	1.50	0.200	0.00	0.00	0.00	0.00	4.200
8	46	3	3.00	1.25	0.500	0.00	0.00	0.00	0.00	4.750
9	14	3	2.50	1.00	1.000	0.00	0.00	0.00	0.00	4.500
10	99	3	2.50	1.25	0.750	0.00	0.00	0.00	0.00	4.500
11	31	3	4.00	0.50	1.000	0.00	0.00	0.00	0.00	5.500
12	76	3	3.50	1.75	0.250	0.00	0.00	0.00	0.00	5.500
13	103	3	3.13	1.89	0.700	0.00	0.00	0.00	0.00	5.720
14	66	3	4.13	1.50	1.500	0.00	0.00	0.00	0.00	7.130
15	65	3	6.00	1.25	0.500	0.00	0.00	0.00	0.00	7.750
16	13	3	4.75	1.50	0.400	0.00	0.00	0.00	0.00	6.650
17	8	3	5.00	0.80	3.500	0.00	0.00	0.00	0.00	9.300
18	52	3	4.00	1.50	0.500	0.00	0.00	0.00	0.00	6.000
19	39	3	2.75	2.25	1.500	0.00	0.00	0.00	0.00	6.500
20	82	3	5.00	0.50	2.500	0.00	0.00	0.00	0.00	8.000
21	59	3	4.25	0.89	2.500	0.00	0.00	0.00	0.00	7.640
22	22	3	3.50	1.25	1.500	0.00	0.00	0.00	0.00	6.250
23	57	3	5.00	0.75	1.500	0.00	0.00	0.00	0.00	7.250
24	74	3	4.50	0.50	0.750	0.00	0.00	0.00	0.00	5.750
25	92	3	3.75	1.50	1.250	0.00	0.00	0.00	0.00	6.500

Contd. Table-27

1	2	3	4	5	6	7	8	9	10	11
26	78	3	4.50	2.00	0.750	0.00	0.00	0.00	0.00	7.250
27	40	3	5.25	2.00	2.000	0.00	0.00	0.00	0.00	9.250
28	110	3	6.25	1.25	1.500	0.00	0.00	0.00	0.00	9.000
29	71	3	7.25	2.25	1.630	0.00	0.00	0.00	0.00	11.130
30	116	3	3.75	1.25	2.130	0.00	0.00	0.00	0.00	7.130
31	28	3	4.50	1.00	0.050	0.00	0.00	0.00	0.00	5.550
32	83	3	8.50	2.00	0.250	0.00	0.00	0.00	0.00	10.750
33	36	3	4.00	3.38	0.630	0.00	0.00	0.00	0.00	8.010
34	79	3	5.00	2.25	1.500	0.00	0.00	0.00	0.00	8.750
35	16	3	7.75	2.25	0.100	0.00	0.00	0.00	0.00	10.100
36	27	3	7.00	2.25	1.250	0.00	0.00	0.00	0.00	10.500
37	54	3	7.00	1.50	0.500	0.00	0.00	0.00	0.00	9.000
38	25	3	7.25	3.00	0.500	0.00	0.00	0.00	0.00	10.750
39	53	3	5.00	2.50	1.250	0.00	0.00	0.00	0.00	8.750
40	48	3	6.75	2.75	2.000	0.00	0.00	0.00	0.00	11.500
41	69	3	5.50	2.00	1.250	0.00	0.00	0.00	0.00	8.750
42	37	3	5.25	1.13	3.000	0.00	0.00	0.00	0.00	9.380
43	115	3	3.50	1.00	2.500	0.00	0.00	0.00	0.00	7.000
44	75	3	6.50	3.25	1.250	0.00	0.00	0.00	0.00	11.000
45	96	3	8.00	3.50	1.500	0.00	0.00	0.00	0.00	13.000
46	101	3	9.50	4.50	0.200	0.00	0.00	0.00	0.00	14.200
47	20	3	11.50	4.00	1.750	0.00	0.00	0.00	0.00	17.250
48	77	3	9.50	2.75	2.000	0.00	0.00	0.00	0.00	14.250
49	12	3	9.00	0.75	2.500	0.00	0.00	0.00	0.00	12.250
50	95	3	8.00	3.00	1.250	0.00	0.00	0.00	0.00	12.250
51	93	3	7.00	2.50	1.250	0.00	0.00	0.00	0.00	10.750
52	62	3	11.00	4.00	2.500	0.00	0.00	0.00	0.00	17.500
53	109	3	12.00	4.75	2.630	0.00	0.00	0.00	0.00	19.380
54	17	3	14.00	4.75	2.000	0.00	0.00	0.00	0.00	20.750
55	68	3	9.50	4.00	3.250	0.00	0.00	0.00	0.00	16.750
56	24	3	37.50	4.50	4.250	0.00	0.00	0.00	0.00	46.250
57	60	3	17.50	4.75	4.250	0.00	0.00	0.00	0.00	26.500
58	18	3	11.00	3.25	4.000	0.00	0.00	0.00	0.00	18.250
59	38	3	11.25	4.25	4.750	0.00	0.00	0.00	0.00	20.250
60	43	3	10.25	4.75	2.250	0.00	0.00	0.00	0.00	17.250

Contd. Table-27

1	2	3	4	5	6	7	8	9	10	11
61	2	3	10.00	6.00	5.000	0.00	0.00	0.00	0.00	21.000
62	49	3	14.50	2.25	6.500	0.00	0.00	0.00	0.00	23.250
63	105	3	17.25	4.38	6.250	0.00	0.00	0.00	0.00	27.880
64	94	3	13.50	5.50	2.000	0.00	0.00	0.00	0.00	21.000
65	70	3	42.50	1.50	6.500	0.00	0.00	0.00	0.00	50.500
66	3	3	15.50	5.00	6.000	0.00	0.00	0.00	0.00	26.500
67	15	4	8.00	2.50	1.000	0.70	0.00	0.00	0.00	12.200
68	33	4	10.00	1.50	0.500	1.00	0.00	0.00	0.00	13.000
69	118	4	8.00	3.00	1.250	0.15	0.00	0.00	0.00	12.400
70	86	4	10.50	4.00	1.250	0.25	0.00	0.00	0.00	16.000
71	7	4	24.50	2.50	10.000	2.00	0.00	0.00	0.00	39.000
72	56	4	13.00	3.00	2.500	0.20	0.00	0.00	0.00	18.700
73	72	4	11.50	1.75	2.500	0.56	0.00	0.00	0.00	16.130
74	119	4	6.50	3.00	2.500	2.75	0.00	0.00	0.00	14.750
75	4	4	13.00	10.50	7.000	2.50	0.00	0.00	0.00	33.000
76	63	4	18.00	3.38	2.380	0.62	0.00	0.00	0.00	24.380
77	107	4	15.00	4.00	2.500	2.00	0.00	0.00	0.00	23.500
78	42	4	10.00	4.75	2.250	2.00	0.00	0.00	0.00	19.000
79	117	4	14.00	2.50	3.250	1.88	0.00	0.00	0.00	21.630
80	81	4	19.50	6.00	3.500	2.50	0.00	0.00	0.00	31.500
81	64	4	19.00	4.50	1.600	3.00	0.00	0.00	0.00	28.100
82	106	4	14.50	6.50	1.500	2.75	0.00	0.00	0.00	25.250
83	30	4	20.50	6.00	4.500	1.50	0.00	0.00	0.00	32.500
84	87	4	17.50	5.00	4.000	1.00	0.00	0.00	0.00	27.500
85	10	4	15.00	3.50	8.000	0.10	0.00	0.00	0.00	26.600
86	58	4	28.50	3.25	4.500	3.50	0.00	0.00	0.00	39.750
87	9	4	16.25	6.00	0.870	1.50	0.00	0.00	0.00	24.625
88	51	4	18.50	7.00	3.000	1.50	0.00	0.00	0.00	30.000
89	32	4	24.00	8.50	2.500	1.75	0.00	0.00	0.00	36.750
90	120	4	15.50	2.00	2.250	4.00	0.00	0.00	0.00	23.750
91	112	4	20.00	6.50	2.750	1.75	0.00	0.00	0.00	31.000
92	41	4	17.75	6.75	3.500	2.75	0.00	0.00	0.00	30.750
93	29	4	32.50	5.50	4.000	4.50	0.00	0.00	0.00	46.500
94	98	4	27.50	5.50	7.500	0.50	0.00	0.00	0.00	41.000
95	21	4	24.50	6.00	3.000	4.00	0.00	0.00	0.00	37.500

Contd. Table-27

1	2	3	4	5	6	7	8	9	10	11
96	50	4	21.50	8.00	2.750	3.50	0.00	0.00	0.00	35.750
97	44	4	23.50	6.50	4.500	4.50	0.00	0.00	0.00	39.000
98	61	4	26.25	8.00	3.500	3.50	0.00	0.00	0.00	41.250
99	1	4	27.75	11.25	4.000	9.00	0.00	0.00	0.00	52.000
100	91	4	35.00	9.00	5.500	5.25	0.00	0.00	0.00	54.750
101	114	4	36.75	8.50	9.000	1.13	0.00	0.00	0.00	55.380
102	108	4	40.00	12.00	4.000	9.00	0.00	0.00	0.00	65.000
103	80	4	36.50	16.50	4.000	4.75	0.00	0.00	0.00	61.750
104	47	4	44.00	12.00	8.500	8.00	0.00	0.00	0.00	72.500
105	45	4	57.00	22.00	8.000	8.00	0.00	0.00	0.00	95.000
106	104	5	35.00	11.50	6.500	2.50	2.25	0.00	0.00	57.750
107	55	5	59.50	11.05	8.500	7.50	5.25	0.00	0.00	92.250
108	6	5	57.50	12.50	12.500	5.00	7.50	0.00	0.00	95.000
109	85	5	67.50	15.00	8.500	2.50	5.00	0.00	0.00	98.500
110	90	5	60.50	12.75	8.750	11.25	1.19	0.00	0.00	94.440
111	84	5	95.50	25.50	11.250	14.00	5.00	0.00	0.00	151.250
112	23	5	97.50	55.50	15.000	7.25	0.05	0.00	0.00	175.300
113	67	5	98.25	34.00	7.750	8.75	5.00	0.00	0.00	153.750
114	100	5	86.50	21.50	9.000	12.00	9.00	0.00	0.00	138.000
115	19	5	112.00	29.00	17.500	7.50	8.75	0.00	0.00	174.750
116	34	5	117.50	32.00	12.500	14.00	13.50	0.00	0.00	189.500
117	5	5	142.50	27.00	16.000	2.00	10.00	0.00	0.00	215.500
118	35	5	110.50	34.25	16.750	7.25	13.00	0.00	0.00	181.750
119	26	5	139.00	42.00	27.750	1.75	4.75	0.00	0.00	225.250
120	111	6	277.00	62.00	43.250	1.50	9.50	11.00	0.00	417.750
Interfluve Area (295.344 sqkm.)			543.25	120.25	-	-	-	150.00	51.25	864.75
Umiam	**Basin**	**7**	**3450.01**	**945.85**	**491.575**	**256.09**	**99.74**	**161.00**	**51.25**	**5455.515**

TABLE-28

BASIN ORDER WISE VARIATION IN STREAM LENGTHS (km)

Order	L1	L2	L3	L4	L5	L6	L7
3	2.00-42.50	0.25-6.00	0.05-6.50	-	-	-	-
4	6.50-57.00	1.50-22.00	0.50-10.00	0.10-9.00	-	-	-
5	35.00-142.50	11.05-55.50	6.50-27.75	1.75-14.00	0.05-13.50	-	-
6	277.00	62.00	43.25	1.50	9.50	11.00	-
Umiam Basin	3450.01	945.83	491.58	256.09	99.74	161.00	51.25

TABLE-29

BASIN ORDER WISE TOTAL STREAM LENGTH (km) VARIATION IN COMPONENT BASINS

Order	Minimum (EL)u	Component Basin No.	Bank of Umiam	Maximum (EL)u	Component Basin No.	Bank of Umiam
3	2.70	73	left	50.50	77	left
4	12.20	15	right	95.00	45	left
5	57.75	104	left	225.25	26	right
6	-	-	-	417.75	111	left

3	Mean : 11.97	Median: 9.26	Mode: 7.74	Std. dev.: 9.38	Coeff. Var. 78.36
4	Mean : 33.27	Median: 31.25	Mode: 35.00	Std. dev.:17.85	Coeff. Var. 53.65
5	Mean :142.86	Median:158.33	Mode:177.78	Std. dev.:55.44	Coeff. Var. 38.81

basins have anomalous (EL)u values.

Order	Bank of Umiam	Component Basin Nos.
3	right	3, 24
	left	49, 60, 70, 105
4	right	1
	left	45, 47, 80, 91, 108, 114
5	right	5, 26
	left	111

MEAN STREAM LENGTH ($\bar{L}u$)

The mean channel lengths $\bar{L}u$ of the component basins is given by $\bar{L}u$ = Lu/Nu. The computed values of different order basins vis-a-vis Umiam Basin is given in Table (30). A perusal of the Table reveal following pattern of mean channel length variations (Table-31).

It is observed that mean channel length increases with increase in order of stream. At the same time, with increase in order of basin the mean channel length, in general decreases. The low mean channel lengths indicate "youthful" stage of evolution of basins with entrenchment of fingertip segments without proportionate lengths. This is very clearly evident from the very low $\bar{L}u$ values of higher order segments in some of the high order basins. The 4th order component basin nos. 10, 56, 86 and 118 have $\bar{L}4$ values between 0.10 and 0.25, the 5th order basin no.23 has $\bar{L}5$ value of 0.05. It implies that these basins are still in embryonic stage of development i.e., a faster rate of headward enlargement in basin configuration. It is also observed that such basins are not controlled by any preferred lithotype in the area. But, the structural elements (joints, fractures) and loss of

TABLE -30

COMPONENT BASIN CHARACTERISTICS

Sl. No.	Comp. Basin Number	U	$\bar{L}u$ → $\bar{L}1$	$\bar{L}2$	$\bar{L}3$	$\bar{L}4$	$\bar{L}5$	$\bar{L}6$	$\bar{R}l$ → $\bar{R}11$	$\bar{R}12$	$\bar{R}13$	$\bar{R}14$	$\bar{R}15$
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	73	3	0.45	0.13	0.20	0.00	0.00	0.00	0.29	1.54	0.000	0.00	0.00
2	113	3	0.40	0.38	0.25	0.00	0.00	0.00	0.95	0.66	0.000	0.00	0.00
3	88	3	0.50	0.25	0.20	0.00	0.00	0.00	0.50	0.80	0.000	0.00	0.00
4	11	3	0.63	0.50	0.20	0.00	0.00	0.00	0.79	0.40	0.000	0.00	0.00
5	89	3	0.60	0.38	0.20	0.00	0.00	0.00	0.63	0.53	0.000	0.00	0.00
6	102	3	0.50	0.38	0.50	0.00	0.00	0.00	0.76	1.32	0.000	0.00	0.00
7	97	3	0.42	0.75	0.20	0.00	0.00	0.00	1.79	0.27	0.000	0.00	0.00
8	46	3	0.50	0.63	0.50	0.00	0.00	0.00	1.26	0.79	0.000	0.00	0.00
9	14	3	0.42	0.50	1.00	0.00	0.00	0.00	1.19	2.00	0.000	0.00	0.00
10	99	3	0.50	0.63	0.75	0.00	0.00	0.00	1.26	1.19	0.000	0.00	0.00
11	31	3	0.44	0.13	1.00	0.00	0.00	0.00	0.30	7.69	0.000	0.00	0.00
12	76	3	0.39	0.58	0.25	0.00	0.00	0.00	1.49	0.43	0.000	0.00	0.00
13	103	3	0.45	0.95	0.70	0.00	0.00	0.00	2.11	0.74	0.000	0.00	0.00
14	66	3	0.52	0.50	1.50	0.00	0.00	0.00	0.96	3.00	0.000	0.00	0.00
15	65	3	0.60	0.42	0.50	0.00	0.00	0.00	0.70	1.19	0.000	0.00	0.00
16	13	3	0.68	0.75	0.40	0.00	0.00	0.00	1.10	0.53	0.000	0.00	0.00
17	8	3	0.63	0.40	3.50	0.00	0.00	0.00	0.64	8.75	0.000	0.00	0.00
18	52	3	0.57	0.75	0.50	0.00	0.00	0.00	1.32	0.67	0.000	0.00	0.00
19	39	3	0.46	1.13	1.50	0.00	0.00	0.00	2.46	1.33	0.000	0.00	0.00
20	82	3	0.45	0.25	2.50	0.00	0.00	0.00	0.56	10.00	0.000	0.00	0.00
21	59	3	0.53	0.45	2.50	0.00	0.00	0.00	0.85	5.56	0.000	0.00	0.00
22	22	3	0.58	0.63	1.50	0.00	0.00	0.00	1.09	2.38	0.000	0.00	0.00
23	57	3	0.50	0.38	1.05	0.00	0.00	0.00	0.76	3.95	0.000	0.00	0.00
24	74	3	0.64	0.25	0.75	0.00	0.00	0.00	0.39	3.00	0.000	0.00	0.00
25	92	3	0.47	0.50	1.25	0.00	0.00	0.00	1.06	2.50	0.000	0.00	0.00

Contd. Table-30

1	2	3	4	5	6	7	8	9	10	11	12	13	14
26	78	3	0.64	1.00	0.75	0.00	0.00	0.00	1.56	0.75	0.000	0.00	0.00
27	40	3	0.53	0.67	2.00	0.00	0.00	0.00	1.26	2.99	0.000	0.00	0.00
28	110	3	0.45	0.31	1.50	0.00	0.00	0.00	0.69	4.84	0.000	0.00	0.00
29	71	3	0.56	0.75	1.63	0.00	0.00	0.00	1.34	2.17	0.000	0.00	0.00
30	116	3	0.47	0.42	2.13	0.00	0.00	0.00	0.89	5.07	0.000	0.00	0.00
31	28	3	0.90	0.50	0.05	0.00	0.00	0.00	0.56	0.10	0.000	0.00	0.00
32	83	3	0.65	1.00	0.25	0.00	0.00	0.00	1.54	0.25	0.000	0.00	0.00
33	36	3	0.50	1.13	0.63	0.00	0.00	0.00	2.26	0.56	0.000	0.00	0.00
34	79	3	0.45	1.13	1.50	0.00	0.00	0.00	2.51	1.33	0.000	0.00	0.00
35	16	3	0.71	0.75	0.10	0.00	0.00	0.00	1.06	0.13	0.000	0.00	0.00
36	27	3	0.77	0.56	1.25	0.00	0.00	0.00	0.73	2.23	0.000	0.00	0.00
37	54	3	0.70	0.50	0.50	0.00	0.00	0.00	0.71	1.00	0.000	0.00	0.00
38	25	3	0.52	1.50	0.50	0.00	0.00	0.00	2.89	0.33	0.000	0.00	0.00
39	53	3	0.56	0.83	1.25	0.00	0.00	0.00	1.48	1.51	0.000	0.00	0.00
40	48	3	0.48	0.92	2.00	0.00	0.00	0.00	1.92	2.17	0.000	0.00	0.00
41	69	3	0.60	0.67	1.29	0.00	0.00	0.00	1.12	1.93	0.000	0.00	0.00
42	37	3	0.66	0.38	3.00	0.00	0.00	0.00	0.58	7.90	0.000	0.00	0.00
43	115	3	0.50	0.50	2.50	0.00	0.00	0.00	1.00	5.00	0.000	0.00	0.00
44	75	3	0.54	1.08	1.25	0.00	0.00	0.00	2.00	1.16	0.000	0.00	0.00
45	96	3	0.62	1.75	1.50	0.00	0.00	0.00	2.82	0.86	0.000	0.00	0.00
46	101	3	0.68	2.25	0.20	0.00	0.00	0.00	3.31	0.09	0.000	0.00	0.00
47	20	3	0.55	0.80	1.75	0.00	0.00	0.00	1.46	2.13	0.000	0.00	0.00
48	77	3	0.50	1.38	2.00	0.00	0.00	0.00	2.76	1.45	0.000	0.00	0.00
49	12	3	0.64	0.25	2.50	0.00	0.00	0.00	0.39	10.00	0.000	0.00	0.00
50	95	3	0.73	0.75	1.25	0.00	0.00	0.00	1.03	1.67	0.000	0.00	0.00
51	93	3	0.64	1.25	1.25	0.00	0.00	0.00	1.95	1.00	0.000	0.00	0.00
52	62	3	0.52	0.67	2.50	0.00	0.00	0.00	1.29	3.73	0.000	0.00	0.00
53	109	3	1.80	1.58	2.63	0.00	0.00	0.00	0.88	1.67	0.000	0.00	0.00
54	17	3	0.52	1.19	2.00	0.00	0.00	0.00	2.29	1.68	0.000	0.00	0.00
55	68	3	0.63	0.80	3.25	0.00	0.00	0.00	1.27	4.06	0.000	0.00	0.00
56	24	3	1.07	1.30	4.25	0.00	0.00	0.00	1.22	3.27	0.000	0.00	0.00
57	60	3	0.70	1.19	4.25	0.00	0.00	0.00	1.70	3.57	0.000	0.00	0.00
58	18	3	0.65	0.81	4.00	0.00	0.00	0.00	1.25	4.94	0.000	0.00	0.00
59	38	3	0.56	0.71	4.75	0.00	0.00	0.00	1.27	6.69	0.000	0.00	0.00
60	43	3	0.68	2.38	2.25	0.00	0.00	0.00	3.50	0.95	0.000	0.00	0.00

Contd. Table-30

1	2	3	4	5	6	7	8	9	10	11	12	13	14
61	2	3	0.66	3.00	5.00	0.00	0.00	0.00	4.55	1.67	0.000	0.00	0.00
62	49	3	0.56	0.75	6.50	0.00	0.00	0.00	1.34	8.67	0.000	0.00	0.00
63	105	3	0.54	0.63	6.25	0.00	0.00	0.00	1.17	9.92	0.000	0.00	0.00
64	94	3	0.59	1.38	2.00	0.00	0.00	0.00	2.34	1.45	0.000	0.00	0.00
65	70	3	1.30	0.25	6.50	0.00	0.00	0.00	0.19	26.00	0.000	0.00	0.00
66	3	3	0.53	1.00	6.00	0.00	0.00	0.00	1.88	6.00	0.000	0.00	0.00
67	15	4	0.50	0.63	0.50	0.70	0.00	0.00	1.26	0.79	1.400	0.00	0.00
68	33	4	0.50	0.25	0.25	1.00	0.00	0.00	0.50	1.00	4.000	0.00	0.00
69	118	4	0.53	0.60	0.63	0.15	0.00	0.00	1.30	1.05	0.240	0.00	0.00
70	86	4	0.48	0.80	0.63	0.25	0.00	0.00	1.67	0.79	0.390	0.00	0.00
71	7	4	1.29	0.50	5.00	2.00	0.00	0.00	0.39	10.00	0.400	0.00	0.00
72	56	4	0.48	0.43	1.25	0.20	0.00	0.00	0.90	2.90	0.160	0.00	0.00
73	72	4	0.64	0.35	1.25	0.56	0.00	0.00	0.55	3.57	0.450	0.00	0.00
74	119	4	0.43	0.60	1.25	2.75	0.00	0.00	1.39	2.08	2.200	0.00	0.00
75	4	4	0.43	1.50	3.50	2.50	0.00	0.00	3.49	2.33	0.710	0.00	0.00
76	63	4	0.55	0.42	1.19	0.62	0.00	0.00	0.76	2.83	0.520	0.00	0.00
77	107	4	0.56	0.44	0.83	2.00	0.00	0.00	0.79	1.89	2.410	0.00	0.00
78	42	4	0.67	0.79	1.13	2.00	0.00	0.00	1.18	1.43	1.770	0.00	0.00
79	117	4	0.52	0.42	1.63	1.88	0.00	0.00	0.89	3.88	1.150	0.00	0.00
80	81	4	0.59	0.86	1.75	2.50	0.00	0.00	1.46	2.04	1.430	0.00	0.00
81	64	4	0.61	0.64	0.53	3.00	0.00	0.00	1.05	0.83	5.660	0.00	0.00
82	106	4	0.51	0.81	0.75	2.75	0.00	0.00	1.59	0.93	3.670	0.00	0.00
83	30	4	0.57	0.50	2.25	1.50	0.00	0.00	0.88	4.50	0.670	0.00	0.00
84	87	4	0.50	0.63	2.00	1.00	0.00	0.00	1.26	3.17	0.500	0.00	0.00
85	10	4	0.48	0.50	4.00	0.10	0.00	0.00	1.04	8.00	0.025	0.00	0.00
86	58	4	0.65	0.36	2.25	3.50	0.00	0.00	0.55	6.25	1.560	0.00	0.00
87	9	4	0.60	1.00	0.44	1.50	0.00	0.00	1.67	0.44	3.410	0.00	0.00
88	51	4	0.64	1.17	1.50	1.50	0.00	0.00	1.83	1.28	1.000	0.00	0.00
89	32	4	0.59	0.94	1.25	1.75	0.00	0.00	1.59	1.33	1.400	0.00	0.00
90	120	4	0.61	0.40	1.13	4.00	0.00	0.00	0.59	2.83	3.540	0.00	0.00
91	112	4	0.74	0.81	1.38	1.75	0.00	0.00	1.09	1.70	1.270	0.00	0.00
92	41	4	0.61	0.68	0.89	2.75	0.00	0.00	1.12	1.31	3.090	0.00	0.00
93	29	4	0.64	0.55	1.33	4.50	0.00	0.00	0.86	2.42	3.380	0.00	0.00
94	98	4	0.61	0.55	3.75	0.50	0.00	0.00	0.90	6.82	0.130	0.00	0.00
95	21	4	0.63	0.67	1.00	4.00	0.00	0.00	1.06	1.49	4.000	0.00	0.00

Contd. Table-30

1	2	3	4	5	6	7	8	9	10	11	12	13	14
96	50	4	0.61	0.89	1.38	3.50	0.00	0.00	1.46	1.55	2.540	0.00	0.00
97	44	4	0.50	0.59	1.50	4.50	0.00	0.00	1.18	2.54	3.000	0.00	0.00
98	61	4	0.56	0.80	1.75	3.50	0.00	0.00	1.43	2.19	2.000	0.00	0.00
99	1	4	0.50	0.70	2.00	9.00	0.00	0.00	1.40	2.86	4.500	0.00	0.00
100	91	4	0.56	0.82	1.38	5.25	0.00	0.00	1.46	1.68	3.800	0.00	0.00
101	114	4	0.51	0.57	3.00	1.13	0.00	0.00	1.12	5.26	0.380	0.00	0.00
102	108	4	0.52	0.67	1.33	9.00	0.00	0.00	1.29	1.99	6.770	0.00	0.00
103	80	4	0.60	0.97	1.33	4.75	0.00	0.00	1.62	1.37	3.570	0.00	0.00
104	47	4	0.50	0.44	1.21	8.00	0.00	0.00	0.88	2.75	6.610	0.00	0.00
105	45	4	0.54	0.79	1.60	8.00	0.00	0.00	1.46	2.03	5.000	0.00	0.00
106	104	5	0.55	0.68	1.30	1.25	2.25	0.00	1.24	1.91	0.960	1.80	0.00
107	55	5	0.59	0.43	1.06	3.75	5.25	0.00	0.73	2.47	3.540	1.40	0.00
108	6	5	0.66	0.66	3.13	2.50	7.50	0.00	1.00	4.74	0.800	3.00	0.00
109	85	5	0.64	0.68	2.13	1.25	5.00	0.00	1.06	3.13	0.590	4.00	0.00
110	90	5	0.56	0.51	1.25	3.75	1.19	0.00	0.91	2.45	3.000	0.32	0.00
111	84	5	0.60	0.73	1.25	7.00	5.00	0.00	1.22	1.71	5.600	0.71	0.00
112	23	5	0.59	1.42	1.50	3.63	0.05	0.00	2.41	1.06	2.420	0.01	0.00
113	67	5	0.59	0.89	0.86	4.38	5.00	0.00	1.51	0.97	5.090	0.00	0.00
114	100	5	0.53	0.61	1.50	6.00	9.00	0.00	1.15	2.46	4.000	1.50	0.00
115	19	5	0.63	0.63	1.59	2.50	8.75	0.00	1.00	2.52	1.570	3.50	0.00
116	34	5	0.60	0.71	1.56	4.67	13.50	0.00	1.18	2.20	2.990	2.89	0.00
117	5	5	0.88	0.69	1.77	6.67	10.00	0.00	0.78	2.56	3.770	1.50	0.00
118	35	5	0.60	0.79	1.52	2.42	13.00	0.00	1.20	1.92	1.590	5.37	0.00
119	26	5	0.59	0.72	1.98	3.92	4.75	0.00	1.22	2.75	1.980	1.21	0.00
120	111	6	0.59	0.65	1.66	3.00	4.75	11.00	1.10	0.55	1.810	1.58	2.32
Interfluve Area (295.344 sqkm.)													
Umiam	**Basin**	**7**	**0.60**	**0.72**	**1.61**	**3.28**	**6.23**	**53.67**	**1.20**	**2.24**	**2.040**	**1.90**	**8.62**

TABLE-31

BASIN ORDER WISE MEAN STREAM LENGTH VARIATIONS

Order	$\bar{L}1$	$\bar{L}2$	$\bar{L}3$	$\bar{L}4$	$\bar{L}5$	$\bar{L}6$	$\bar{L}7$
3	0.39-1.80	0.13-3.00	0.20-6.50	-	-	-	-
4	0.43-1.29	0.25-1.50	0.25-5.00	0.10-9.00	-	-	-
5	0.53-0.88	0.43-1.42	0.86-3.13	1.25-7.00	0.05-13.50	-	-
6	0.59	0.65	1.66	3.00	4.75	11.00	-
Umiam Basin	0.60	0.72	1.61	3.28	6.23	53.67	51.25*

Remarks : * Only one segment of 7th order

TABLE-33

BASIN ORDER WISE VARIATION IN DRAINAGE FREQUENCY (nos./km^2)

Order	Minimum Fu	Component Basin No.	Bank of Umiam	Maximum Fu	Component Basin No.	Bank of Umiam
3	2.84	2	right	17.80	73	left
4	3.96	120	left	10.49	33	right
5	4.37	35	right	6.21	104	left
6	-	-	-	5.21	111	left
Umiam Basin	-	-	-	5.24	-	-

3	Mean : 6.52	Median : 6.67	Mode : 6.89	Std. dev.: 3.04	Coeff. Var. 46.70
4	Mean : 6.59	Median : 6.58	Mode : 6.60	Std. dev.: 1.58	Coeff. Var. 23.99
5	Mean : 5.29	Median : 5.17	Mode : 5.09	Std. dev.: 0.70	Coeff. Var. 0.00

vegetation cover has largely influenced their development.

STREAM LENGTH RATIO ($\bar{R}l$)

It is the ratio between the mean stream length of one order to that of an order below i.e. $\bar{R}l = \bar{L}u/\bar{L}u\text{-}1$. The computed $\bar{R}l$ values of all component basins and the whole Umiam Basin is given in Table (30). The $\bar{R}l$ values show wide fluctuations,the order wise variations in the values are given below.

BASIN ORDER WISE VARIATION IN STREAM LENGTH RATIOS

Order	$\bar{R}l1$	$\bar{R}l2$	$\bar{R}l3$	$\bar{R}l4$	$\bar{R}l5$
3	0.19-4.55	0.10-26.0	-	-	-
4	0.39-3.49	0.44-10.0	0.025-6.77	-	-
5	0.73-2.41	0.97-4.74	0.59-5.60	0.01-5.37	-
6	1.10	0.55	1.81	1.58	2.32
Umiam Basin	1.20	2.24	2.04	1.90	8.62

The extremely high values in individual component basins indicate their "youth stage" of evolution i.e. the drainage net has yet to stabilise in the terrain. It also indicates disproportionate channel network development i.e. more number of low order segments with low channel lengths than the downstream higher order segments. In such a situation the branching of channel segments does not keep pace with their valley lengths, implying heavy headward erosion.

Following component basins have abnormal $\bar{R}l$ values suggestive of rapid channel branching along the brittle weak zones (joints-fractures) in the various rock types.

Order	Bank of Umiam	Component Basin Nos.
3	right	2, 3, 8, 12, 18, 25, 31, 37, 38, 43
	left	49, 59, 70, 77, 82, 96, 101, 105, 110, 115, 116
4	right	1, 4, 7, 10, 21, 29, 30,33
	left	45, 47, 58, 64, 72, 91, 98, 108, 114
5	right	5, 6, 19, 23, 35
	left	67, 84, 85, 100

Such branching of segments result in heavy erosions which is also accentuated by large scale deforestation in and around these basins.

DRAINAGE FREQUENCY (Fu)

It is the ratio between the total segments of all orders within a basin to the area of the basin and is expressed by Fu = (EN)u/Au. Its values are given in Table (32). The Fu values varies from 2.84 nos. per sq.km to 17.80 nos. per sq.km. The order wise variation of Fu values is given in Table (33).

The above analysis reveal that highest variation of Fu is in 3rd order basins which reflect their "youth stage" of development. The higher order basins reflect their stabilised nature by lesser variation in Fu values. The drainage frequency above mean + 1 std. dev. have been considered anomalous i.e. basins with high drainage frequency. The following component basins have anomalous drainage frequency.

TABLE -32

COMPONENT BASIN CHARACTERISTICS

Sl. No.	Comp. Basin Number	U	Fu	Du	Tu	Rc	Re	Ff	Rf	Cc	Kc	Rz	Rr	Rn
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	73	3	17.780	6.000	106.68	1.116	0.797	0.499	1.574	0.95	0.167	0.2947	0.124	1.68
2	113	3	12.310	4.670	56.87	0.773	0.910	0.650	1.208	1.14	0.216	0.1800	0.055	0.84
3	88	3	12.130	4.990	60.52	0.761	0.778	0.475	1.653	1.15	0.200	0.1680	0.060	1.04
4	11	3	8.880	4.690	41.65	1.090	0.771	0.466	1.684	0.95	0.213	0.0769	0.033	0.47
5	89	3	9.500	4.690	44.56	0.752	0.829	0.539	1.457	1.15	0.213	0.1920	0.064	1.13
6	102	3	9.140	4.280	39.12	0.543	0.660	0.342	2.297	1.36	0.234	0.0875	0.030	0.60
7	97	3	9.820	4.580	44.98	0.638	0.636	0.317	2.474	1.25	0.218	0.0200	0.080	1.56
8	46	3	7.870	4.150	32.66	0.575	0.690	0.374	2.102	1.32	0.241	0.2971	0.104	2.16
9	14	3	7.620	3.810	29.03	0.245	0.613	0.295	2.659	1.43	0.262	0.1175	0.043	0.90
10	99	3	6.730	3.790	25.51	0.493	0.559	0.246	3.198	1.42	0.264	0.1000	0.040	0.83
11	31	3	10.980	4.310	47.32	0.445	0.797	0.498	1.576	1.50	0.232	0.2569	0.069	1.77
12	76	3	9.200	3.890	35.79	0.644	0.866	0.588	1.335	1.25	0.257	0.1253	0.036	0.73
13	103	3	7.020	4.010	28.15	0.497	0.612	0.294	2.666	1.42	0.249	0.0909	0.033	0.80
14	66	3	8.340	4.960	41.37	0.722	0.732	0.420	1.868	1.18	0.201	0.1081	0.040	0.99
15	65	3	9.530	5.280	50.32	0.738	0.805	0.508	1.544	1.16	0.189	0.2118	0.072	1.90
16	13	3	6.580	4.380	28.82	0.763	0.818	0.526	1.494	1.14	0.228	0.1382	0.047	1.03
17	8	3	6.920	5.850	4.48	0.601	0.647	0.328	2.391	1.28	0.171	0.0727	0.028	0.94
18	52	3	6.180	3.710	22.93	0.565	0.756	0.449	1.750	1.33	0.269	0.1368	0.043	0.97
19	39	3	5.450	3.950	21.53	0.368	0.630	0.312	2.517	1.65	0.253	0.0609	0.019	0.55
20	82	3	8.210	4.690	38.50	0.595	0.819	0.527	1.491	1.30	0.213	0.0778	0.023	0.66
21	59	3	6.450	4.480	28.89	0.381	0.655	0.337	2.329	1.62	0.223	0.1547	0.046	1.56
22	22	3	5.140	3.570	18.35	0.520	0.622	0.304	2.584	1.39	0.280	0.0750	0.028	0.64
23	57	3	7.350	4.100	30.14	0.424	0.613	0.295	2.664	1.54	0.244	0.1388	0.047	1.39
24	74	3	5.590	3.220	18.00	1.403	0.943	0.698	1.124	0.84	0.311	0.3031	0.121	1.56
25	92	3	6.600	3.580	23.63	0.584	0.801	0.503	1.560	1.31	0.279	0.1053	0.032	0.72

Contd. Table-32

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
26	78	3	5.460	3.960	21.62	0.693	0.679	0.362	2.168	1.20	0.253	0.1156	0.045	1.03
27	40	3	7.640	5.050	38.58	0.640	0.764	0.459	1.713	1.25	0.198	0.0930	0.031	0.94
28	110	3	10.040	4.760	47.79	0.562	0.706	0.391	2.008	1.33	0.210	0.1636	0.056	1.71
29	71	3	8.290	5.430	45.01	0.429	0.521	0.213	3.680	1.53	0.184	0.0968	0.039	1.63
30	116	3	5.760	3.420	19.70	0.534	0.958	0.721	1.089	1.37	0.292	0.1453	0.035	0.84
31	28	3	3.820	2.650	10.12	0.537	0.760	0.453	1.733	1.37	0.377	0.1116	0.034	0.64
32	83	3	7.480	5.030	37.62	0.477	0.825	0.535	1.469	1.45	0.199	0.0935	0.025	0.94
33	36	3	5.460	3.640	19.37	0.606	0.744	0.435	1.806	1.28	0.275	0.1000	0.033	0.82
34	79	3	6.090	3.800	23.14	0.378	0.482	0.183	4.301	1.63	0.263	0.0794	0.032	1.07
35	16	3	6.370	4.290	27.33	0.526	0.963	0.727	1.080	1.38	0.233	0.2111	0.051	1.63
36	27	3	5.740	4.310	24.74	0.510	0.665	0.347	2.261	1.40	0.232	0.1057	0.036	1.21
37	54	3	5.680	3.650	20.73	0.631	0.908	0.648	1.212	1.26	0.273	0.0615	0.017	0.44
38	25	3	6.650	4.210	27.99	0.571	0.622	0.304	2.583	1.32	0.238	0.0490	0.019	0.60
39	53	3	5.060	3.410	17.25	0.398	0.670	0.352	2.228	1.58	0.293	0.0444	0.013	0.41
40	48	3	6.790	4.340	29.47	0.633	0.645	0.326	2.406	1.26	0.230	0.2105	0.082	2.60
41	69	3	4.890	3.290	16.09	0.593	0.897	0.632	1.242	1.30	0.304	0.1254	0.034	0.85
42	37	3	4.250	3.320	14.11	0.393	0.632	0.314	2.501	1.60	0.301	0.0817	0.026	0.81
43	115	3	3.530	2.470	8.72	0.632	0.760	0.453	1.733	1.26	0.401	0.2544	0.085	1.57
44	75	3	4.540	3.120	14.16	0.692	0.783	0.484	1.624	1.20	0.321	0.1630	0.055	1.37
45	96	3	4.440	3.610	16.03	0.558	0.659	0.341	2.303	1.34	0.277	0.1179	0.043	1.38
46	101	3	4.400	3.680	16.19	0.401	0.727	0.415	1.890	1.58	0.272	0.0708	0.019	0.79
47	20	3	6.960	4.450	30.97	0.487	0.808	0.513	1.530	1.43	0.225	0.1455	0.040	1.78
48	77	3	5.560	3.600	20.02	0.393	0.516	0.209	3.753	1.60	0.278	0.0729	0.028	1.14
49	12	3	4.540	3.090	14.03	0.360	0.832	0.543	1.444	1.67	0.324	0.0796	0.018	0.66
50	95	3	3.620	2.770	10.03	0.283	0.778	0.475	1.653	1.88	0.361	0.1256	0.027	1.06
51	93	3	3.140	2.410	7.57	0.508	0.794	0.495	1.586	1.40	0.415	0.1103	0.032	0.80
52	62	3	6.070	3.790	23.01	0.420	0.630	0.311	2.522	1.54	0.264	0.1018	0.033	1.49
53	109	3	4.290	3.780	16.22	0.381	0.441	0.153	5.147	1.62	0.265	0.0517	0.023	1.11
54	17	3	6.200	4.020	24.92	0.490	0.754	0.447	1.758	1.43	0.249	0.1235	0.037	1.69
55	68	3	3.990	3.190	12.73	0.349	0.569	0.254	3.092	1.69	0.313	0.0873	0.029	1.27
56	24	3	7.440	8.610	6.06	0.321	0.436	0.149	5.258	1.76	0.116	0.0455	0.019	2.35
57	60	3	5.570	4.930	27.46	0.511	0.738	0.427	1.838	1.40	0.203	0.1169	0.036	2.05
58	18	3	4.060	3.370	13.68	0.648	0.674	0.356	2.203	1.24	0.297	0.1077	0.041	1.42
59	38	3	4.430	3.320	4.71	0.490	0.648	0.330	2.380	1.43	0.301	0.0558	0.019	0.80
60	43	3	2.850	2.730	7.78	0.365	0.516	0.209	3.754	1.66	0.366	0.0896	0.033	1.35

Contd. Table-32

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
61	2	3	2.840	3.310	9.40	0.407	0.569	0.254	3.093	1.57	0.319	0.1216	0.043	2.01
62	49	3	4.560	3.530	16.10	0.422	0.591	0.274	2.864	1.54	0.283	0.1523	0.053	2.63
63	105	3	5.690	3.970	22.59	0.305	0.490	0.189	4.158	1.81	0.252	0.0302	0.011	0.73
64	94	3	3.920	2.940	11.53	0.623	0.616	0.298	2.638	1.27	0.340	0.0802	0.033	1.16
65	70	3	5.100	6.440	32.84	0.280	0.424	0.141	5.559	1.89	0.155	0.0506	0.020	2.43
66	3	3	4.430	3.350	14.84	0.388	0.588	0.271	2.898	1.61	0.298	0.1424	0.048	2.58
67	15	4	9.560	5.070	48.47	0.472	0.796	0.497	1.579	1.46	0.197	0.0909	0.025	1.01
68	33	4	10.490	4.710	49.41	0.708	0.596	0.278	2.819	0.43	0.212	0.1460	0.066	2.17
69	118	4	7.430	4.010	29.79	0.739	0.845	0.560	1.401	1.16	0.249	0.1362	0.044	1.28
70	86	4	8.070	4.300	34.70	0.730	1.012	0.805	0.976	1.17	0.233	0.1023	0.028	0.95
71	7	4	6.720	9.700	65.18	0.481	0.620	0.302	2.602	1.44	0.103	0.1260	0.045	4.46
72	56	4	8.570	4.330	37.11	0.670	0.957	0.720	1.091	1.22	0.231	0.1478	0.040	1.57
73	72	4	5.720	3.590	20.53	0.325	0.553	0.240	3.269	1.75	0.278	0.0644	0.021	1.01
74	119	4	4.940	3.170	15.66	0.299	0.482	0.183	4.298	1.83	0.315	0.0695	0.025	1.11
75	4	4	7.670	6.330	48.55	0.495	0.736	0.426	1.845	1.42	0.158	0.2057	0.063	4.56
76	63	4	8.330	4.620	38.48	0.502	0.648	0.330	2.378	1.41	0.216	0.0950	0.033	1.76
77	107	4	7.490	4.400	32.96	0.368	0.745	0.436	1.800	1.65	0.227	0.0871	0.023	1.17
78	42	4	4.120	3.260	13.43	0.696	0.726	0.414	1.895	1.20	0.307	0.1280	0.047	1.56
79	117	4	6.060	3.640	22.06	0.677	0.764	0.459	1.712	1.22	0.275	0.0722	0.025	0.95
80	81	4	7.230	5.290	38.25	0.311	0.656	0.337	2.327	1.79	0.189	0.0914	0.025	2.03
81	64	4	7.040	4.710	33.16	0.499	0.861	0.582	1.348	1.42	0.212	0.1313	0.034	1.98
82	106	4	6.350	4.110	26.10	0.536	0.666	0.348	2.256	1.37	0.243	0.0631	0.022	1.09
83	30	4	8.180	5.220	42.07	0.463	0.640	0.322	2.439	1.47	0.192	0.1364	0.046	3.13
84	87	4	6.750	4.040	27.27	0.594	0.867	0.589	1.332	1.30	0.247	0.0827	0.023	1.14
85	10	4	5.980	3.880	23.20	0.624	1.095	0.940	0.835	1.27	0.258	0.1000	0.023	1.05
86	58	4	7.990	5.670	45.30	0.449	0.657	0.338	2.320	1.49	0.176	0.0703	0.023	1.81
87	9	4	5.120	3.510	17.97	0.450	0.831	0.542	1.448	1.49	0.285	0.0686	0.018	0.87
88	51	4	5.100	4.030	20.55	0.513	0.616	0.298	2.634	1.40	0.248	0.1480	0.055	2.98
89	32	4	6.800	4.720	32.09	0.408	0.650	0.331	2.369	1.57	0.212	0.1268	0.040	2.90
90	120	4	3.960	3.030	12.00	0.520	0.607	0.290	2.711	1.39	0.330	0.0675	0.026	1.06
91	112	4	6.260	3.890	24.35	0.461	0.511	0.205	3.837	1.47	0.257	0.0576	0.024	1.40
92	41	4	5.490	3.840	21.08	0.348	0.799	0.501	1.567	1.69	0.260	0.1350	0.032	2.07
93	29	4	7.710	5.120	39.48	0.419	0.739	0.429	1.829	1.55	0.195	0.1304	0.036	3.07
94	98	4	6.150	4.350	26.75	0.700	0.730	0.418	1.879	1.20	0.230	0.0768	0.028	1.59
95	21	4	5.450	3.930	21.42	0.440	0.894	0.627	1.252	1.51	0.254	0.0923	0.022	1.41

Contd. Table-32

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
96	50	4	4.900	3.720	18.23	0.283	0.560	0.246	3.194	1.38	0.269	0.1298	0.054	3.02
97	44	4	6.210	3.910	24.28	0.424	0.686	0.369	2.125	1.54	0.256	0.0808	0.024	1.64
98	61	4	5.480	3.770	20.66	0.611	0.879	0.606	1.295	1.28	0.265	0.0976	0.028	1.56
99	1	4	6.370	4.420	28.16	0.543	0.842	0.556	1.411	1.36	0.226	0.1002	0.028	2.04
100	91	4	5.610	3.940	22.10	0.316	0.601	0.284	2.766	1.78	0.254	0.0621	0.019	1.71
101	114	4	6.090	3.710	22.60	0.649	0.801	0.503	1.561	1.24	0.270	0.1064	0.034	2.15
102	108	4	6.010	3.950	23.74	0.331	0.539	0.228	3.444	1.74	0.253	0.0453	0.015	1.52
103	80	4	4.910	3.740	18.36	0.560	0.764	0.459	1.711	1.34	0.267	0.0448	0.014	1.01
104	47	4	6.400	3.770	24.13	0.561	0.697	0.381	2.059	1.34	0.265	0.0980	0.034	2.62
105	45	4	5.340	3.650	19.49	0.396	0.707	0.392	2.000	1.59	0.274	0.0674	0.019	2.00
106	104	5	6.210	4.030	25.03	0.450	0.929	0.678	1.158	1.50	0.248	0.0522	0.012	0.97
107	55	5	6.190	4.110	25.44	0.303	0.538	0.227	3.461	1.82	0.243	0.0392	0.013	1.60
108	6	5	4.860	4.090	19.88	0.507	0.664	0.346	2.270	1.40	0.244	0.0902	0.031	3.03
109	85	5	5.600	4.120	23.07	0.471	0.890	0.622	1.262	1.46	0.242	0.0700	0.017	1.79
110	90	5	5.930	3.890	23.07	0.357	0.863	0.584	1.344	1.66	0.257	0.0684	0.015	1.72
111	84	5	5.960	4.400	26.22	0.363	0.683	0.366	2.146	1.66	0.227	0.0558	0.016	2.38
112	23	5	5.900	4.770	28.14	0.458	0.937	0.690	1.138	1.48	0.209	0.0658	0.015	2.29
113	67	5	5.720	4.050	23.17	0.313	0.626	0.308	2.549	1.79	0.247	0.5225	0.015	2.34
114	100	5	5.320	3.560	18.94	0.304	0.470	0.173	4.528	1.81	0.281	0.0478	0.018	2.55
115	19	5	5.550	4.060	22.53	0.497	1.036	0.843	0.931	1.42	0.246	0.0628	0.014	1.82
116	34	5	5.510	4.140	22.31	0.278	0.830	0.050	1.453	1.90	0.242	0.0845	0.017	3.22
117	5	5	4.580	4.620	21.16	0.479	0.816	0.523	1.502	1.45	0.216	0.1038	0.028	4.53
118	35	5	4.370	3.520	15.38	0.343	0.599	0.282	2.079	1.71	0.284	0.0500	0.015	2.36
119	26	5	5.970	4.320	25.79	0.362	0.647	0.328	2.392	1.66	0.231	0.1905	0.006	1.04
120	111	6	5.210	3.620	18.86	0.226	0.516	0.209	3.757	2.10	0.276	0.0295	0.009	2.51
Interfluve Area (295.344 sqkm.)														
Umiam	**Basin**	**7**	**5.240**	**3.820**	**20.02**	**0.180**	**0.451**	**0.160**	**4.918**	**2.36**	**0.262**	**0.0200**	**0.006**	**7.29**

Order	Bank of Umiam	Component Basin Nos.
3	right	31
	left	73, 88, 97, 110, 113
4	right	15, 30, 33
	left	56, 63
5	left	55, 104

Higher the drainage frequency, larger the channelised run off signifying availability of large hydraulic capacity to transport the detritus from source to mouth in the component basins. These component basins do not show any preferred lithological distribution but, have their development controlled by geostructures.

DRAINAGE DENSITY (Du)

The drainage density is defined as the ratio between total length of channels of all orders in a basin to that of the area of the basin. It is expressed by Du = (EL)u/Au. Its values are given in Table (32). The Du values varies from 2.4 km per sq.km to 9.70 km per sq.km. The order wise variation in Du values is given in Table (34).

The basins with Du values above mean + 1 std. dev. have been considered anomalous i.e. basins with high drainage density. The following component basins have anomalous drainage density.

Order	Bank of Umiam	Component Basin Nos.
3	right	8. 24
	left	65, 70, 71, 73
4	right	4, 7
	left	58
5	right	23

TABLE-34

BASIN ORDER WISE VARIATION IN DRAINAGE DENSITY (km/km^2)

Order	Minimum Du	Component Basin No.	Bank of Umiam	Maximum Du	Component Basin No.	Bank of Umiam
3	2.41	93	left	8.61	24	right
4	3.03	120	left	9.70	7	right
5	3.52	35	right	4.77	23	right
6	-	-	-	3.62	111	left
Umiam Basin	-	-	-	3.82	-	-

3	Mean : 4.06	Median : 3.90	Mode : 3.75	Std. dev.: 1.03	Coeff. Var. 25.41
4	Mean : 4.32	Median : 4.04	Mode : 3.76	Std. dev.: 1.15	Coeff. Var. 26.66
5	Mean : 4.29	Median : 4.42	Mode : 4.42	Std. dev.: 0.41	Coeff. Var. 9.57

TABLE-35

BASIN ORDER WISE VARIATION IN DRAINAGE TEXTURE

Order	Minimum Tu	Component Basin No.	Bank of Umiam	Maximum Tu	Component Basin No.	Bank of Umiam
3	4.48	8	right	106.68	73	left
4	12.00	120	left	65.18	7	right
5	15.38	35	right	28.14	23	right
6	-	-	-	18.86	111	left
Umiam Basin	-	-	-	20.02	-	-

3	Mean : 26.29	Median :23.18	Mode :21.67	Std. dev.:16.65	Coeff. Var. 63.35
4	Mean : 29.12	Median :25.50	Mode :22.00	Std. dev.:11.49	Coeff. Var. 39.47
5	Mean : 22.86	Median :23.64	Mode :24.21	Std. dev.: 4.10	Coeff. Var. 17.95

It is observed that the component basins with anomalous drainage frequencies necessarily do not have higher drainage densities. It is indicative of rapid branching of channel segments without commensurate enlargements of channel lengths.

DRAINAGE TEXTURE (Tu)

It is defined as product of drainage frequency and drainage density (Pal 1972) i.e. Tu = Fu x Du. Its value is given in Table (32). A perusal of the Table (32) reveal wide fluctuation in Tu values, varying from 4.48 to 106.68. The variations in different component basins, order wise vis-a-vis Umiam Basin is given in Table (35).

The 3rd order component basins have the widest variations, while the 5th order basins show least variation in Texture values. Lesser fluctuations in Tu means more stability in the basins. The Texture value above mean + 1 std. dev. are considered here as anomalous i.e. the component basins have high Texture or relatively high dissection or higher denudation or higher rate of lowering of topography. The following component basins have anomalous drainage texture.

Order	Bank of Umiam	Component Basin Nos.
3	right	31
	left	65, 71, 73, 88, 89, 97, 110, 113
4	right	4, 7, 15, 30, 33
	left	58
5	right	23

These are the component basins which are prone to rapid erosion and would be able to transport higher detritus out of the basin.

CONSTANT OF CHANNEL MAINTENANCE (Kc)

It is a measure of dissection of terrain and has been defined by Schumm (1956) as inverse of drainage density i.e., Kc = 1/Du. It signifies the area in sq.km or in sq.m (Kc Value x 1000) required to maintain 1 km or 1m of channel segment. It is an useful index to compare surface erodibility, and drainage network development. Low value of Kc means higher erodibility. (Schumm op. cit.) The computed values of Kc are given in Table (32). A perusal of the Table reveals following pattern of Kc variation. The variation in different basins is given in Table (36).

The component basins with Kc values less than mean - 1 std. dev. has been considered here as component basins with high erodibility. The following component basins have risk of higher erodibility.

Order	Bank of Umiam	Component Basin Nos.
3	right	8, 24, 40
	left	65, 66, 70, 71, 73, 83, 88
4	right	4, 7
	left	58, 81
5	right	5, 23

In general the Kc values is less in most of the

TABLE-36

BASIN ORDER WISE VARIATION IN CONSTANT OF CHANNEL MAINTENANCE (km^2/km)

Order	Minimum Kc	Component Basin No.	Bank of Umiam	Maximum Kc	Component Basin No.	Bank of Umiam
3	0.116	24	right	0.415	93	left
4	0.103	7	right	0.330	120	left
5	0.209	23	right	0.284	35	right
6	-	-	-	0.276	111	left
Umiam Basin	-	-	-	0.262	-	-

3	Mean : 0.26	Median : 0.26	Mode : 0.25	Std. dev.:0.059	Coeff. Var. 22.72
4	Mean : 0.24	Median : 0.24	Mode : 0.25	Std. dev.:0.049	Coeff. Var. 20.68
5	Mean : 0.24	Median : 0.23	Mode : 0.23	Std. dev.:0.020	Coeff. Var. 8.70

TABLE-37

BASIN ORDER WISE VARIATION IN RELATIVE RELIEF OF BASIN

Order	Minimum Rr	Component Basin No.	Bank of Umiam	Maximum Rr	Component Basin No.	Bank of Umiam
3	0.011	105	left	0.124	73	left
4	0.014	80	left	0.066	33	right
5	0.006	26	right	0.031	6	right
6	-	-	-	0.009	-	-
Umiam Basin	-	-	-	0.262	-	-

3	Mean :0.042	Median :0.037	Mode :0.036	Std. dev.:0.024	Coeff. Var. 56.24
4	Mean :0.032	Median :0.028	Mode :0.025	Std. dev.:0.013	Coeff. Var. 40.85
5	Mean :0.017	Median :0.018	Mode :0.016	Std. dev.:0.006	Coeff. Var. 35.41

component basins therefore most of the basins are eroding the terrain heavily. But, the above component basins are degrading the terrain heavily due to high erodibility capacity of their drainage network. Similar results have been obtained by Mithra and Rao (1993) from Errakalava river basin of West Godavari district of Andhra Pradesh.

RELATIVE RELIEF OF BASIN (Rr)

Melton (1957) defined Relative Relief of the basin as the ratio between the maximum basin relief and perimeter of the basin i.e., Rr = Z/Pu x 1000, where Z is in metres. It is an index of intensity of erosion, higher values of Rr indicate higher risks of erosion or sediment delivery rates in the basin. The computed Rr values are given in Table (32). The component basins have variations in Rr values as shown in Table (37).

The highest variation of Rr values is noticed in 3rd order basins and the minimum Rr value of 0.006 is observed in 5th order component basin No.5 draining the area around Barmarjong. The Rr values above mean + 1 std. dev. have been considered as anomalous i.e. the basins with such high Rr values have greater erosion risks.

The following component basins have been identified as high erosion prone areas.

Order	**Bank of Umiam**	**Component Basin Nos.**
3	right	31
	left	46, 48, 65, 73, 74, 115
4	right	4, 30, 33, 42
	left	50, 51
5	right	5, 6

BASIN RELIEF RATIO (Rz)

It is defined as the ratio of maximum basin elevation to the axial length of the basin. Schumm (1956) defined it as the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line. It is expressed as Rz = Z/Lb x 1000,where Z is in metres. It measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on the slopes of the basin. Strahler (1958) and Schumm (1954) suggested that sediment loss per unit area is closely correlated with basin relief ratio. The computed value of Rz for all component basins is given in Table (32). The value varies from 0.020 to 0.523 with wide fluctuations in the different order basins. The variation of Rz in different order basins is given in Table (38).

The above analysis reveal that highest variation of Rz is seen in 3rd order basins indicating their youthful stage of development. However extreme high Rz value of 0.523 is observed in 5th order basin. The basin relief ratio above mean + 1 std. dev. have been considered as anomalous i.e. basins with high intensity of erosion. Following component basins have been identified as basins having high risk of erosion.

Order	**Bank of Umiam**	**Component Basin Nos.**
3	right	16, 31
	left	46, 48, 65, 73, 74, 89, 115
4	right	4, 30, 33
	left	51, 56, 118
5	left	67

TABLE-38

BASIN ORDER WISE VARIATION IN BASIN RELIEF RATIO

Order	Minimum Rz	Component Basin No.	Bank of Umiam	Maximum Rz	Component Basin No.	Bank of Umiam
3	0.020	97	left	0.303	74	left
4	0.044	80	left	0.206	4	right
5	0.039	55	left	0.523	67	left
6	-	-	-	0.030	111	left
Umiam Basin	-	-	-	0.029	-	-

3 Mean :0.122 Median :0.108 Mode :0.076 Std. dev.:0.063 Coeff. Var. 51.61
4 Mean :0.101 Median :0.094 Mode :0.077 Std. dev.:0.034 Coeff. Var. 33.89
5 Mean :0.108 Median :0.070 Mode :0.060 Std. dev.:0.123 Coeff. Var.113.01

TABLE-39

BASIN ORDER WISE VARIATION IN RUGGEDNESS NUMBER

Order	Minimum Rn	Component Basin No.	Bank of Umiam	Maximum Rn	Component Basin No.	Bank of Umiam
3	0.41	53	left	2.63	49	left
4	0.87	9	right	4.56	4	right
5	0.97	104	left	4.53	5	right
6	-	-	-	2.51	-	-
Umiam Basin	-	-	-	7.29	-	-

3 Mean :1.235 Median :1.100 Mode :0.875 Std. dev.:0.573 Coeff. Var. 46.37
4 Mean :1.930 Median :1.725 Mode :1.409 Std. dev.:0.895 Coeff. Var. 46.39
5 Mean :2.286 Median :2.200 Mode :2.000 Std. dev.:1.013 Coeff. Var. 44.30

RUGGEDNESS NUMBER (Rn)

It is the product of maximum basin relief and density, where both parameters are in same units (Strahler 1958,1964), i.e. Rn = Z x Du/1000, where Z is in meters. The Ruggedness Number signify steepness of slopes in the basin. If density increases while maximum relief remains constant, the average distance from divides to adjacent channel is reduced, with an accompanying increase in slope steepness. If maximum basin relief increases while the density remains constant, the elevation difference between divides and adjacent channel will also increase so that steepness of slope will increase. Extremely high value of Rn occurs when both Z and Du are high, signifying steep and long slopes. Strahler (1964) has reported low Rn values upto 0.06 in the subdued relief of the Louisiana coastal plain to over 1.0 in coast ranges of California.

The computed Rn values of different component basins is given in Table (32). The values varies from 0.41 to 4.53 and show wide variation (Table-39).

The Rn values above mean + 1 std. dev. have been considered here as anomalous i.e. extremely high values signifying steep and long slopes in the basin, implying rapid debris - detritus transport capacities of the channel networks. The following component basins have been identified with anomalous Ruggedness Number.

Order	Bank of Umiam	Component Basin Nos.
3	right	2, 3, 24
	left	46, 48, 49, 60, 70
4	right	4, 7, 29, 30, 32
	left	50, 51
5	right	5

These above basins not only have steeper basin slopes but, also long slopes which facilitate easy and rapid erosion.

BASIN ELONGATION RATIO (Re)

It is an index to express the shape of a form of the basin. Schumm (1956) defined it as the ratio of the diameter of a circle of the same area as the basin to the maximum basin length. It can be mathematically expressed as $Re = 2\sqrt{A}/\sqrt{\pi} \times Lb$. According to Schumm (op.cit). Re values vary between 0.6 to 1.0 over a wide variety of climatic and geologic terrain conditions. Values near 1.0 are typical of regions of very low relief, whereas values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes.

The computed Re values vary from 0.012 to 0.963 and are given in Table (32). The variation of Re in different order basins is given in Table (40).

Higher values i.e., the values close to 1 indicate the shapes of basin approaching circle similar to the Wadel sphericity ratio used in sedimentary petrology (Krumbein and

TABLE-40

BASIN ORDER WISE VARIATION IN BASIN ELONGATION RATIO

Order	Minimum Re	Component Basin No.	Bank of Umiam	Maximum Re	Component Basin No.	Bank of Umiam
3	0.424	70	left	0.963	16	right
4	0.482	119	left	1.095	10	right
5	0.470	100	left	1.036	19	right
6	-	-	-	0.516	-	-

3 Mean :0.702 Median :0.695 Mode :0.676 Std. dev.:0.131 Coeff. Var. 18.61
4 Mean :0.736 Median :0.723 Mode :0.710 Std. dev.:0.149 Coeff. Var. 20.29
5 Mean :0.771 Median :0.800 Mode :0.857 Std. dev.:0.179 Coeff. Var. 23.20

TABLE-41

BASIN ORDER WISE VARIATION IN FORM FACTOR

Order	Minimum Ff	Component Basin No.	Bank of Umiam	Maximum Ff	Component Basin No.	Bank of Umiam
3	0.141	70	left	0.727	16	right
4	0.183	119	left	0.940	10	right
5	0.050	34	right	0.843	19	right
6	-	-	-	0.209	111	left
Umiam Basin	-	-	-	0.160	-	-

3 Mean :0.398 Median :0.389 Mode :0.375 Std. dev.:0.144 Coeff. Var. 36.09
4 Mean :0.433 Median :0.407 Mode :0.370 Std. dev.:0.171 Coeff. Var. 39.57
5 Mean :0.429 Median :0.350 Mode :0.325 Std. dev.:0.213 Coeff. Var. 49.78

Pettijohn 1938). The low Re values signify elongated basin with steep slopes resulting in more efficient sediment transport or erosion.

The Re values below mean - 1 std. dev. have been considered here to be anomalous i.e., such basins have potential of high risk for heavy erosion. Following component basins have been identified with potential of heavy erosion risk.

Order	Bank of Umiam	Component Basin Nos.
3	right	2, 24, 43
	left	68, 70, 71, 77, 79, 99, 109
4	left	50, 72, 108, 112, 119
5	left	55, 100

The low elongation ratios of the component basins (Table-32) is not due to differential erosion of the lithologies but is a result of strong influence of geostructures and youthful stage of development of the basins. Mithra and Rao (1993) have also concluded similar views from their work in Errakalava river basin in Andhra Pradesh.

FORM FACTOR (Ff)

It is the ratio of the basin area to the square of basin length (Horton 1932). Mathematically it is expressed as $Ff=Au/Lb^2$. The shape of the basin affects stream discharge characteristics, a long narrow basin with high bifurcation ratios would attenuate flood discharge periods while round basins of low bifurcation ratios would have sharp peaked flood discharges

(Strahler 1964). The computed Ff is given in Table (32). The values vary from 0.050 to 0.940. The variation on Ff values in different basins is given in Table (41).

The low Ff values indicate elongated shape while higher Ff values signify circular shapes. The Ff values below mean - 1 std. dev. have been considered here as anomalous i.e. unusually elongated basins, thereby prone to heavy erosion. Following components basins have high risk of heavy erosion.

Order	**Bank of Umiam**	**Component Basin Nos.**
3	right	12, 16
	left	54, 69, 74, 76, 113, 116
4	right	10, 21
	left	56, 61, 86
5	right	19, 23
	left	104

BASIN CIRCULARITY (Rc)

It expresses the ratio between the basin area and area of a circle having the same perimeter. (Miller 1953). Mathematically it can be expressed as $Rc = 4\pi Au/Pu^2$. According to Miller (op.cit.) Rc values remain remarkably uniform in the range of 0.6 to 0.7 for 1st and 2nd order basins over homogeneous lithologies indicating small order basins to have tendencies to preserve geometrical similarities over homogeneous geological materials. He also noticed Rc value to come down to 0.4 and 0.5 in 1st and 2nd order basins situated over moderately dipping quartzites in Clinch mountain area with strongly elongated basins.

The computed Rc values are given in Table (32). The values vary from 0.245 to 1.403. The variation of Rc values in different component basins is given in Table (42).

The low Rc values indicate that the basins are elongated (c.f. Rc = 0.180 of Umiam Basin) and depict overall a youthful stage of development irrespective of lithologies. The Rc values below mean - 1 std. dev. are considered as anomalous. Such anomalous values signify that the basins are highly elongated, consequently having efficient transport capacity or are prone to erosion. Following component basins have been identified as high risk basins.

Order	Bank of Umiam	Component Basin Nos.
3	right	14, 24
	left	70, 95, 105
4	right	41
	left	50, 72, 81, 91, 107, 108, 119
5	right	34
	left	55, 67, 100

ROTUNDITY FACTOR (Rf)

It is an index of shape of the basin similar to the lemniscate ratio of chorley et al. (1957). The Rotundity factor is mathematically expressed as $Rf = \pi Lb^2/4Au$. The computed Rf values are given in Table (32). A perusal of the Table reveal that Rf values vary from 1.080 to 5.559 in different basins. The variation in Rf value in different order basins is given in Table (43).

TABLE-42

BASIN ORDER WISE VARIATION IN CIRCULARITY RATIO

Order	Minimum Rc	Component Basin No.	Bank of Umiam	Maximum Rc	Component Basin No.	Bank of Umiam
3	0.245	14	right	1.403	74	left
4	0.283	50	left	0.739	118	left
5	0.278	34	right	0.507	6	right
6	-	-	-	0.226	-	-
Umiam Basin	-	-	-	0.180	-	-

3 Mean :0.553	Median :0.533	Mode :0.518	Std. dev.:0.212	Coeff. Var. 38.36
4 Mean :0.504	Median :0.487	Mode :0.455	Std. dev.:0.136	Coeff. Var. 26.91
5 Mean :0.393	Median :0.386	Mode :0.375	Std. dev.:0.073	Coeff. Var. 18.54

TABLE-43

BASIN ORDER WISE VARIATION IN ROTUNDITY FACTOR

Order	Minimum Rf	Component Basin No.	Bank of Umiam	Maximum Rf	Component Basin No.	Bank of Umiam
3	1.080	16	right	5.559	70	left
4	0.835	10	right	4.298	119	left
5	0.931	19	right	4.528	100	left
6	-	-	-	3.757	111	-
Umiam Basin	-	-	-	4.918	-	-

3 Mean :2.326	Median :2.077	Mode :1.769	Std. dev.:1.009	Coeff. Var. 43.36
4 Mean :2.112	Median :1.975	Mode :1.438	Std. dev.:0.786	Coeff. Var. 37.23
5 Mean :2.036	Median :2.000	Mode :1.250	Std. dev.:1.013	Coeff. Var. 49.75

The higher Rf values indicate elongated basins conducive to large sediment transport capacity. Following component basins have been identified as basins with very high risk of erosion.

Order	Bank of Umiam	Component Basin Nos.
3	right	24, 43
	left	70, 71, 77, 79, 105, 109
4	left	50, 72, 108, 119
5	left	55, 100

COMPACTION COEFFICIENT (Cc)

This factor has been devised by Gravelius (Horton 1932) and is expressed as $Cc = Pu/2\sqrt{\pi Au}$. The computed Cc is given in Table (32) and varies from 0.84 to 2.10. The variation in Cc values in different order basins is given in Table (44).

The high Cc values are suggestive of basin elongation i.e. basin with efficient sediment transport capacities. The Cc values above mean + 1 std. dev. have been considered anomalous i.e. basins with high risk of erosion and sediment loss. Following basins have been identified as high erosion prone areas.

Order	Bank of Umiam	Component Basin Nos.
3	right	12, 24, 39, 43
	left	68, 70, 95, 105
4	right	41
	left	72, 81, 91, 108, 119
5	right	34
	left	55, 100

The drainage analysis reveal that the Umiam Basin, by and large depict litho-structural control. It is highly elongated

TABLE-44

BASIN ORDER WISE VARIATION IN COMPACTION COEFFICIENT

Order	Minimum Cc	Component Basin No.	Bank of Umiam	Maximum Cc	Component Basin No.	Bank of Umiam
3	0.84	74	left	1.89	70	left
4	0.43	33	right	1.83	119	left
5	1.50	104	left	1.90	34	right
6	-	-	-	2.10	111	left
Umiam Basin	-	-	-	2.36	-	-

3 Mean :1.417 Median :1.414 Mode :1.405 Std. dev.:0.224 Coeff. Var. 15.84
4 Mean :1.407 Median :1.401 Mode :1.380 Std. dev.:0.273 Coeff. Var. 19.37
5 Mean :1.607 Median :1.600 Mode :1.500 Std. dev.:0.200 Coeff. Var. 12.44

parallel to the formational trends and has expanded along structural weak zones like joints-fracture system. Polycyclic rejuvenation of the terrain along reactivated lineaments have produced stepped erosional surfaces cascading down to the northeast. Interestingly on microscale its component basins have elongation oblique to the formational trends and depict steep slopes and evidences of vigorous headward erosion. Incidental the basins with anomalous morphometric attributes have lesser forest cover and higher incidences of gully development. Such terrain characters have produced high geomorphic risks in parts of the Umiam Basin.

CORRELATION OF PARAMETERS

The following 19 fundamental and derived morphometric parameters have been utilised for correlation studies.

1.	Area of Component Basins	**Au**
2.	Perimeter of Component Basins	**Pu**
3.	Length of Component Basins	**Lb**
4.	Total Stream Segments in Component Basins	**(En)u**
5.	Total Stream Length in Component Basins	**(El)u**
6.	Drainage Frequency	**Fu**
7.	Drainage Density	**Du**
8.	Drainage Texture	**Tu**
9.	Average Bifurcation Ratio	$\bar{R}b$
10.	Weighted Mean Bifurcation Ratio	$\bar{R}bw$
11.	Basin Relief Ratio	**Rz**
12.	Ruggedness Number	**Rn**
13.	Relative Relief of Basin	**Rr**
14.	Compaction Coefficient	**Cc**
15.	Basin Circularity	**Rc**
16.	Basin Elongation Ratio	**Re**
17.	Form Factor	**Ff**
18.	Rotundity Factor	**Rf**
19.	Constant of Channel Maintenance	**Kc**

The interrelationship between the different morphometric parameters in all the 3rd 4th and 5th order component basins (120) has been evaluated by Karl Pearson's coefficient of correlation. The computation has been performed on PC-386 using programme developed in Geography Department of NEHU, Shillong. The correlation is tested at t(0.1), t(0.05) and t(0.01) level of significance and classified into weak, moderate strong correlation. The degree of mutual dependency of the morphometric parameters is also assessed by coefficient of determination values. (R^2).

CORRELATION IN 3RD ORDER COMPONENT BASINS

The correlation matrix of the morphometric parameters is given in Table (45). The mutual correlation between different morphometric parameters has been classified into weak, moderate and strong (Table-46) correlation depending upon level of significance of testing (t) for 64 degrees of freedom (n=66). The degree of mutual dependency of different parameters is evaluated and has been graded into seven classes viz., negligible dependency to very high dependency (Table-47). A perusal of Tables (46 & 47) reveal following association of morphometric parameters with strong positive mutual correlation and very high degree of mutual dependency.

1) Au, Pu, Lb, (EN)u, (EL)u, $\bar{R}b$.
2) Pu, Au, Lb, (EN)u, (EL)u, $\bar{R}b$, Cc.
3) Lb, Au, Pu, (EN)u, (EL)u, $\bar{R}b$, Rf.
4) Fu, Tu.

TABLE-45

CORRELATION MATRIX OF MORPHOMETRIC PARAMETERS OF 3RD ORDER COMPONENT BASINS

	Au	Pu	Lb	(EN)u	(EL)u	Fu	Du	Tu	$\overline{Rb}$	$\overline{Rbw}$	Rz	Rn	Rr	Cc	Rc	Re	Ff	Rf	Kc
Au	1.000	0.952	0.919	0.868	0.855	-0.623	-0.187	-0.542	0.862	0.706	-0.317	0.398	-0.352	0.582	-0.471	-0.469	-0.444	0.509	0.318
Pu		1.000	0.936	0.847	0.858	-0.640	-0.143	-0.567	0.851	0.701	-0.405	0.344	-0.469	0.790	-0.659	-0.551	-0.520	0.607	0.280
Lb			1.000	0.843	0.891	-0.554	-0.006	-0.496	0.850	0.729	-0.427	0.397	-0.395	0.692	-0.562	-0.734	-0.695	0.799	0.148
(EN)u				1.000	0.927	-0.318	0.195	-0.296	0.930	0.713	-0.293	0.505	-0.322	0.546	-0.440	-0.455	-0.421	0.537	-0.090
(EL)u					1.000	-0.381	0.295	-0.358	0.867	0.705	-0.342	0.514	-0.348	0.584	-0.449	-0.529	-0.485	0.650	-0.119
Fu						1.000	0.602	0.935	-0.386	-0.378	0.379	0.043	0.477	-0.474	0.459	0.263	0.257	-0.242	-0.683
Du							1.000	0.502	0.116	0.095	-0.020	0.319	0.072	-0.052	0.099	-0.159	-0.134	0.264	-0.930
Tu								1.000	-0.356	-0.354	0.397	0.085	0.493	-0.443	0.450	0.254	0.245	-0.238	-0.616
$\overline{Rb}$									1.000	0.907	-0.317	0.475	-0.348	0.566	-0.478	-0.484	-0.452	0.550	-0.013
$\overline{Rbw}$										1.000	-0.287	0.421	-0.286	0.474	-0.410	-0.475	-0.447	0.521	0.017
Rz											1.000	0.441	0.871	-0.476	0.509	0.485	0.480	-0.464	0.005
Rn												1.000	0.486	0.140	-0.069	-0.255	-0.242	0.285	-0.237
Rr													1.000	-0.577	0.628	0.300	0.289	-0.312	-0.088
Cc														1.000	-0.918	-0.607	-0.582	0.637	0.138
Rc															1.000	0.556	0.549	-0.529	-0.142
Re																1.000	0.994	-0.936	0.091
Ff																	1.000	-0.892	0.076
Rf																		1.000	-0.156
Kc																			1.000

TABLE-46

NATURE OF CORRELATION OF MORPHOMETRIC PARAMETERS OF 3RD ORDER COMPONENT BASINS

PARAMETER	POSITIVE CORRELATION			NEGATIVE CORRELATION		
	Weak (t0.1)	Moderate (t0.05)	Strong (t0.01)	Weak (t0.1)	Moderate (t.0.05)	Strong (t0.01)
1	2	3	4	5	6	7
Au	-	-	Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Rn, Cc, Rf, Kc	-	-	Fu, Tu, Rz, Rr, Rc, Re, Ff
Pu	-	Kc	Au, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Rn, Cc, Rf	-	-	Fu, Tu, Rz, Rr, Rc, Re, Ff
Lb	-	-	Au, Pu, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Rn, Cc, Rf	-	-	Fu, Tu, Rz, Rr, Rc, Re, Ff
(EN)u	-	-	Au, Pu, Lb, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Rn, Cc, Rf	-	Tu, Rz	Fu, Rr, Rc, Re, Ff
(EL)u	-	Du	Au, Pu, Lb, (EN)u, $\overline{Rb}$, $\overline{Rb}$w, Rn, Cc, Rf	-	-	Fu, Tu, Rz, Rr, Rc, Re, Ff
Fu	-	Re, Ff	Du, Tu, Rz, Rr, Rc	Rf	-	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Cc, Kc
Du	-	(EL)u, Rf	Fu, Tu, Rn	-	-	Kc
Tu	-	Re, Ff	Fu, Du, Rz, Rr, Rc	Rf	(EN)u	Au, Pu, Lb, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Cc, Kc
$\overline{Rb}$	-	-	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$w, Rn, Cc, Rf	-	-	Fu, Tu, Rz, Rr, Rc, Re, Ff
$\overline{Rb}$w	-	-	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, Rn, Cc, Rf	-	Rz, Rr	Fu, Tu, Rc, Re, Ff

Cont.Table-46

PARAMETER	POSITIVE CORRELATION			NEGATIVE CORRELATION		
	Weak (t0.1)	Moderate (t0.05)	Strong (t0.01)	Weak (t0.1)	Moderate (t.0.05)	Strong (t0.01)
1	2	3	4	5	6	7
Rz	-	-	Tu, Rn, Rr, Rc, Re, Ff, Fu	-	(EN)u, $\overline{Rb}$w	Au, Pu, Lb, (EL)u, $\overline{Rb}$, Cc, Rf
Rn	-	Rf	Au, Pu, Lb, (EN)u, (EL)u, Du, $\overline{Rb}$, $\overline{Rb}$w, Rz, Rr	Ff, Kc	Re	-
Rr	-	Re, Ff	Fu, Tu, Rz, Rn, Rc	-	$\overline{Rb}$w	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, Cc, Rf
Cc	-	-	Au, Pu, Lb, (ENu), (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Rf	-	-	Fu, Tu, Rz, Rr, Rc, Re, Ff
Rc	-	-	Fu, Tu, Rz, Rr, Re, Ff	-	-	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Cc, Rf
Re	-	Fu, Tu, Rr	Rz, Rc, Ff	-	Rn	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Cc, Rf
Ff	-	Fu, Tu, Rr	Rz, Rc, Re	Rn	-	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Cc, Rf
Rf	-	Du, Rn	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rb}$w, Cc	Fu, Tu	-	Rz, Rr, Rc, Re, Ff
Kc	-	Pu	Au	Rn	-	Fu, Du, Tu

Remarks : Based on Coefficient of Correlation

TABLE-47

DEGREE OF DEPENDENCY OF MORPHOMETRIC PARAMETERS OF 3RD ORDER BASINS

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Au	Du	Rz, Rn, Rr, Ff, Kc	Tu, Rc, Re, Rf	Fu, Cc	$\overline{R}$bw	-	Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$
Pu	Du, Kc	Rz, Rn	Rr, Ff	Tu, Re, Rf	Fu, $\overline{R}$bw, Rc	-	Au, Lb, (EN)u, (EL)u, $\overline{R}$b, Cc
Lb	Du, Kc	Rz, Rn, Rr	Tu	Fu, Rc	Cc, Ff	$\overline{R}$bw, Re	Au, Pu, (EN)u, (EL)u, $\overline{R}$b, Cc
(EN)u	Du, Tu, Rz, Kc	Fu, Rr, Rc, Ff	Rn, Cc, Re, Rf	-	-	$\overline{R}$bw	Au, Pu, Lb, (ELu), $\overline{R}$b
(EL)u	Du, Kc	Fu, Tu, Rz, Rr	Rn, Rc, Re, Ff	Cc	$\overline{R}$bw, Rf	-	Au, Pu, Lb, (EN)u, $\overline{R}$b
Fu	Rn, Re, Ff, Rf	(EN)u, (EL)u, $\overline{R}$b, $\overline{R}$bw, Rz	Rr, Cc, Rc	Au, Lb, Du	Pu, Kc	-	Tu
Du	Au, Pu, Lb, (EN)u, (EL)u, $\overline{R}$b, $\overline{R}$bw, Rz, Rr, Cc, Rc, Re, Ff, Rf	Rn	Tu	Fu	-	-	Kc

Contd. Table-47

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Tu	(EN)u, Rn, Re, Ff, Rf	(EL)U, $\overline{Rb}$, $\overline{Rb}$w, Rz, Cc	Au, Lb, Du, Rr, Rc	Pu, Kc	-	-	Fu
$\overline{Rb}$	Du, Kc	Fu, Tu, Rz, Rr	Rc, Re, Ff, Rn	Cc, Rf	-	-	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$w
$\overline{Rb}$w	Du, Rz, Rr, Kc	Fu, Tu, Rn, Rc, Ff	Cc, Re, Rf	-	Au, Pu, (EL)u	Lb, (EN)u	$\overline{Rb}$
Rz	(EN)u, Du, $\overline{Rb}$w, Kc	Au, Pu, Lb, (EL)u, Fu, Tu, $\overline{Rb}$, Rn	Rc, Cc, Re, Ff, Rf	-	-	-	Rr
Rn	Fu, Tu, Cc, Rc, Re, Ff, Rf, Kc	Au, Pu, Lb, Du, $\overline{Rb}$w, Rz	(EN)u, (EL)u, $\overline{Rb}$, Rr	-	-	-	-
Rr	Du, $\overline{Rb}$w, Re, Ff, Rf, Kc	Au, Lb, (EN)u, (EL)u, $\overline{Rb}$	Pu, Fu, Tu, Rn	Rc, Cc	-	-	Rz
Cc	Du, Rn, Kc	Tu	(EN)u, Fu, $\overline{Rb}$w, Rz	Au, (EL)u, $\overline{Rb}$, Rr, Re, Ff	Lb, Rf	-	Pu, Rc
Rc	Du, Rn, Kc	(EN)u, $\overline{Rb}$w	Au, (EL)u, Fu, Tu, $\overline{Rb}$, Rz, Rf	Lb, Rr, Re, Ff	Pu	-	Cc

Contd.Table-47

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Re	Fu, Du, Tu, Rn, Rr, Kc	-	Au, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rbw}$, Rz	Pu, Cc, Rc	-	Lb	Ff, Rf
Ff	Fu, Du, Tu, Rn, Rr, Kc	Au, (EN)u, $\overline{Rbw}$	Pu, (EL)u, $\overline{Rb}$, Rz	Cc, Rc	Lb	-	Re, Rf
Rf	Fu, Du, Tu, Rn, Rr, Kc		Au, (EN)u, $\overline{Rbw}$, Rz, Rc	Pu, $\overline{Rb}$	(EL)u	-	Lb, Re, Ff
Kc	Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rbw}$, Rz, Rn, Rr, Cc, Rc, Re, Ff, Rf	Au	-	Tu	Fu	-	Du

Remarks : Based on Values of R^2 (coefficient of determination)
L = less than
G = greater than

5) $\bar{R}b$, Au, Pu, Lb, (EN)u, (EL)u, $\bar{R}bw$

6) $\bar{R}bw$, $\bar{R}b$.

7) Rz, Rr.

8) Cc, Pu.

9) Re, Ff.

10) Rf, Lb.

However, the following association of morphometric parameters have strong mutual negative correlation and very high degree of mutual dependency

1) Du, Kc.
2) Cc, Rc.
3) Rc, Rf.
4) Ff, Rf.

It is evident from above analysis that no single parameter has controlled the development of other parameters completely.

CORRELATION OF 4TH ORDER COMPONENT BASINS

The correlation matrix of the morphometric parameters is given in Table (48). The nature of mutual correlation between the parameters is tested for 37 degrees of freedom (n=39) and given in Table (49). The degree of mutual dependency of parameters vary from negligible to very high and is given in Table (50). A perusal of Tables (49 & 50) reveal following association of morphometric parameters with strong positive mutual correlation and very high degree of mutual dependency.

1) Au, Pu, Lb, (EN)u, (EL)u, $\bar{R}b$.

2) Pu, Au, Lb, (EN)u, $\bar{R}b$

TABLE-48

CORRELATION MATRIX OF MORPHOMETRIC PARAMETERS OF 4th ORDER COMPONENT BASINS

	Au	Pu	Lb	(EN)u	(EL)u	Fu	Du	Tu	$\overline{Rb}$	$\overline{Rbw}$	Rz	Rn	Rr	Cc	Rc	Re	Ff	Rf	Kc
Au	1.000	0.909	0.833	0.957	0.818	-0.431	-0.296	-0.428	0.854	0.414	-0.370	0.044	-0.352	0.214	-0.189	-0.086	-0.106	0.022	0.305
Pu		1.000	0.889	0.866	0.693	-0.467	-0.256	-0.420	0.805	0.435	-0.434	0.058	-0.449	0.536	-0.535	-0.271	-0.281	0.224	0.262
Lb			1.000	0.780	0.576	-0.478	-0.255	-0.418	0.716	0.394	-0.441	0.127	-0.268	0.394	-0.474	-0.577	-0.573	0.541	0.305
(EN)u				1.000	0.815	-0.195	-0.171	-0.231	0.927	0.473	-0.289	0.131	-0.301	0.182	-0.163	-0.060	-0.085	-0.019	0.116
(EL)u					1.000	-0.268	0.017	-0.141	0.771	0.406	-0.129	0.295	-0.159	0.136	-0.122	0.007	-0.034	-0.131	-0.004
Fu						1.000	0.472	0.821	-0.154	-0.074	0.366	0.170	0.322	-0.364	0.226	0.144	0.133	-0.175	-0.681
Du							1.000	0.887	-0.114	0.008	0.391	0.678	0.349	-0.005	-0.055	-0.070	-0.087	-0.011	-0.925
Tu								1.000	-0.177	-0.050	0.448	0.527	0.407	-0.197	0.077	0.011	-0.006	-0.081	-0.939
$\overline{Rb}$									1.000	0.683	-0.259	0.184	-0.299	0.208	-0.190	-0.037	-0.061	-0.042	-0.010
$\overline{Rbw}$										1.000	-0.234	0.108	-0.266	0.140	-0.092	-0.023	0.018	-0.051	-0.114
Rz											1.000	0.690	0.889	-0.344	0.230	0.205	0.187	-0.253	-0.442
Rn												1.000	0.697	0.011	-0.178	-0.259	-0.282	0.146	-0.630
Rr													1.000	-0.503	0.256	-0.124	-0.134	0.065	-0.351
Cc														1.000	-0.839	-0.316	-0.308	0.328	0.043
Rc															1.000	0.550	0.537	-0.550	-0.035
Re																1.000	0.993	-0.942	-0.025
Ff																	1.000	-0.898	0.001
Rf																		1.000	0.120
Kc																			1.000

TABLE-49

NATURE OF CORRELATION OF MORPHOMETRIC PARAMETERS OF 4th ORDER COMPONENT BASINS

PARAMETER	POSITIVE CORRELATION			NEGATIVE CORRELATION		
	Weak (t0.1)	Moderate (t0.05)	Strong (t0.01)	Weak (t0.1)	Moderate (t.0.05)	Strong (t0.01)
1	2	3	4	5	6	7
Au	Kc	-	Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rbw}$	Du	Rr, Rz	Fu, Tu
Pu	-	-	Au, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rbw}$, Cc	Re, Ff	-	Fu, Tu, Rz, Rr, Rc
Lb	Kc	$\overline{Rbw}$, Cc	Au, Pu, (EN)u, (EL)u, $\overline{Rb}$, Rf	Rr	-	Fu, Tu, Rz, Rc, Re, Ff
(EN)u	-	-	Au, Pu, Lb, (EL)u, $\overline{Rb}$, $\overline{Rbw}$	Rz, Rr	-	-
(EL)u	Rn	-	Au, Pu, Lb, (EN)u, $\overline{Rb}$, $\overline{Rbw}$	Fu	-	-
Fu	-	Rz, Rr	Du, Tu	(EL)u,	Cc	Au, Pu, Lb, Kc
Du	-	Rz, Rr	Tu, Rn, Fu	Au	-	Kc
Tu	-	-	Rz, Rn, Rr, Fu, Du	-	-	Kc, Au, Pu, Lb,
$\overline{Rb}$	-	-	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rbw}$	Rr	-	-
$\overline{Rbw}$	-	Lb	Au, Pu, (EN)u, (EL)u, $\overline{Rb}$	Rr	-	-

Contd. Table-49

PARAMETER	POSITIVE CORRELATION			NEGATIVE CORRELATION		
	Weak (t0.1)	Moderate (t0.05)	Strong (t0.01)	Weak (t0.1)	Moderate (t.0.05)	Strong (t0.01)
1	2	3	4	5	6	7
Rz	-	Fu, Du	Rn, Rr, Tu	(EN)u	Cc, Au	Kc, Pu, Lb
Rn	(EL)u	-	Rr, Du, Tu, Rz	Ff	-	Kc
Rr	-	Fu, Du	Tu, Rz, Rn	Lb, (EN)u, $\overline{Rb}$, $\overline{Rb}$w	Au, Kc	Pu, Cc
Cc	-	Lb, Rf	Pu	Ff	Re, Fu, Rz	Rc, Rr
Rc	-	-	Re, Ff	-	-	Pu, Lb, Rf, Cc
Re	-	-	Ff, Rc	Pu	Cc	Rf, Lb
Ff	-	-	Rc, Re	Pu, Rn, Cc	-	Rf, Lb
Rf	-	Cc	Lb	-	-	Rc, Re, Ff
KC	Au, Lb	-	-	-	Rr	Fu, Du, Tu, Rz, Rn

Remarks : Based on Coefficient of Correlation
L = less than
G = greater than

TABLE-50

DEGREE OF DEPENDENCY OF MORPHOMETRIC PARAMETERS OF 4th ORDER COMPONENT BASINS

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Au	Du, Rn, Cc, Rc, Re, Ff, Rf, Kc	Fu, Tu, $\overline{Rbw}$, Rz, Rr	-	-	-	-	Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$
Pu	Du, Rn, Re, Ff, Rf, Kc	Tu, $\overline{Rbw}$, Rz	Fu, Rr, Cc, Rc	-	(EL)u	-	Au, Lb, (EN)u, $\overline{Rb}$
Lb	Du, Rn, Rr, Kc	Tu, $\overline{Rbw}$, Rz, Cc	Fu, Rc, Rf	(EL)u, Re, Ff	-	$\overline{Rb}$	Au, Pu, (EN)u
(EN)u	Fu, Du, Tu, Rz, Rn, Rr, Cc, Rc, Re, Ff, Rf, Kc	-	$\overline{Rbw}$	-	-	-	Au, Pu, Lb, (ELu), $\overline{Rb}$
(EL)u	Fu, Du, Tu, Rz, Rn, Rr, Cc, Re, Rc, Ff, Rf, Kc	$\overline{Rbw}$	-	Lb	Pu	$\overline{Rb}$	Au, (EN)u
Fu	(EN)u, (EL)u, $\overline{Rb}$, $\overline{Rbw}$, Rn, Rc, Re, Ff, Rf	Au, Rz, Rr, Cc	Pu, Lb, Du	-	Kc	-	Tu

Contd.Table-50

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Du	Au, Pu, Lb, (EN)u, (EL)u, $\bar{R}$b, $\bar{R}$bw, Cc, Rc, Re, Ff, Rf	Rz, Rr	Fu	-	Rn	-	Tu, Kc
Tu	(EN)u, (EL)U $\bar{R}$b, $\bar{R}$bw, Cc, Rc, Re, Ff, Rf	Au, Pu, Lb, Rr	Rz, Rn	-	-	-	Fu, Du, Kc
$\bar{R}$b	Fu, Du, Tu, Rz, Rn, Rr, Cc, Rc, Re, Ff, Rf, Kc	-	-	-	$\bar{R}$bw	Lb, (EL)u,	Au, Pu, (EN)u
$\bar{R}$bw	Fu, Du, Tu, Rz, Rn, Rr, Cc, Rc, Re, Ff, Rf, Kc	Au, Pu, Lb, (EL)u	(EN)u	-	$\bar{R}$b	-	-
Rz	(EN)u, (EL)u, $\bar{R}$b, $\bar{R}$bw, Rc, Re, Ff, Rf	Au, Pu, Lb, Fu, Du, Cc, Kc	Tu	-	Rn	-	Rr

Contd. Table-50

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Rn	Au, Pu, Lb, (EN)u, (EL)u, Fu, $\overline{R}$b, $\overline{R}$bw, Cc, Rc, Re, Ff, Rf	-	Tu	Kc	Du, Rz, Rr	-	-
Rr	Lb, (EN)u, (EL)u, $\overline{R}$b, $\overline{R}$bw, Rc, Re, Ff, Rf	Au, Fu, Du, Tu, Kc	Pu, Cc	-	Rn	-	Rz
Cc	Au, (EN)u, (EL)u, Du, Tu, $\overline{R}$b, $\overline{R}$bw, Rn, Re, Ff, Kc	Lb, Fu, Rz, Rf	Pu, Rr	-	-	-	Rc
Rc	Au, (EN)u, (EL)u, Fu, Du, Tu, $\overline{R}$b, $\overline{R}$bw, Rz, Rn, Rr, Kc	-	Pu, Lb, Ff	Re, Rf	-	-	Cc
Re	Au, Pu, (EN)u, (El)u, Fu, Du, Tu, $\overline{R}$b, $\overline{R}$bw, Rz, Rn, Rr, Cc, Kc	-	-	Lb, Rc	-	-	Ff, Rf

Contd.Table-50

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Ff	Au, Pu, (EN)u, (El)u, Fu, Du, Tu, $\overline{Rb}$, $\overline{Rbw}$, Rz, Rn, Rr, Cc, Kc	-	Rc	Lb	-	-	Re, Rf
Rf	Au, Pu, (EN)u, (EL)u, Fu, Du, Tu, $\overline{Rb}$, $\overline{Rbw}$, Rz, Rn, Rr, Kc	Cc	Lb	Rc	-	-	Re, Ff
Kc	Au, Pu, Lb, (EN)u, (EL)u, $\overline{Rb}$, $\overline{Rbw}$, Cc, Rc, Re, Ff, Rf	Rz, Rr	-	Rn	Fu	-	Du, Tu

Remarks : Based on Values of R (coefficient of determination)

3) Lb, Au, Pu, (EN)u.
4) Fu, Tu.
5) Du, Tu
6) Rz, Rr
7) Re, Ff

However, the following association of morphometric parameters have strong negative mutual correlation and very high degree of mutual dependency.

1) Du, Kc
2) Tu, Kc
3) Cc, Rc
4) Re, Rf
5) Ff, Rf

It is observed from this analysis that no parameter has contributed independently in the development of basin geometry.

CORRELATION OF 5TH ORDER COMPONENT BASINS

The correlation matrix of the morphometric parameters is given in Table (51). The nature of mutual correlation between the parameters is tested for 12 degrees of freedom (n=14) and is given in Table (52). The degree of mutual dependency of different parameters is evaluated and graded into seven classes varying from negligible to very high dependency (Table-53). A perusal of Tables (52 & 53) indicate presence of following association of the parameters with strong positive mutual correlation and very high degree of mutual dependency.

1. Au, Pu, (EN)u, (EL)u, $\overline{Rb}$
2. Pu, Au, Lb, (EN)u, (EL)u, $\overline{Rb}$
3. Lb, Pu
4. Fu, Tu
5. Rn, Rr
6. Re, Ff
7. Rc, Ff

TABLE-51

CORRELATION MATRIX OF MORPHOMETRIC PARAMETERS OF 5th ORDER COMPONENT BASINS

	Au	Pu	Lb	(EN)u	(EL)u	Fu	Du	Tu	$\overline{Rb}$	$\overline{Rbw}$	Rz	Rn	Rr	Cc	Rc	Re	Ff	Rf	Kc
Au	1.000	0.887	0.648	0.936	0.958	-0.470	0.046	-0.302	0.816	0.139	0.194	0.363	-0.113	0.243	-0.240	-0.158	-0.282	0.052	0.006
Pu		1.000	0.784	0.870	0.794	-0.295	-0.160	-0.297	-0.817	0.222	0.273	0.280	-0.233	0.657	-0.650	-0.414	-0.616	0.317	0.203
Lb			1.000	0.580	0.505	-0.379	-0.382	-0.461	0.608	0.246	0.220	0.201	-0.082	0.595	-0.605	-0.830	-0.710	0.765	0.431
(EN)u				1.000	0.937	-0.146	0.170	-0.004	0.885	0.141	0.271	0.155	-0.334	0.311	-0.316	-0.110	-0.254	0.058	-0.133
(EL)u					1.000	-0.367	0.325	-0.081	0.816	0.122	0.208	0.412	-0.074	0.119	-0.116	-0.030	-0.176	-0.067	-0.276
Fu						1.000	0.245	0.848	-0.179	-0.244	0.075	-0.705	-0.660	0.176	-0.203	0.188	0.186	-0.033	-0.292
Du							1.000	0.716	0.155	-0.050	0.053	0.239	0.115	-0.403	0.408	0.419	0.326	-0.430	-0.994
Tu								1.000	-0.037	-0.217	0.077	-0.405	-0.435	-0.105	0.084	0.348	0.324	-0.251	-0.743
$\overline{Rb}$									1.000	0.555	0.294	0.289	-0.137	0.331	-0.324	-0.206	-0.350	0.203	-0.115
$\overline{Rbw}$										1.000	0.167	0.392	0.378	0.096	-0.071	-0.182	-0.310	0.237	0.059
Rz											1.000	0.022	-0.106	0.237	-0.238	-0.207	-0.173	0.116	-0.075
Rn												1.000	0.809	-0.046	0.097	-0.081	-0.268	0.012	-0.197
Rr													1.000	-0.375	0.423	-0.036	-0.064	-0.002	-0.104
Cc														1.000	-0.993	-0.614	-0.809	0.583	0.410
Rc															1.000	0.625	0.782	-0.581	-0.416
Re																1.000	0.803	-0.917	-0.438
Ff																	1.000	-0.686	-0.334
Rf																		1.000	0.447
Kc																			1.000

TABLE-52

NATURE OF CORRELATION OF MORPHOMETRIC PARAMETERS OF 5th ORDER COMPONENT BASINS

PARAMETER	POSITIVE CORRELATION			NEGATIVE CORRELATION		
	Weak (t0.1)	Moderate (t0.05)	Strong (t0.01)	Weak (t0.1)	Moderate (t.0.05)	Strong (t0.01)
1	2	3	4	5	6	7
Au	-	Lb	Pu, (EN)u, (EL)u, $\bar{R}b$	Fu	-	-
Pu	-	Cc	Au, Lb, (EN)u, (EL)u, $\bar{R}b$	-	Rc, Ff	-
Lb	(EL)u	Au, (EN)u, $\bar{R}b$, Cc	Pu, Rf	Tu,	Rc	Re, Ff
(EN)u	-	Lb	Au, Pu, (EL)u, $\bar{R}b$	-	-	-
(EL)u	-	Lb	Au, Pu, (EN)u, $\bar{R}b$	-	-	-
Fu	-	-	Tu	Au,	Rr	Rn
Du	-	-	Tu	-	-	Kc
Tu	-	-	Fu, Du	Lb	-	Kc
$\bar{R}b$	-	Lb, $\bar{R}bw$	Au, Pu, (EN)u, (EL)u	-	-	-
$\bar{R}bw$	-	$\bar{R}b$	-	-	-	-
Rz	-	-	-	-	-	-

Contd.Table-52

PARAMETER	POSITIVE CORRELATION			NEGATIVE CORRELATION		
	Weak (t0.1)	Moderate (t0.05)	Strong (t0.01)	Weak (t0.1)	Moderate (t.0.05)	Strong (t0.01)
1	2	3	4	5	6	7
Rn	-	-	Rr	-	-	Fu
Rr	-	-	Rn	-	Fu	-
Cc	-	Pu, Lb, Rf	-	-	Re	Rc, Ff
Rc	-	Re	Ff	-	Pu, Lb, Rf	Cc
Re	-	Rc	Ff	-	Cc	Lb, Rf
Ff	-	-	Rc, Re	-	Pu	Lb, Cc, Rf
Rf	-	Cc	Lb	-	-	Re, Ff
Kc	-	-	-	-	-	Du, Tu

Remarks : Based on Coefficient of Correlation

TABLE-53

DEGREE OF DEPENDENCY OF MORPHOMETRIC PARAMETERS OF 5th ORDER COMPONENT BASINS

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Au	Tu, $\bar{R}\bar{b}w$, Rz, Rr, Cc, Rc, Re, Ff, Rf, Kc, Du	Rn	Fu	-	Lb	-	Pu, (EN)u, (EL)u, $\bar{R}\bar{b}$
Pu	Fu, Du, Tu, $\bar{R}\bar{b}w$, Rz, Rn, Rr, Kc	Re, Rf	-	Ff	Cc, Rc	-	Au, Lb, (EN)u, (EL)u, $\bar{R}\bar{b}$
Lb	$\bar{R}\bar{b}w$, Rz, Rn, Rr	Fu, Du, Kc	(EL)u, Tu	(EN)u, $\bar{R}\bar{b}$, Cc, Rc	Au	Ff, Rf	Pu, Re
(EN)u	Fu, Du, Tu, $\bar{R}\bar{b}w$, Rz, Rn, Cc, Rc, Re, Ff, Rf, Kc	Rr	-	Lb	-	-	Au, Pu, (EL)u, $\bar{R}\bar{b}$
(EL)u	Tu, $\bar{R}\bar{b}w$, Rz, Rr, Cc, Rc, Re, Ff, Rf, Kc	Fu, Du, Rn	Lb	-	-	-	Au, Pu, (EN)u, $\bar{R}\bar{b}$

Contd.Table-53

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Fu	Pu, (EN)u, Du, $\overline{R}b$, $\overline{R}bw$, Rz, Cc, Rc, Re, Ff, Rf, Kc	Lb, (EL)u	Au	-	Rn, Rr	-	Tu
Du	Au, Pu, (EN)u, Fu, $\overline{R}b$, $\overline{R}bw$, Rz, Rn, Rr	Lb, (EL)u, Cc, Rc, Re, Ff, Rf	-	-	-	Tu	Kc
Tu	Au, Pu, (EN)u, (EL)u, $\overline{R}b$, $\overline{R}bw$, Rz, Cc, Rc, Rf,	Rn, Rr, Re, Ff	Lb	-	-	Du, Kc	Fu
$\overline{R}b$	Fu, Du, Tu, Rz, Rn, Rr, Re, Rf, Kc,	Cc, Rc, Ff	-	Lb, $\overline{R}bw$	-	-	Au, Pu, (EN)u, (EL)u,
$\overline{R}bw$	Au, Pu, Lb, (EN)u, (EL)u, Fu, Du, Tu, Rz, Cc, Rc, Re, Ff, Rf, Kc,	Rn, Rr	-	$\overline{R}b$	-	-	-

Contd. Table-53

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Rz	Au, Pu, Lb, (EN)u, (EL)u, Fu, Du, Tu, $\overline{Rb}$, $\overline{Rb}$w, Rn, Rr, Cc, Rc, Re, Ff, Rf, Kc	-	-	-	-	-	-
Rn	Pu, Lb, (EN)u, Du, $\overline{Rb}$, Rz, Cc, Rc, Re, Ff, Rf, Kc	Au, (EL)u, Tu, $\overline{Rb}$w	-	-	Fu	-	Rr
Rr	Au, Pu, Lb, (EL)u, Du, $\overline{Rb}$, Rz, Re, Ff, Rf, Kc	(EN)u, Tu, $\overline{Rb}$w, Rc, Cc	-	-	Fu	-	Rn
Cc	Au, (EN)u, (EL)u, Fu, Tu, $\overline{Rb}$w, Rz, Rn	Du, $\overline{Rb}$, Rr, Kc	-	Lb, Re, Rf	Pu	-	Rc, Ff
Rc	Au, (EN)u, (EL)u, Fu, Tu, $\overline{Rb}$w, Rz, Rn	Du, $\overline{Rb}$, Rr, Kc	-	Lb, Re, Rf	Pu	-	Cc, Ff

Contd. Table-53

Independent Parameter	DEPENDENT PARAMETER						
	Negligible L-10%	Very Low 10% - 20%	Low 20% - 30%	Moderate 30% - 40%	Moderately High 40% - 50%	High 50% - 60%	Very High G - 60%
1	2	3	4	5	6	7	8
Re	Au, (EN)u, (EL)u, Fu, $\bar{R}b$, $\bar{R}bw$, Rz, Rn, Rr	Pu, Du, Tu, Kc	-	Cc, Rc	-	-	Lb, Ff, Rf
Ff	Au, (EN)u, (EL)u, Fu, $\bar{R}bw$, Rz, Rn, Rr	Du, Tu, $\bar{R}b$, Kc	-	Pu	Rf	Lb	Cc, Rc, Re
Rf	Au, (EN)u, (EL)u, Fu, Tu, $\bar{R}b$, $\bar{R}bw$, Rz, Rn, Rr	Pu, Du, Kc	-	Cc, Rc	Ff	Lb	Re
Kc	Au, Pu, (EN)u, (EL)u, Fu, $\bar{R}b$, $\bar{R}bw$, Rz, Rn, Rr	Lb, Cc, Rc, Re, Ff, Rf	-	-	-	Tu	Du

Remarks : Based on Values of R^2 (coefficient of determination)
L = less than
G = greater than

However, the following association of morphometric parameters have strong mutual negative correlation and very high degree of mutual dependency.

1. Lb, Rc,
2. Du, Kc,
3. Ff, Cc,
4. Rf, Re,

The above analysis reveal that all parameters do not have interdependency and have not contributed equitably in the development of drainage basin hydraulics.

The correlation study of the parameters as discussed above have indicated that:

1. All the 19 parameters have not uniformly contributed in the development of the component basins of Umiam river system.

2. The 3rd, 4th and 5th order component basins do not have identical association of parameters with positive or negative mutual correlation.

3. The basin areas and basin perimeters of same order basins do not show prorata increase with rise in drainage frequency and drainage density. It implies that rise in Fu and Du tends to unload the topography instead of basin enlargement. It signifies existence of vigorous erosion conditions in the component basins, the cumulative effect of which has in general lowered the topography in the whole Umiam basin

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CHAPTER - VI

GEOMORPHIC CHARACTERISTICS

GEOMORPHIC CHARACTERISTICS

Geomorphology is the branch of natural science dealing with the study of genesis and development of landforms or landscapes. Physiography and topography are the other terms which are also used for the study of landforms or earth's relief features. But, geomorphology is a more comprehensive term covering all aspects of the evaluation of landforms both of erosional and depositional types. (Smith 1935; Hammond 1964; Durry 1967; Thornbury 1969; Sparks 1972).

The identification, delineation and characterisation help largely in the evaluation of the processes responsible for sculpturing them, and the materials that compose the landforms. This then, further aids in proper terrain evaluation for environmental management (Cooke and Doornkamp 1974).

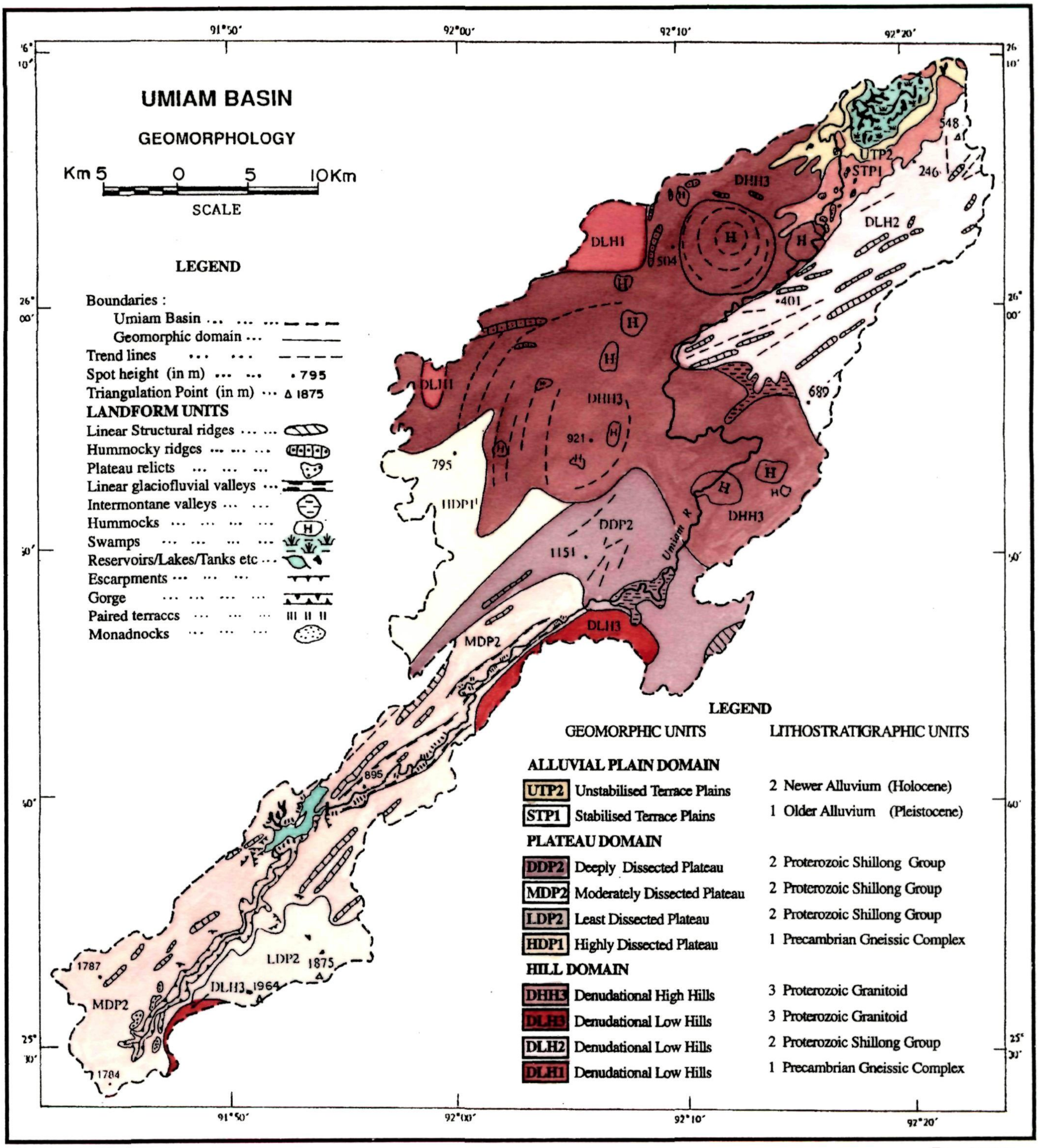
All terrains or landscapes can be divided into smaller identifiable units. Some of the units may be unique but most are made up of a number of repeated landforms (Ollier 1977). A geomorphic unit also termed as a physiographic unit is the product of various geomorphic processes acting in an area. The Umiam basin forms part of a spectacular landscape consisting of plateau and hill components with associated valleys (Fig.2).

A landform is a distinct morphologic configuration of the earth's landsurfaces. It exerts far reaching influences on the pattern of human activities. So, indirectly, landforms control developmental planning and cultural activities in an area. Landforms can be described morphologically as well as genetically. A genetic description is useful in understanding the development of landforms because landforms are always "sequential" in nature. Any landscape is nothing more than an existing stage in a great struggle to resist the denudation, the ultimate fate of which is a peneplain.

LANDFORM EVALUATION

Landform evaluation helps in reconstructing the geomorphic history of an area and to identify the geohazards in it. Photogeological, remote sensing product analysis and field studies in the basin were carried out to identify and classify the different landforms and a geomorphic map is prepared (Fig.27).

The basin characteristically has lateral "stepped" or "staircase" surfaces (Fig.13 & 14). These cascading surfaces occur as steps on the landscape falling in heights from source to mouth of the basin. Such multitier landscapes have been recognised as a consequence of multiple erosional cycles worldover. According to Ruhe (1975), the Loluba basin in Africa exemplifies stepped erosional surfaces in humid area. Similar stepped surfaces have been reported from Hawaii, Iowa and New Mexico also. The erosion surfaces occurring at the highest levels are the oldest while, that at the lowest levels are the youngest. Hence, these stepped surfaces demonstrate a chronological sequence.



UMIAM BASIN
GEOMORPHOLOGY
Km 5 0 5 10Km
SCALE
LEGEND
Boundaries :
Umiam Basin
Geomorphic domain
Trend lines
Spot height (in m) • 795
Triangulation Point (in m) Δ 1875
LANDFORM UNITS
Linear Structural ridges
Hummocky ridges
Plateau relicts
Linear glaciofluvial valleys
Intermontane valleys
Hummocks
Swamps
Reservoirs/Lakes/Tanks etc
Escarpments
Gorge
Paired terraces
Monadnocks
LEGEND
GEOMORPHIC UNITS
LITHOSTRATIGRAPHIC UNITS
ALLUVIAL PLAIN DOMAIN
UTP2 Unstabilised Terrace Plains
2 Newer Alluvium (Holocene)
STP1 Stabilised Terrace Plains
1 Older Alluvium (Pleistocene)
PLATEAU DOMAIN
DDP2 Deeply Dissected Plateau
2 Proterozoic Shillong Group
MDP2 Moderately Dissected Plateau
2 Proterozoic Shillong Group
LDP2 Least Dissected Plateau
2 Proterozoic Shillong Group
HDP1 Highly Dissected Plateau
1 Precambrian Gneissic Complex
HILL DOMAIN
DHH3 Denudational High Hills
3 Proterozoic Granitoid
DLH3 Denudational Low Hills
3 Proterozoic Granitoid
DLH2 Denudational Low Hills
2 Proterozoic Shillong Group
DLH1 Denudational Low Hills
1 Precambrian Gneissic Complex
Umiam R.

Fig.(27)

Absence of Post Shillong Group formations within the basin does not necessarily mean that this part of the Shillong Massif remained a positive terrain all through and no supracrustals existed over the Gneissic Complex - Shillong Group since Proterozoic. However, ample justifications exist in construing the presence of post Proterozoic supracrustals which were subsequently stripped off the area due to accelerated northward lowering of topography in response to repeated rejuvenation. As a consequence, the northward sloping Proterozoic and pre-Proterozoic peneplained topography has been exhumed. Such rejuvenation has caused general northward lowering of topography. Rai (1987) has related the uplift of Meghalaya Plateau with the rejuvenation of Deccan Foreland.

The present limit of Gondwana and undifferentiated Cretaceous - Tertiary exposures as north as 25^{o} 43'N latitude indicate their northward extension over the peneplained Shillong Massif. Their further northward existence prior to imposition of Quaternary fluvial processes is not ruled out. Hence the Massif has evidences of polycyclic denudational history with imprints of at least four major erosional surfaces. These in decreasing order of antiquity correspond to (a) Precambrian Peneplanation episode, (b) Permo-Carboniferous Peneplanation episode, (c) Cretaceous - Tertiary Erosional episode, (d) Quaternary Erosional episode (ongoing).

The above episodes have manifestations of *major* unconformities and signify prolong denudation. These polycyclic events have gradually stripped off the supracrustals from the Massif and exhumed the topography "buried" under the unconformities. So, what is seen today is a rejuvenated terrain with overprinting of major fluvial cycles producing a "staircased" landscape with streams reflecting structural adaptation. Remnants of palaeoplains are a common feature of most upland regions (Twidale 1981). Marvashvili (1981) has reported 6 peneplanation surfaces from Alpine Mountain.

Broadly the basin is divided into following three geomorphic domains which are described below.

1. The Alluvial Plain Domain
2. The Plateau Domain
3. The Hill Domain

Each geomorphic domain has characteristic landform elements and relief features. Some of the landform elements described are too small to be depicted in the geomorphic map (Fig.27). Similarly the microrelief and minor landform features are not shown in the map. However, the same are discussed as they are important genetic indicators of the geomorphic evolution of the basin.

THE ALLUVIAL PLAIN DOMAIN

These are lowlands confined in the terminal part of the basin with general elevation less than 60m above m.s.l. conspicuously the Domain has triangular shape. It commences from near Amjonggaon, where Umiam leaves behind the hilly tract and continues in northeast direction merging with the Kopili - Brahmaputra left bank flood plains (Plate-11).

Due to low elevation (<60m) and alluvial nature its physiographic or natural relief features have long been obliterated and reduced by fluvial cycles as well as continuing anthropogenic activities. As a result the Domain is a gentle, almost relief less plain sloping towards north. However, the area proximal to Hill Domain between Amjonggaon and Nelli Tea Garden, has a few relict hills jutting out as monadnocks, rising upto 80m above the alluvial plain.

The northern boundary of the Domain is also the terminal limit of the basin. In absence of any physiographic feature, it is defined by man made "relief" - the "bunds" or dikes for the mitigation of floods from overbank flows of Kopili - Brahmaputra river systems. Thus prior to these dikes, this part of the basin (flood plain) had direct and normal access to the hydrological signatures as bank oscillations of the Kopili and Brahmaputra rivers. As a result the Domain has formed by the progressive migration of meandering channels and a sequence of fluvial deposits created by this process (Wolman and Leopold 1957; Allen 1970; Bluck 1971; Cloves and Peter 1982; Brazier et al. 1993). The western boundary of the Domain is irregular with narrow and linear embayments into the adjoining Hill Domain. These embayments are the manifestations of relatively accelerated erosion along structurally weak zones, now concealed below the alluvium. In contrast the southeastern boundary is remarkably straight and coincides with the northeastern segment of the Tyrsad - Barapani Shear Zone passing through the basin.

The Alluvial Geomorphic Domain is divisible into two sub Domains based on elevation and morphological differences

(a) Unstabilised Terrace Plains (UTP2)
(b) Stabilised Terrace Plains (STP1)

UNSTABILISED TERRACE PLAINS (UTP2) :

The Unstabilised Terrace Plains represent the Holocene sediments and occupy the present day flood plain levels i.e., <55m above m.s.l. These plains are prone to periodic flooding due to overbank flows and backwaters. At the same time the shallow ground water table, around 55m above m.s.l. makes large part (22.576sq.km) of these plains water logged and swampy. As a result it hosts 32 number of bils (lakes) and water bodies varying in size from 0.005sq.km to 0.736sq.km. These bils and associated swamps are the ideal wetland in this part of the basin. During winters when the water table lowers down and the swamps recede, the wetland shrinks making multilevel micro terraces/micro scarps visible on the plains. Thus the terraced nature of this Domain becomes very apparent indicating the operation of minor and short-lived fluvial cycles in the evolution of these plains (Wolman and Leopold 1970). These shortlived fluvial cycles are the "responses" of rivers to Active Tectonics (Howard 1967; Adams 1980; Russ 1982; Burnett and Schumm 1983; Gregory and Schumm 1987). Due to sheet flow and swift overland flows (Negi 1986) minor shallow gullies have formed over these Terraces representing the microrelief features of Harris (1968).

STABILISED TERRACE PLAINS (STP1)

The Stabilised Terrace Plains represent the late Pleistocene sediments. They together with the Palaeo colluvium - scree - landslide debris aprons form the higher level terraces occurring between 60m and 55m elevation above m.s.l. In general, these are level plains sloping northwards representing the older flood plain deposits of Umiam - Kopili - Brahmaputra Rivers. Its boundary with the underlying Unstabilised Terrace Plains is very well defined by a "bluff line" or by an escarpment about 5m high (Plate - 11). These plains also depict a multilevel terrace geometry suggestive of gradual northward migration of fluvial cycles. Micro relief features like gullies, bank collapse, bank or bluff slumps and associated cracks are quite common in vicinity of Umiam segment as well as other drainage lines.

Conspicuously, the Umiam segment passing through the Alluvial Plain Domain is very shallow and does not show any explicit signatures of bank line migration at present. It indicates presence of an incised thalweg in the bedrock lying at shallow depths below the alluvium. Such river entrenchment is suggestive of terrain rejuvenation and adjustment of base level (Thornbury 1969; Selby 1985).

THE PLATEAU DOMAIN

It is a segment of the uplands extending from near the central part of the basin to its headwaters in the southwest (Fig.27). It mostly defines the narrowest part of the basin depicting multitier terraced plateau configuration. The Domain is by and large carved out of Shillong Group of rocks except in the northwestern portion where it is on the Gneissic Complex. Its general elevation varies from 800m to > 1900m above m.s.l., increasing in southwest direction. The basin profiles (Fig.14 & 16) reveal the presence of cascading multilevel terraced plateau surfaces suggesting the presence of polycyclic peneplanation events. A number of lineaments cut through the basin (Fig. 7) along which segments of the Shillong Massif have suffered differential vertical movements, inducing rejuvenation to the fluvial cycles. Signatures of such rejuvenation are remarkably noticed over the erosional surfaces in the form of microrelief features like micro scarps - terracettes, gullies, rills and structural adaptation of channel segments. Due to the differential movements, the present elevations of the various erosional surfaces corresponding to the plateau terraces do not reflect the original heights of the operating erosional process but, reveal the elevations above m.s.l. of the rejuvenated surfaces. As a result, these peneplanation surfaces have superimposed imprints of long linear entrenched valleys and depict high incidences of misfit streams or development of low order stream valleys disproportionate to their discharge and gradients. The Plateau Domain is divisible into four sub Domains (Fig.27) based on degree of incision and elevation differences, viz.,

(a) Deeply Dissected Plateau (DDP2)
(b) Moderately Dissected Plateau (MDP2)
(c) Least Dissected Plateau (LDP2)
(d) Highly Dissected Plateau (HDP1)

DEEPLY DISSECTED PLATEAU (DDP2)

It is carved out of the Shillong Group of rocks lying to the east of Highly Dissected Plateau sub Domain. The general elevation of the sub Domain varies from 800m to 1200m above m.s.l. It is flanked in the north by Nongpoh Pluton and in the south by the Kyrdem Pluton. In the vicinity of these Plutons the Shillong Group of rocks have undergone thermal metamorphism and metasomatic alterations due to high influx of potash. These altered rocks are highly prone to weathering, resulting in their rapid erosion. As a result the sub Domain has suffered higher denudation and the multilevel terraced feature of the plateau is largely obliterated. However, the existence of flat topped ridges and spurs still depict discernible accordance of summit.

The polycyclic fluvial processes and attendant drainage system has subdued the topography but, the rapid downcutting due to repeated rejuvenation has produced localised ridges adjacent to prominent drainage line.

A large intermontane terrace filled valley is associated with the Umiam segment passing through the sub Domain between component basins 17 and 20, north of Tarsa. This localised shallow depression is an anomalous valley occupying elevations from 780m to 760m above m.s.l., indicating accelerated erosion locally. At the same time, the Umiam in this part, is segmented into sinuous as well as straight segments and is entrenched into the bedrock.Such entrenchment of river courses is suggestive of alteration of baselevel and or rejuvenation of terrain (Morisawa 1968; Thornbury 1969; Cloves and Peter 1982; Morisawa 1985; Selby 1985). Such alluvial fills and local meanders are fluvial anomalies, which are the positive indicators of Active Tectonics (DeBlieux 1951; Lattman 1959; Deblieux 1962).

MODERATELY DISSECTED PLATEAU (MDP2)

It forms the narrowest portion of the basin and is confined towards the southwestern part of the area only. The sub Domain is carved out of Shillong Group and characteristically depicts multilevel terraced plateau configuration. The terrain has large segments of rock terraces usually with a veneer of regolith and soil, with elevation varying between 1000m and 1800m above m.s.l. The general elevation increases southwestwards. The sub Domain has long continuous leveled skyline as well as wide rolling rock terraces and multilevel benches (Plate-12). Due to vertical block movements along lineaments the terraced plateau has assumed cascading landscape.

It has conspicuously the most diverse imprints of fluvial as well as glacio-fluvial processes. Overprinting of multiple cycles of erosion are very well seen in this sub Domain

(Plate–12) : Multilevel structural benches, note the microscarps and, large scale deforestation.

(Plate–13) : Moderately dissected plateau, note leveled skyline and deforested patches due to jhumming.

along the Umiam segment from near the Umiam lake to near Tarsa (Fig.27). The rejuvenation of the terrain has left its signatures in the form of micro relief features like truncation of rock terraces and Palaeolandslide-debris deposits towards the Umiam valley slopes. By far this sub Domain has the maximum development of various landform, viz.,

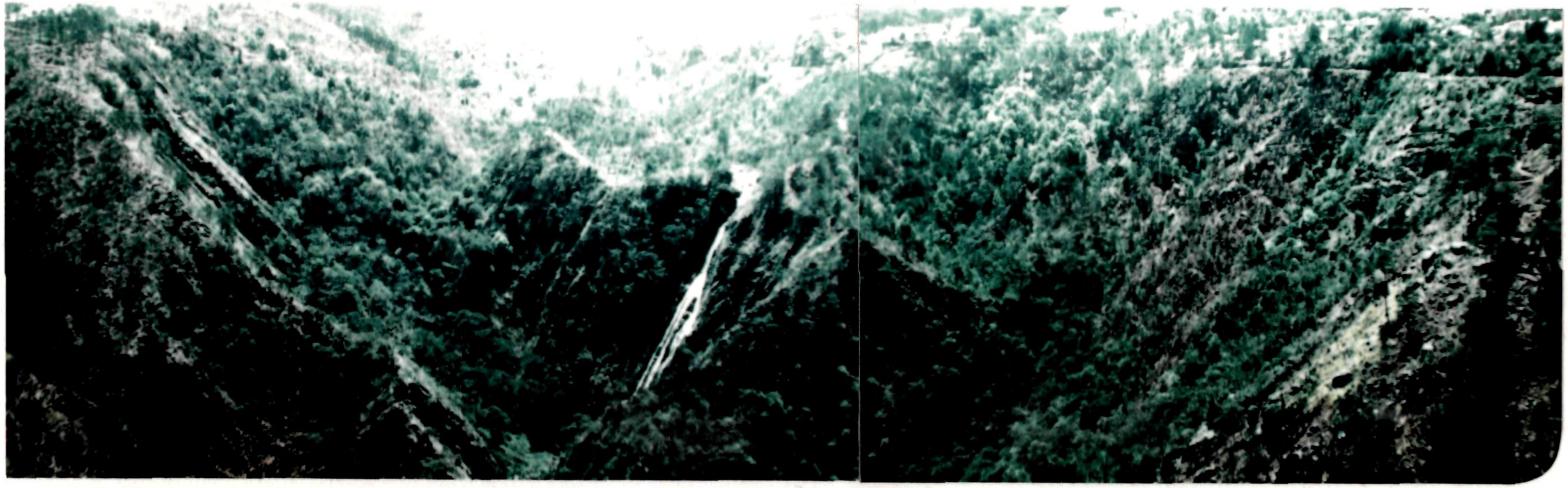
(a) **Linear Structural Ridges** : These are narrow elongated ridges aligned NE-SW in conformity to the trend of the Shillong Group. These are mainly confined along the left bank of Umiam however, southeast of Umiam lake, the right bank also has these ridges, rarely. Such ridges have formed by differential weathering - erosion due to variation in rock competency. The harder rock units like quartzite and the Khasi Greenstone stands out during differential erosion. Moreover the Active Tectonics (Gregory and Schumm 1987) has imposed accelerated down cutting and slope retreat in structurally adapted streams, enhancing linearity of spurs and ridges.

(b) **Plateau Relicts** : These are small irregular remnants of high level plateau terraces. It represents an older, uplifted peneplained surface (Plate-13). The post Jurassic uplift of the peneplain rejuvenated the terrain and a new set of terrain characters have developed on it due to polycyclic fluvial and fluvio-glacial processes. Some of the Palaeo characters of the peneplanations are still persisting, like the "rolling topography," "misfit streams" and "micro-scarps".

The rejuvenation of the peneplained surface has changed the baselevel of streams, resulting in vigorous downcutting and headward erosion (Plate-14), and due to spurts of subsequent block uplifts, the initial peneplain has suffered extensive denudation. The resultant scenario is a dissected plateau with relicts of plateau terraces. These "Relicts" are restricted towards the headwaters of Umiam and would disappear in course of time with advancement of headward erosion and branching of stream network. Such Relict Plateau occurs at different levels or with differing absolute relief. The varying levels are due to reactivation of subsurface fractures along which differential uplift has taken place. Such reactivation is also reflected by structural adaptation of channel networks to lineaments (Fig. 7).

(c) **Umiam Lake** : The lake has a spread of 10.0sq.km when full, submerging an area, southwest of Barapani upto 980m contour level. It is formed by the construction of a 73.2m high and 195m long concrete dam across Umiam river near Barapani (Plate - 1). The northeastern limit of the lake is re-stricted by two dikes. The main dike, located north of the dam, is an earthdam 37.2m high and 463.4m long with NH-40 passing over it. The second dike is also an earthdam 17.4m high and 167.7m long over which the UCC college road passes.

The lake is aligned in NE-SW direction and occupies a spectacular linear depression, north of Shillong. It has irregular boundary depending upon the 980m contour



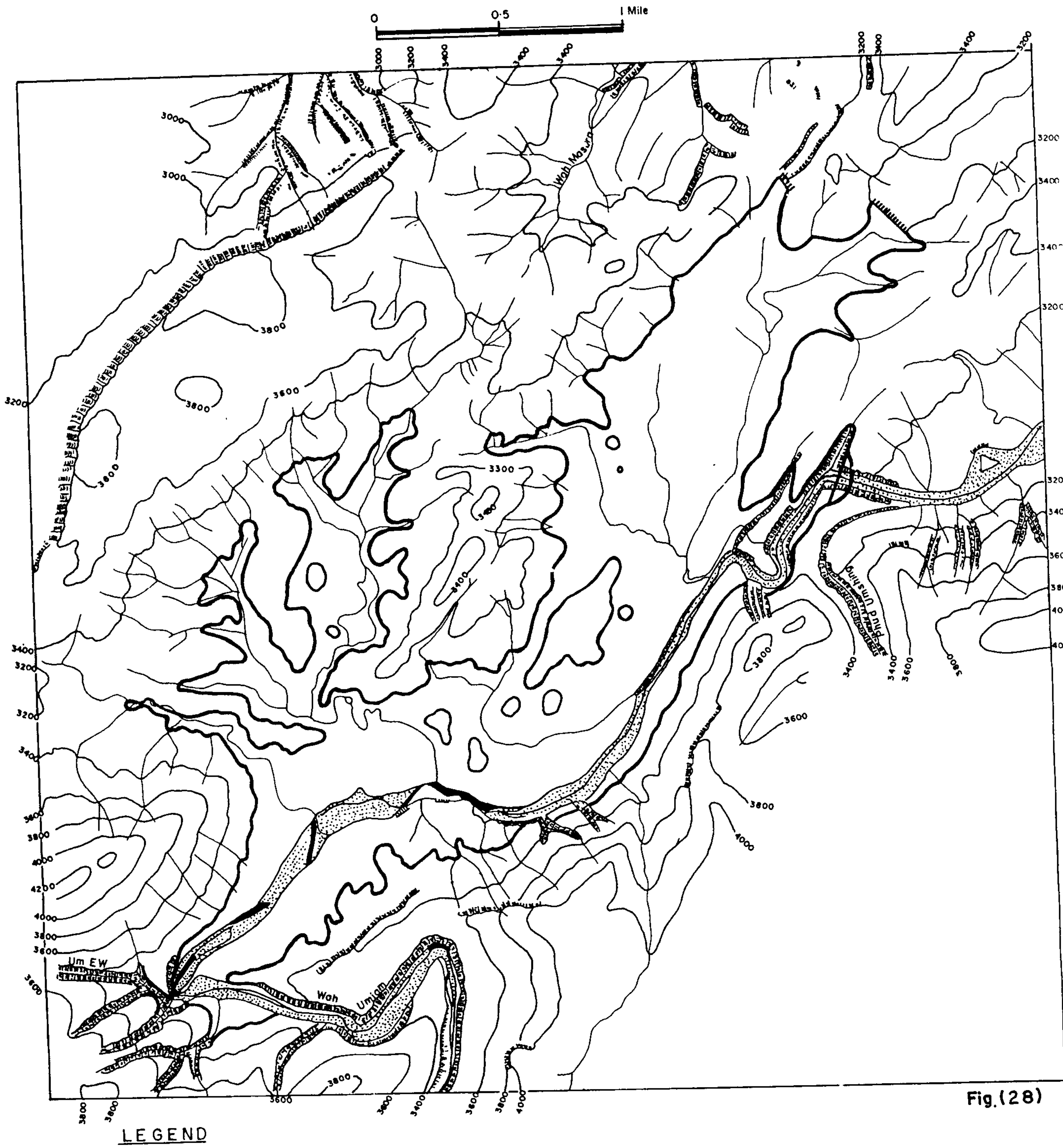
(Plate–14) :-Impersistent gorges along channel segments. Note the leveled skyline of plateau relict and, an active patch of rockfall on the steep slope.

configuration. The bottom profile of the lake is also highly irregular due to the rolling nature of the pre-lake topography (Fig.28). The lake shows wide fluctuations in water level during the year. Over a span of 12 years (1977-1988), the highest and lowest water level recorded are 981.70m in October 1983 and 961.91m in April 1986 respectively. The variation in water level *causes emergence and submergence of topographic "rolls" as* islands.

The linear depression occupied by the lake represents the downfaulted block or the Barapani graben block (Agarwal 1989). It is bounded on the southern flank by the Tyrsad - Barapani shear zone and its northern flank is bounded by a concealed complimentary fault passing through the Sumer ridge. In contrast to the southern flank, the northern flank is highly embayed due to numerous upstream inlets along wide stream valleys.

The impounding of Umiam water by a dam across it at Barapani has changed the whole hydrologic factors in the stream regimen. Hydrologic changes due to man's manipulation in stream regimen are quick to appear (Langbein and Leopold 1964; Schumm 1968; Stall and Yang 1970; Ruhe 1971; Gregory et al. 1985). The Umiam inlet segment into the lake has become sluggish because of the backwaters from the lake. Moreover, the lake has become a local baselevel midway in the stream regimen. Its consequences have appeared in the form of channel fill deposits at the inlet

PRE DAM TOPOGRAPHY IN THE LAKE AREA



LEGEND

RESERVOIR LEVEL AT 3200' CONTOUR

ESCARPMENT/GORGE

D DAM

DYKE

Fig.(28)

site. The normal bedload carrying capacity of the stream has decreased in the lake section of Umiam.

(d) **Glacio-Fluvial Valleys** : These are narrow elongated NE-SW trending valleys over the Shillong Group of rocks, essentially confined downstream of Umiam Lake. They remarkably depict "u-shaped" smooth cross profiles, and are disproportionate to the discharge and gradient of streams flowing through them. These elongated smooth valleys are the vestiges of late Pleistocene glacial signatures in the basin which is undergoing active modification by present fluvial processes. The valley sides are gullied and rilled by the present expanding channel networks, marking the micro-relief indentations in the basin. Relicts of these valleys are traceable upto west of Tarsa. These signatures indicate presence of valley glaciers during Pleistocene in this part of the Indian subcontinent as south as $24^{o}45'$N latitude.

(e) **Escarpments** : These are scattered in the south-western part of the sub Domain. Their length varies from 500m to about 1200m approximately and are confined within the Shillong Group. Two types of escarpments are identified viz., one associated with steep slopes giving rise to cuesta and the other type is structurally controlled possibly related to faults. They have alignments parallel as well as oblique to the formational trends. Those parallel to the strike of Shillong Group are usually associated with cuesta. In general the northern slopes of cuesta are steeper than the southern slopes. But, the oblique escarpments represent manifestation of reactivated faults.

The sumer ridge forming the basin boundary north of Umiam lake is a linear escarpment and is a surface expression of the concealed complementary "northern fault" of the Barapani graben.

(f) **Gorges** : The Umiam segment between source to Lake has spectacular gorge section incised in Shillong Group of rocks. The gorge coincides with the southwestern segment of Tyrsad - Barapani Shear Zone. The fractured rocks and vertical to subvertical dips along the shear zone have made the rocks prone to enhanced physical weathering and rapid downcutting as well as lateral erosion by the Umiam channel. The river has cut more than 400m deep gorge in its source area. Significantly this segment of Umiam has steep gradient,very clearly evident in its longitudinal profile (Figs.25a & 25b).

The stupendous downcutting of more than 400m in hard rocks is not only induced by the shear zone alone but, by pulses of rejuvenation along the reactivated lineaments, which is abundantly evident by the presence of truncated spurs and multilevel ridge or ledge shoulders along the slopes of Umiam gorge.

Minor impersistent gorge sections aligned parallel as well as oblique to the trends of Shillong Group are quite common, between Nongthliew and Barmarjong. These impersistent gorges are usually associated with steep slopes along channel segments (Plate-14), a product of minor reactivated faults. However, these impersistent gorges are not depictable in the Geomorphic map due to scale constraint.

(g) **Paired Terraces** : These upland terraces occur as impersistent Quaternary deposits along both banks of Umiam mostly confined between 980m and 760m above m.s.l. These high level terraces are by and large seen along the periphery of Umiam lake and downstream of it upto west of Tarsa. Broadly the terraces can be differentiated into two types. The older compact lateritic sediments flanking the Umiam lake represent the early Pleistocene terraces (Plate - 5). It is unconformably overlain by the younger friable grey coloured sediments with colluvial aprons representing the Holocene terraces. By and large the older lateritic terrace are best exposed around the lake only, but, downstream, these are not seen. The terraces around the lake are undergoing gully erosion resulting in dissection due to which the lake forms "creek" like inlets into the terraces.

The base of the older terrace is not seen due to submergence by the lake water but, its exposed thickness varies from 15m to 20m. The Umiam valley downstream of the dam from near its confluence with Phud Umshing has three Holocene terraces on both banks.

The paired terraces are generally taken as an indicator of sudden rejuvenation (Howard et al. 1968). The oldest terrace (T3) is about 18m above the present river bed and is about 7m to 8m thick comprising coarse sands with minor pebbles. The second terrace (T2) is about 10m above the river bed and is about 5m thick. It comprises very coarse sand, gravels, pebbles and cobbles of Khasi Greenstone mostly and subordinate carbon phyllite - phyllitic quartzite etc. The general size of the pebbles/cobbles vary from 2cm to 10cm. However, rare boulders of Khasi Greenstone upto 30cm across are also seen in this terrace. The pebbles - cobbles and boulders are well rounded. Since the provenance of these clasts is not far from depositional sites, the well rounded forms indicate their polycyclic nature. The youngest terrace (T1) is about 5m above the present river bed and is about 5m thick. It is composed of highly assorted aggregate of Khasi Greenstone boulders with negligible sands. But, locally thin patches and layers of fine to coarse sand and gravel beds occur as shoe string deposits. Such an agglomeration indicate wide fluctuations in hydrodynamic conditions.

The present river bed downstream of the dam shows large accumulation of boulders, gravels, sands as channel lag deposits - point bars. After the construction of dam, Umiam hardly carries any bedload into this part of the valley particularly from near its confluence with Phud Umshing. The Umiam water from the lake is diverted to the adjoining Umtru basin for hydroelectric project. The present channel deposits represent the prelake accretions. At present downstream of the dam the discharge of Umiam is almost negligible except that contributed by the downstream tributaries. Thus the impact of man's manipulation (Hart 1986) of river is evidently seen in this part of the valley. Morisawa (1985) has documented similar fluvial changes from Vertison mountains of Greece. Gregory et al. (1985) have reported similar changes from Wales and England.

The nature of the above paired terraces indicate wide fluctuations in the hydrodynamic conditions of the Umiam. The oldest terrace (T3) reveals moderate energy environment representing stabilised provenance. Subsequent terraces indicate higher energy conditions and high influx of large size boulders. This high energy changes reflect changes in watershed geometry due to block movements along reactivated lineaments.

LEAST DISSECTED PLATEAU (LDP2)

It has limited distribution and is confined towards the southwestern part of the basin, bordering Mylliem Pluton. The sub Domain is carved out of Shillong Group of rocks and support highest urban growth in whole Meghalaya. The Shillong Agglomeration comprising 6 townships with a population of 2,22,773 (Anon 1992) is sprawled over its rolling to gentle leveled plateau terraced segments.

The general elevation of the sub Domain varies from

1400m in the north to over 1900m above m.s.l. in the south. Its northern limit is defined by Umiam gorge as well as the sharp break in slope at its boundary with the moderately Dissected Plateau. Its southern limit is the basin boundary segment defined by the highest summits of the Shillong Massif.

In general the sub Domain has roughly eastwest trending structural rock terraces occurring at 1400m, 1500m and 1700m contour levels (c.f. Fig.3). It is conspicuous by low development of drainage network. Due to rolling topography the existing drainage is sluggish. However, steep gradients are present locally where channel segments coincides with lineaments. A number of springs are located in the terraced plateau wherever the ground water charged fracture zones have been exposed along slopes. By far the plateau terrace of 1500m contour level has the highest incidences of springs and shallow dug wells. The Ward Lake and Fruit Garden Lake located in component basin no.5 (Fig.24) are situated over the 1500m level terrace and receives the water from the fracture zones of the rocks. Similarly Malsi Lake (Fig.24) is located in component basin no.3 and is situated on the 1700m level terrace. Significantly the 1700m terrace has evidences of late Pleistocene lakes over it.

These plateau terraces are the peneplained surfaces undergoing present fluvial operations. As a result wide pseudo flood plain deposits are locally formed by meandering streams when flowing over leveled rock terraces.

HIGHLY DISSECTED PLATEAU (HDP1)

It is confined to the southwestern corner of the central portion of the basin, comprising the Gneissic Complex. It is highly dissected terrain with elevation varying between 800m and 1000m above m.s.l. The sub Domain has low relief and subdued topography depicting "Knobs" or isolated spurs with leveled skyline. Its plateau nature appears to have been obliterated when viewed in plan or vertically. But, in perspective view or when viewed tangentially, the plateau nature is clearly visible by the accordance of summits and a smooth profile at the horizon.

The contact between the Gneissic Complex and the overlying Shillong Group marks an unconformity. It implies presence of a erosional surface at the base of Shillong Group. The denudation of Shillong Group has exposed this Proterozoic erosional surface and exhumed the old pre-Proterozoic topography.

The knoby and subdued physiography is the result of superimposition of a fluvial cycle over the already peneplained pre-Proterozoic exhumed topography. The Shillong Massif has attained its present elevation only after Jurassic, with reference to the present sea level. If the post Jurassic uplift (600m-1800m) of the Shillong Massif is eliminated, its pre-Jurassic peneplanation surfaces remarkably "match" with the level of contiguous coastal Orissa and Chota Nagpur peneplanation surfaces. This "palaeo reconstruction" therefore indicates that the exhumed erosional surfaces over the Shillong Massif correspond to the Precambrian peneplained surfaces of the Indian Peninsular Shield tract.

THE HILL DOMAIN

It is part of the upland physiography which has due to continuing denudation lost its typical plateau identity. However, the accordance of summits is still persisting indicating it to be part of the plateau only, which has suffered extensive erosion. Such features are clearly borne out in the longitudinal as well transverse profiles of the basin (Figs.14 & 16). The domain extends from near the terminal part to the central part of the basin. Small crescentric strips of it are also present along the southeastern flank of this basin, particularly southwest of Tarsa and Malsi Lake.

The domain has developed on the Gneissic Complex, the Shillong Group and the Granitoid Plutons. However, the Granitoid terrain depicts the maximum development of this domain with distinct domal expressions. Its general elevation varies from 100m in the northeast to 800m above m.s.l. in the southwest, indicating a general unloading of topography towards northeast.

It remarkably possess highly irregular and subdued topography with residual hills and knobs etc. in contrast to the Plateau Domain. This difference is due to the overprinting of repeated fluvial cycles on the exhumed rejuvenated erosional surfaces. The domain has shallow incised valleys except, locally, where the valley entrenchment coincides with reactivated lineaments. Signatures of Neotectonic movements or Active Tectonics are apparent in the domain in the form of microrelief, truncation of spurs and Quaternary depositional surfaces (terraces).

Due to stripping of successive older supracrustals (Cretaceous-Tertiary; Permo-Carboniferous and Proterozoic), the exhumed topography has been lowered down to present level, retaining the original multitier peneplained topography.

Broadly the Hill Domain is divisible into two sub Domains, the Denudational High Hills and the Denudational Low Hills, based on degree of denudation and elevation differences, viz.,

(i) Denudational High Hills (DHH3)
(iia) Denudational Low Hills (DLH3)
(iib) Denudational Low Hills (DLH2)
(iic) Denudational Low Hills (DLH1)

The Denudational Low Hills are separated into three types depicting development over three different country rocks.

DENUDATIONAL HIGH HILLS (DHH3)

It is carved out on the Proterozoic Granitoid defining the Nongpoh Pluton. The sub Domain stretches from the central part of the basin to near the terminal part around Amjonggaon. The general elevation within the sub Domain increases from 100m in the northeast near Amjonggaon to 1000m above m.s.l. in the central part of the basin.

The Plutons are traversed by criss-cross fracture system having expressions as impersistent lineaments which have controlled the erosional pattern to a large extent.

The ridge - valley - hills and intermontane valleys have curvilinear trends, a manifestation of the warped peripheral country rocks around the diapiric and magmatic centres as well as the ghost gneissosity of the parent Gneissic Complex. The topographic "highs" in general, mark the magmatic centres and, the structural adaptation of streams reveal the traces of folds and lineaments (Fig. 7).

The polycyclic erosion and rejuvenation have produced following landforms.

(a) **Hummocky Ridges** : These are linear low ridges, with saddles in between segmenting it into Hummocks. These ridges in general have a relief of about 100m indicating low dissection of the terrain - a consequence of younger (Quaternary) superimposed fluvial cycle over the rejuvenated peneplained terrain. The Hummocky ridges are distinctly aligned in conformity to the fold traces and warped ghost gneissosity of the country rocks.

(b) **Hummocks** : These are isolated, irregular scattered mounds and hills, a product of continuing lateral erosion of topographic "highs" associated with the acid magmatic centres. These hummocks are bouldery due to dislodging of blocks along joints and fractures. The hummocks though domal in appearance lack the "baldness" so typical of central and southern Indian Plutons.

(c) **Intermontane Valleys** : It is a narrow valley at the interface of Denudational Low Hills on Shillong Group (DLH2) and Denudational High Hills on Nongpoh Pluton (DLH3), formed by Um Swat river in component basin no. 26. It owes its existence to the intersecting lineaments and possible subsurface alkaline - mafic - ultramafic - carbonatite intrusives.

(d) **Monadnocks** : These are sharply defined residual hills jutting out 80m above the Alluvial Plain Domain near Amjonggaon. Similar residual granitoid hills in arid region are known as inselbergs (Twidale 1981). These monadnocks lie at the embayed interface of the Alluvial Plain and the Hill Domains. These residual hills and knobs are the surviving resistant rocks, isolated by embayments cut by the Quaternary fluvial cycles. In due course these residual hills would wear out unless the ongoing fluvial cycle is interrupted by vertical (tectonic) movements. Thus the gradual northward unloading of topography is advancing the alluvial plains into the Hill Domain through these embayed sutures.

DENUDATIONAL LOW HILLS

This sub Domain is carved out of the Gneissic Complex, Shillong Group and the Granitoid Plutons.

The sub Domain **(DLH1)** over the Gneissic Complex is confined towards the northwestern fringe of the Denudational High Hill sub Domain (DHH3). Its development has been controlled by the distribution of the Gneissic Complex within the basin, and its elevation varies from 200m to 600m above m.s.l. The sub Domain has characteristically low hills and ridges with flat tops.

The sub Domain **(DLH3)** is confined over the northwestern extremities of the Mylliem and Kyrdem Plutons, occurring as narrow strips only in the basin near Marbisu and Tarsa. Its distribution is restricted by the extent of these two Plutons in the basin. The elevation of the Domain over the Mylliem Pluton varies from 1500m to 1800m above m.s.l. and over the Kyrdem Pluton varies from 800m to 1100m above m.s.l. The sub Domain is characterised by hummocky low hills with exfoliated and polished large granitoid blocks. Due to criss-cross lineaments cutting through the basin, deep linear valleys have been incised locally indicating impact of reactivation of lineaments on erosion.

The sub Domain **(DLH2)** developed over the Shillong Group, is confined towards the terminal part of the basin, bordering the DHH3 sub Domain. Its general elevation varies from 100m in the northeast to 800m above m.s.l. in the southwest. In contrast to the sub Domain over Plutons (DHH3 & DLH3), the sub Domain **(DLH2)** over the Shillong Group depicts linear narrow and sharp ridge - valley system indicating a pronounced structural control of landforms in conformity to the trends of the Shillong Group and fold traces within it. Noticeably the linearity is prominent and topography rugged in vicinity of the Tyrsad - Barapani shear zone passing through the sub Domain (c.f. Fig.7). However, away from the shear zone towards south, the ridges become wide and flat topped as the dips of the formations also flatten out.

The geomorphic characters of the basin reveal presence of various geomorphic risks like gorges, escarpments, neotectonic signatures, swamps, flood prone areas, bank line oscillations etc. These geomorphic risks cannot be avoided altogether but their recognition would help to adopt suitable precautionary measures during implementation of developmental schemes in the basin.

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CHAPTER - VII

GEOENVIRONMENTAL DEGRADATION: PROCESSES AND MITIGATION

GEOENVIRONMENTAL DEGRADATION : PROCESSES AND MITIGATION

The degradation of environment is basically the onset of different kinds of geohazards in an area. The study of causative factors of degradation and their mitigation is primarily part of geoenvironmental management.

Environmental management is essentially a process of rational utilisation of natural resources and their conservation practices (Vink 1983). It just not ends in recognising the need to protect environment but goes beyond it. It integrates the needs of man's sustenance with his environment. The environmental management considers ecological conservation and natural resource development as environmental and socio-economic problems which cannot be tackled in isolation (Jacobson and Robinson 1990). The need to coordinate and integrate approaches for natural resource management is increasingly being recognised (Downs et al. 1991). The resource utilisation always have multiple objectives with conflicting interests (Wolman 1980). 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 an unified way (Grzybowski and Slocombe 1988). The whole concept of environmental management tends to transform the "predator" man into a "conservator" man (Drake and Hubbard 1990; Slatyer 1991).

The environmental perceptions have changed considerably since United Nation's Conference on Human Environment held in Stockholm in 1972 (Caldwell 1991). The paradigm has shifted from "development only" or "exploitation only" to sustainable development (Kemf 1990; Ghildyal 1991). The concept of sustainable development was spawned in mid 1960's and has become a main feature of UN's development and environment philosophy (Batie 1989 in Jacobson and Robinson 1990).

The emergence of the concept of sustainable development in recent years has brought in general realisation that social perceptions must shift towards ecological compatible and qualitative growth within the limits of ecosystem's carrying capacity. It implies that a regional environment has only limited assimilative and supportive capacities to developmental processes. This forms the pivot around which environmental management must move (Khanna and Saraswat 1990).

The use of biosphere is punctuated with two inescapable facts. The first is that the biosphere and its 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 (Slatyer 1991). Therefore, geoenvironmental characterisation becomes an important component in an environmental management scheme.

The sustainable development must posses both economic and ecologic sustainability (Caldwell 1991). It enforces optimal utilisation of natural resources (Kitabatake 1989; Khanna and

Saraswat 1990; Swaminathan 1991). If at all difficulties arise in optimisation processes, it is because of lack of or limited understanding of the causes and consequences of environmental degradation (Rosenbaum 1991). Therefore, it is the prerequisite of environmental management to have geoenvironmental characterisation 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 geohazards or geomorphic risks and their causative factors in a terrain have to be evaluated for environmental characterisation.

RESOURCE BASE IN THE BASIN

The natural assets in the Umiam basin can be classified into the following categories and their status is discussed below:

(a) Forest Cover
(b) Mineral Potential
(c) Hydroelectric Potential
(d) Ground water Potential
(e) Miscellaneous Economic Potential

Forest Cover

Forests are one of the most valuable and renewable natural resources which need greater attention specially due to increased population pressure in recent times. Forests, though, do not contribute in the major portion of the GDP or employment, but, form the main component of the life supporting system in the biosphere. Forests protect and enrich the soil mantle by reducing soil erosion and nutrient loss. They also protect hydrological systems or watersheds and regulate stream flow, provide valuable environmental services and add to the agricultural economy. The forest based industries play an important role in the economic development of a region. The symbiotic relationship between rural people and their natural surroundings from which they draw sustenance is the central theme of the newly emerging concept of natural resource management (Anon 1994; Mukherjee and Sharma 1994; Rawat 1994).

In the present study, forest refers to all areas with "tree canopy" in the basin including areas under social forestry, avenue plantation and areas under various afforestation schemes but, excludes orchards and plantations. In the whole of north-eastern part of India, much of the forests are owned by public or community organisations. The nodal agencies responsible for governing forest in the country have little say in the management of forest in this part of the country. The classification of forest in Meghalaya is given in Table (54).

TABLE-54

Classification of Meghalaya Forests (Gupta et al. 1986)

Sl. No.	Present Type Status	Approximate area	Ownership
1.	Reserve Forest	821sq.km	Owned and managed by State Government.
2.	Unclassified State Forest	7417sq.km	Owned and managed by District Council.
3.	Protected Forest	179sq.km	Managed by District Council or State Government.

4.	**Raid Forest**	768sq.km	Owned and managed by Raids.
5.	**Village Forest**	25.90sq.km	Owned and managed by Village community.
6.	**Private Forest**	348sq.km	Owned and managed by Syiem, Lyngdoh and Sardars etc.
	Total	**9558.9sq.km**	

The total area of the state is 22,429sq.km in which 42.62% area is under forest cover. However, the norm for hill areas suggested by the Indian forest policy is 60% forest cover (Thapar 1975).

The status of forest covered area in the basin as per 1964-68 database is shown in Fig. (30). The basin has 889.20sq.km of forest cover in total basin area of 1429.510sq.km which is 62.20% of the total area and conforms to the statistical norm for the hill area in the country. In order to evaluate the changes in the status of forest cover over a long period of time, another forest cover map was prepared with 1910-1921 database (Fig. 29). It indicates a forest cover of 861.759sq.km in the basin accounting 60.284% of the total basin area which also conforms to the all India norms. However, this statistical figure does not reveal the actual changes undergone in the forest cover. A comparison of the Fig.(29) and Fig.(30) depicts significant changes in the distribution of forest cover in the basin. It is worth noting that over a period of about 50 years, although, the percentage cover of forest has not altered significantly but, the

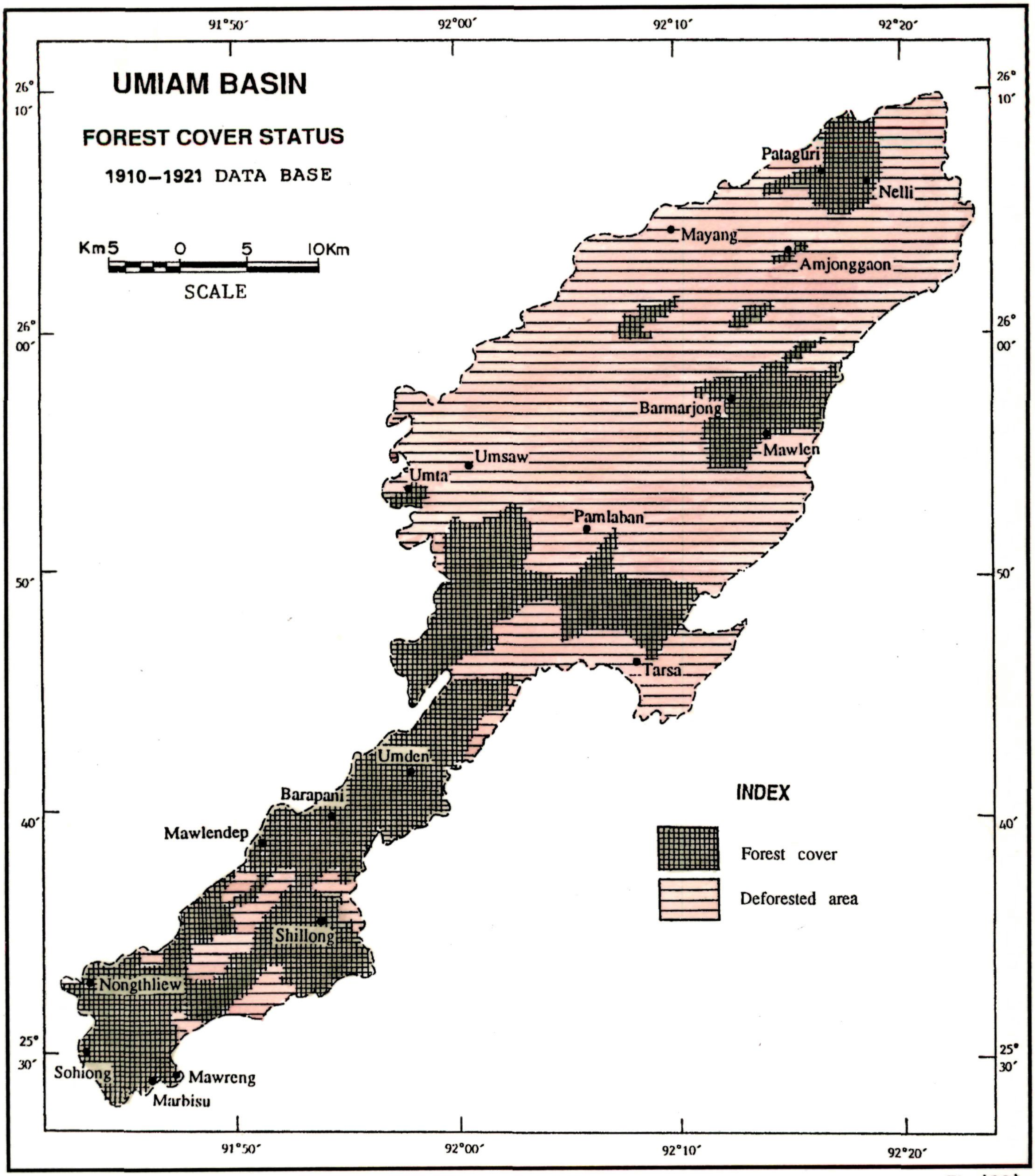
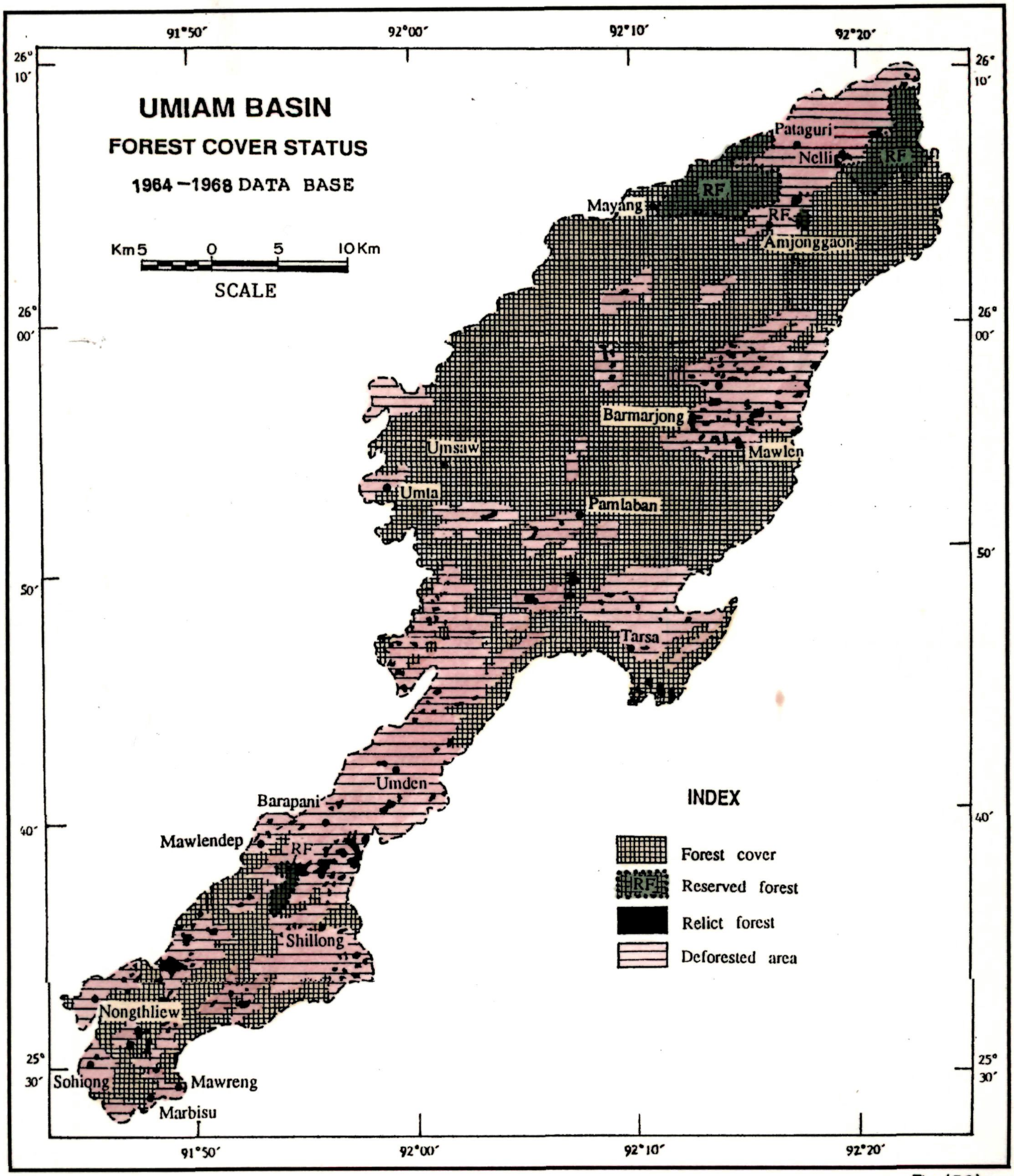

UMIAM BASIN
FOREST COVER STATUS
1910–1921 DATA BASE
Km5 0 5 10Km
SCALE
INDEX
Forest cover
Deforested area
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′
Pataguri
Nelli
Mayang
Amjonggaon
Barmarjong
Mawlen
Umsaw
Umta
Pamlaban
Tarsa
Umden
Barapani
Mawlendep
Shillong
Nongthliew
Sohiong
Mawreng
Marbisu

Fig. (29)


UMIAM BASIN
FOREST COVER STATUS
1964 –1968 DATA BASE
Km 5 0 5 10 Km
SCALE
INDEX
Forest cover
Reserved forest
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Deforested area
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Pataguri
Nelli
Mayang
Amjonggaon
Barmarjong
Mawlen
Umsaw
Umla
Pamlaban
Tarsa
Umden
Barapani
Mawlendep
Shillong
Nongthliew
Sohiong
Mawreng
Marbisu
91°50′
92°00′
92°10′
92°20′
26° 10′
26° 00′
50′
40′
25° 30′

Fig.(30)

distribution has changed drastically with respect to 1910-1921 database as base year. It is seen that the forest cover around Shillong township and Umiam lake has shrunk considerably due to urban growth and manifold developmental activities. Though during the 50 years span, the forest cover has not changed much but, what is alarming is the "health" of the forest. Selected traverses taken in the forest cover patches revealed that the forest have been under continuing depredation and are being over exploited mainly for logging and timber operations. Consequently, the primary forest has almost disappeared from the basin. As a result, much of the forest is 30-35 yrs. old except where the forest have been protected. In these forests, scattered patches with very thin canopy cover have also been identified which indicates ongoing deforestation operations. Such patches have been termed as "relict forest" (Fig.30) and vary in size from 0.008sq.km to 2.63sq.km.

Broadly, the canopy cover in the basin has been identified as coniferous forests, broad leaved forests and bamboo forests depending upon altitude. In all the altitudinal zones, there are rare incidences of existence of mature trees i.e. over 60 years. However, they are only seen in protected canopy cover areas. Canopy cover older than 100 years are recorded in the urban areas particularly in and around Shillong, in selective patches specially in cantonment area and around settlements where they enjoy public protection. Similarly, the terminal part of the basin falling in Karbi Anglong and Nowgong districts of Assam has a better scenario of canopy cover due to better operation of forest governing system.

The total reserve forest in the basin is 43.86sq.km (3.07% of the total basin area) distributed in East Khasi Hills, Karbi Anglong and Nowgong districts of Meghalaya and Assam. The break up of the reserve forest in the basin is given below.

DISTRIBUTION OF RESERVE FOREST IN THE BASIN

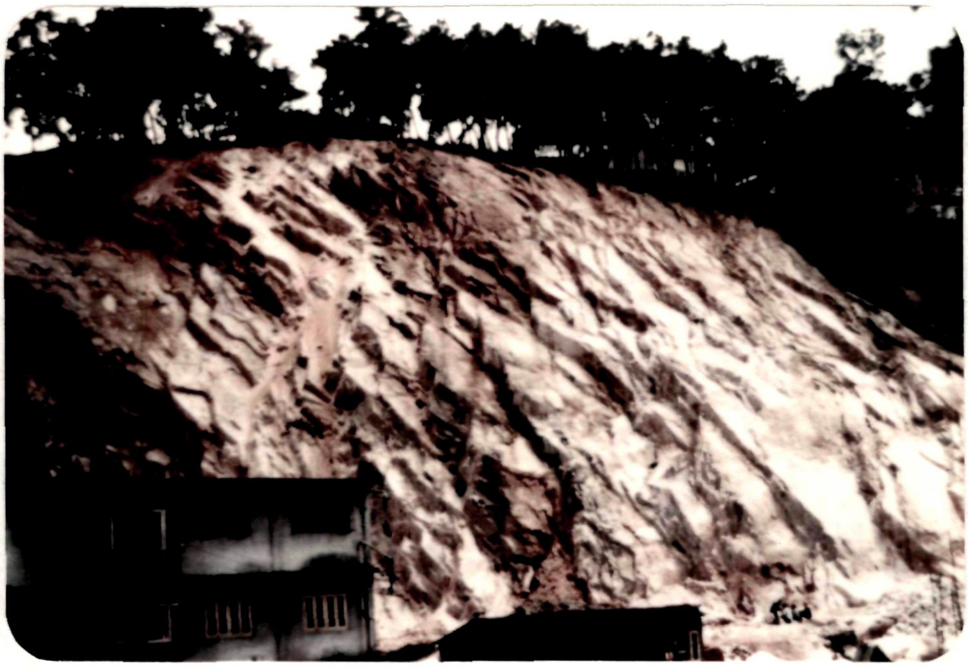
Name of Reserve Forest	Area sq.km	Area %	Area c.um.%	% of Basin Area	Remarks
1. **MEGHALAYA**					
(i) East Khasi Hills District					1. Total basin area : 1429.510sq.km
(a) Riat Khawan Reserve Forest	3.074	7.01	7.01	0.215	2. Total Forest area in the basin : 889.20 sq.km 3. Total Reserve
2. **ASSAM**					Forest in the basin : 43.857 sq.km
(i) Nowgong District					
(a) Sonaikuchi Reserve Forest	15.948	36.36	43.37	1.116	4. Total Reserve Forest falling
(b) Auguri Reserve Forest	0.442	1.01	44.38	0.031	in Meghalaya : 3.074sq.km
(c) Kholahat Reserve Forest (part)	9.295	21.19	65.57	0.650	5. Total Reserve Forest falling in Assam : 40.783sq.km.
(ii) Karbi Anglong District					
(a) Kholahat Reserve Forest (part)	15.098	34.43	100.0	1.056	
TOTAL	**43.857**	**100.0**		**3.068**	

The forest cover in the basin is rich in diverse commercially important trees for various industries viz., building, furniture, packing, plywood, pulp-paper etc., and needs to be exploited in a sustained way.

Mineral Potential

At present no mineral deposit worth mentioning is recorded from the basin. However, minor minerals like sand, gravel roadmetal abounds in the form of hard rocks like granitoid and quartzite. Since the trunk stream and its feeder tributaries have high gradient, their beds and banks are poor in sands and gravels, which are essential components in construction activities. Moreover, due to high relief, it is not economically viable to exploit these materials from the river beds and haul it to long distances at construction sites. The requirements of these building materials are being met from the hard rocks exposed in the basin. The weathered friable quartzite supplements the need of river sand (Plate-2). In the terminal part of the basin, the Umiam bed, downstream of Amjonggaon has minor accretions of sand suitable for construction activities. The quartzite wherever hard and compact, Khasi Greenstone and Granitoid are amenable to opencast mining and crushing thus suitable as roadmetal and building materials. A number of road side quarries have cropped up to meet the local demand of building and construction materials (Plate-15).

The Nongpoh Granitoid, homophanous as well as the



(Plate–15) : Quartzite quarry for constructional materials within the Shillong Agglomeration.

(Plate–17) : Deforestation on the ridges. Note recent jhum patch (left corner) with potato cultivation – a source of heavy upland soil erosion.

megacrystic varieties are suitable for dimensional stones (slabs, panels, tiles, blocks etc.). This industry is labour intensive and generates high employment avenues with little financial inputs. The Nongpoh Granitoid Pluton is spread over an area of more than 350sq.km in the basin. A very conservative possible reserves of about 3000 million cu.m of polishable Granitoid is estimated down to a depth of 30m below the ground level. The Granitoid is well connected by NH-40 (Shillong - Guwahati Road) and other arterial road networks. It is highly suitable to initiate small scale mineral based industries in the basin.

Incidence of gold is reported from near Mawphlang, southwest of Marbisu (outside basin boundary) from the Tyrsad-Barapani shear zone passing through the Shillong Group of rocks (Anon 1973; Anon 1974). Since the shear zone passes all along the axial part of the basin cutting through Shillong Group of rocks, its Granitoid proximal parts are conceptually repositories for mineralisation related to acid magmatism and associated remobilisation. Such locales are favourable sites for basemetal sulphides, tin-tungsten, molybdenum and gold. It is worth mentioning that the shear zone in vicinity of the Granitoids does show manifestation of sulphide mineralisation as Pyrite, Galena, Molybdenum, Pyrrhotite disseminations. These "shows" and the gold incidence of Mawphlang gives at least a conceptual geological potentiality for mineralisation in the basin.

Hydroelectric Potential

The hydroelectric project on Umiam River at Barapani is one of the most important developmental scheme in East Khasi Hills. The river has been dammed near Barapani to form the Umiam lake/reservoir in 1965. To impound water in the narrow depression the Umiam River is dammed by constructing a concrete dam, an earth dam and a road dike (Plate-1). The salient features of the hydroelectric project is given below (Anon 1985; 1990).

1. Catchment Area upto Dam	:	221.44sq.km
2. Length of Umiam segment upto Dam	:	24.25km
3. Area of Umiam Lake	:	10.15sq.km
(a) No. of Component Basins upto Dam (Component Basin Nos.1 to 5 and 44 to 52)	:	14nos.
4. Concrete Dam		
(a) Length	:	195m
(b) Height from the Deepest Foundation Level	:	73.2m
5. Main Earth Dam		
(a) Length	:	463.4m
(b) Height from deepest foundation level	:	37.2m
6. Road Dike		
(a) Length	:	167.7m
(b) Height from deepest foundation level	:	17.4m
7. Maximum Water Level of the Lake	:	981.46m
8. Minimum Drawdown Level	:	960.12m
9. Live Storage of the Reservoir	:	141.93m cu.m. (14193 ha.m)
10. Dead storage of the Reservoir	:	39.49m cu.m (3949 ha.m)
11. Installed capacity of Power Generation	:	4x9000kw

The power house is located outside the Umiam basin, near Sumer, at an elevation of 807.7m and is connected by 2057.80m long tunnel to the Umiam lake. The intake of the power house is in the Umiam basin but the "tailrace" water goes to the adjacent Umtru Basin. As a result, only the "head" (about 165m) is utilised for the power generation and the water is diverted into another basin starving the Umiam, downstream of the dam, of its own discharge.

The Umiam river, downstream of the Umiam lake, does not contain enough discharge to support any multipurpose river valley projects or another hydroelectric project. However, there is ample scope for installing micro hydel projects in the Umiam basin utilising the available "head" (relief) in the component basins having sustained discharges. The component basins with potential for microhydel projects are enumerated below.

COMPONENT BASINS WITH MICROHYDEL POTENTIAL

Component Basin Order	Component Basin Nos.	Area (sq.km)	Available Relief (m)	Remarks
1	2	3	4	5
3	70	7.838	377.0	1. The Component Basins Nos.1, 5, 44, 45 and 47 form part of the Umiam lake catchment. Rest of the Component Basins are located down-stream of the lake.
	94	7.144	393.0	
	105	7.025	184.0	
4	1	11.775	461.0	
	44	9.988	420.0	
	45	26.044	549.0	
	47	19.217	696.0	
	61	10.950	415.0	
	80	16.513	269.0	

Component Basin		Area (sq.km)	Available Relief (m)	Remarks
Order	Nos.			
1	2	3	4	5
	91	13.906	435.0	2. Component Basin
	108	16.469	385.0	Nos.1, 5, 19, 23,
	114	14.942	580.0	34, 44, 45, 47, 55, 61, 70, 85 and 91
5	5	46.681	981.0	fall in moderate to
	19	43.088	449.0	high Geohazard areas
	23	36.756	480.0	therefore harnessing
	26	52.113	240.0	them at present
	34	45.733	777.0	would accentuate
	35	51.683	671.0	degradational pro-
	55	22.456	390.0	cesses in the area.
	67	37.938	580.0	
	84	34.413	541.0	3. Since large
	85	23.919	434.0	number of Component
	90	24.292	441.0	Basins have hydel
	100	38.750	715.0	potential the
	104	14.342	240.0	Component Basins located in very low
6	111	115.381	694.0	to low Geohazard areas in the basin need to be exploited only.

In contrast to mega or large scale hydroelectric projects, the microhydel projects would have following advantages in the area.

1. Little or no submergence of land resources
2. Little or no displacement of habitation
3. Low gestation period and easy maintenance
4. Easy installation in remote and underdeveloped areas
5. Low degradation of forest and land resulting in lesser soil erosion
6. No starvation of feeder stream of its own discharge
7. No large scale manipulation in stream regime, no downstream modification in fluvial morphology
8. Condusive for opening frontiers of development and self employment in remote areas

The above advantages of microhydel projects make it ideally environmental friendly developmental activity in the fragile mountainous and remote areas.

Groundwater Potential

As far as groundwater is concerned, the basin area can be divided into two following sectors.

(a) Hard rock sector and,
(b) Terrace sediment sector

Each sector has distinct ground water potentiality and is discussed below.

(a)**Hard Rock Sector :**

Major part of the basin i.e. 1366.147sq.km (95.57%) exposes hard rocks represented by Gneisses, Granitoids and Shillong Group of rocks thus ruling out possibilities of "primary aquifer systems". However, the hard rocks are not devoid of ground water as is often the misconception. The Gneissic terrain in drought prone parts of South India has yielded perennial ground water source in the form of dug wells. The hard rocks as a source of ground water is being gradually appreciated globally.

In the Umiam basin, the ground water in the hard rocks occur in the following two contrasting geological environments :

(i) The Weathered Mantle
(ii) The Deep Fracture System

(i) **The weathered mantle** : It is the top part of the decomposed bedrocks resulting from deep weathering under tropical monsoonic conditions and is a repository of rainwater infiltration. The thickness of this zone varies from 10 to 30m, generally increasing in the topographic depressions. The ground water in this zone occurs in the interstitial spaces of the weathered rock mass (Saha 1988). This zone is extensively developed over all rock types, and forms "pseudo-aquifers". The weathered mantle has large rain water infiltration capacity wherever it is texturally coarse and granular. In general, the depth of waterlevel in this zone varies from 1 to 6m below ground surface and shows seasonal fluctuations as its recharging is a function of rainfall.

The groundwater from this zone can be tapped by open, shallow dug wells and the water is in general, potable except where it is contaminated by drain seepages, poor sanitation and garbage leachates. A number of dug wells have been sunk in the topographic depressions and topographic breaks in and around Laitumkhrah, Mawlai and Polo Ground localities of the Shillong Agglomeration. Interestingly, wherever the weathered zone is abruptly "cut" for road making or building constructions, the water seeps out in trickles and/or as springs. The dug wells have shown yields varying from 5 to 10 cubic metre per day (Saha 1988). The ground water from the springs and the dug wells is slightly acidic with pH varying from 5.4 to 6.8 and has low electric conductivity and total dissolved salts and the water is soft. The maximum total iron content is 0.3 ppm which is well within the permissible limits of Indian Standards (within 1 ppm) and WHO (within 0.3 ppm).

This zone though water bearing, cannot be exploited for sustained yields as it has limited water retention capacity and required hydrostatic potential for transmission. Moreover, rapid urbanisation and deforestation are affecting the water saturation in this zone.

(ii) **The Deep Fracture System** : This is the most important ground water repository in the hard rocks and forms a zone of permanent saturation invariably under confining conditions. The ground water in this zone occurs within the open joints, fractures and fissures. Due to hydrostatic pressure, the water is able to permeate and transmit through microfractures for long distances. Since these fractures and joints are not pervasive or uniformly distributed, the zone of permanent saturation also remains highly localized. These fractures are in fact, zones of "dilations" associated with faults or structural dislocations manifested as lineaments in the basin. Minor springs and small natural ponds seen in and around Shillong Agglomeration are the direct consequences of the ground water saturated "dilation zones". The springs are prominently located in vicinity of drainage lines in Laitumkhrah, New Colony, Malki etc. (Shillong township). Some of the important ponds like Malsi Lake, Fruit Garden Lake and Ward Lake (Fig.24) are also due to seepage from these zones of dilation. The ground water within these fractured rocks extends upto about 90m depth below the ground surface. The bore wells from these zones have yields ranging from 10 to 25 cubic metre per hour. Exceptionally high yield (36 cubic metre per hour) is reported from the NEHU Campus near Umshing (north of Shillong town) drilled down to a depth of 62.30m (Saha 1988). The water quality of the bore wells is compatible with the water quality of the dug wells. However, locally high iron content upto 6 ppm. is also reported. Perhaps the G.I. pipes used in these wells are the main source of higher iron content in the water. Now-a-days, instead of G.I. pipes, P.V.C. pipes are used to check the iron content.

The ground water requirements in the basin are basically to cater the potable "water needs" rather than agricultural or industrial needs. The Shillong Agglomeration with a present population of about 2.25 lakhs (provisional) as per 1991 census faces acute water scarcity inspite of its locations in the high rainfall area with tropical monsoonic climate. The magnitude of the water scarcity can be understood from the Table (55) enumerating the supply and shortfall in the water requirements.

It is seen from the Table (55) that during dry season, there is a shortfall of about 9,600 cubic meter per day. Even during the wet season, the present supply of water is inadequate. The ground water resource if utilised can partly augment the water supply to some extent as can be seen by the few attempts made so far to draw sustainable yields of ground water by deep

TABLE-55

AVAILABILITY AND SHORTFALL IN WATER SUPPLY IN SHILLONG AGGLOMERATION
(after Saha 1988)

Sl.No.	Source	Supply (cu.m per day) Wet season	Dry season	Short fall(cu.m per day) in dry season
1.	Wah Jalynnoh	4050	1800	2250
2.	Wah Risa	2250	1350	900
3.	Madan Laban	1350	675	675
4.	*Wah Dieng Lieng*	900	450	450
5.	Crinoline	1350	675	675
6.	Umjasai	4500	1350	3150
7.	Sericulture Campus	2520	1620	900
8.	Rynjah*	200	103.60	96.40
9.	Nongthymmai*	900	607.50	292.50
10.	Mawlai (Stream)*	1125	1125	Nil
11.	Umpling (Stream)*	900	675	225
12.	Pynthorumkhra*	157.5	157.50	Nil
				9613.90

*Source outside municipal limits

TABLE-56

GROUND WATER YIELDS IN DEEP BORE WELLS OF SHILLONG AGGLOMERATION
(after Saha 1988)

Well No.	Location	Radial distance (km)	Depth drilled (m)	Discharge (cu.m/hr)
1.	NEHU Campus	5.00	62.30	36.00
2.	P & T, Pologround	2.00	67.60	25.20
3.	Pynthorumkhrah	2.00	56.40	18.00
4.	Pynthor Bah	2.00	61.50	16.20
5.	Lalchand Basti	1.50	99.90	18.90
6.	Assembly Hostel	0.50	110.00	12.40
7.	Lady Hydery Park	0.50	90.00	9.90
8.	Stoney Land,Dhanketi	0.00	145.50	2.25
9.	St.Edmund College	0.40	91.80	9.00
10.	Motinagar	0.75	91.80	7.40
11.	New Colony	1.00	99.90	4.50
12.	Mawpat	3.00	152.00	19.00
	TOTAL			178.75

tube wells (Table-56). These deep bore wells have been drilled by the Department of Public Health Engineering, Government of Meghalaya.

The Table (56) reveals a cumulative yield of 178.75 cubic metre/hour which results in about 2100 cubic metre per day of yield drawn on twelve hours per day basis. It is evident from the Table (56) that the yield is highly variable and is not uniform even within a very short radial distance of 2.0km. The best results are from depths ranging from about 56m to 67m. The higher yields are in topographic depressions and linear valleys which invariable are the locii of intersecting lineaments. Nevertheless, the hard rocks in the basin are conducive for ground water exploitation but, with a caution to avoid close spacing of bore holes for checking undesired excessive drawdown.

b) **Terrace sediment Sector :**

This sector in the basin is mainly represented by Pleistocene - Holocene alluvial and colluvial terraces. These terraces are confined as continuous blanket deposits only in the terminal part of the basin occupying 63.363sq.km. (4.43%) area. Minor strips of alluvium - colluvium fringing the ridges on the upland are insignificant as far as ground water is concerned due to their very limited areal and depth wise extent.

The alluvial deposits though spatially account for less than 5% of the basin area, they are however, the largest repository of ground water for the following reasons :

(i) They are continuous blanket deposits contiguous with the vast Brahmaputra Alluvial Plains. The alluvium has high permeability and transmissivity - a prerequisite for good aquifer system.

(ii) Presence of shallow ground water table in the alluvium - about 1 to 5m below ground surface.

(iii) Continuous recharging and replenishment of ground water from shallow water table as well as through the water saturated dilation zones (lineaments) coming down the uplands and transecting the alluvium.

The thickness of the alluvium increases from southwest to northeast gradually. It is less than 10m close to the monadnocks and the flanks of the hills but, increases to over 250m towards the confluence of Umiam with Kopili river.

A few bore wells drilled around Nelli and adjoining Brahmaputra plains have yields varying from 35 to 45 cubic metre per day with a drawdown of 2 to 3m in lean period. Moreover, the water table in this alluvial part of the basin shows seasonal fluctuations of about 2 to 3m only. Hence, the aquifers in this alluvial tract can give sustained yields for longer periods. However, large part of this alluvial tract, 22.576sq.km (35.63%) remains waterlogged - swampy and hosts number of bils (ponds). Thus the daily water requirements of the local population, which is mainly rural in this part of the basin, can be met adequately from the surface water sources only. Therefore, the ground water resource has not been exploited fully here. However, with increasing siltation in the bils and river training for flood control together with encroachment of swampy lands, the surface water sources are gradually turning stagnant and polluted. Therefore much reliance have to be paid in coming years to the ground water resources for which deeper aquifers have to be tapped.

It is abundantly clear that the availability of the ground water resource in the basin is mainly controlled by the geology. Nevertheless both the hard rocks as well as the terrace deposits are repository of ground water resource. If harnessed under ground water management backup, it can meet the present demand deficiency of water and help in prognostic planning for development. It is needless to say that a shift in policy of water management in the basin is required to meet the water demand of the expanding urban as well as rural centres undergoing modernisation.

Miscellaneous Economic Potential

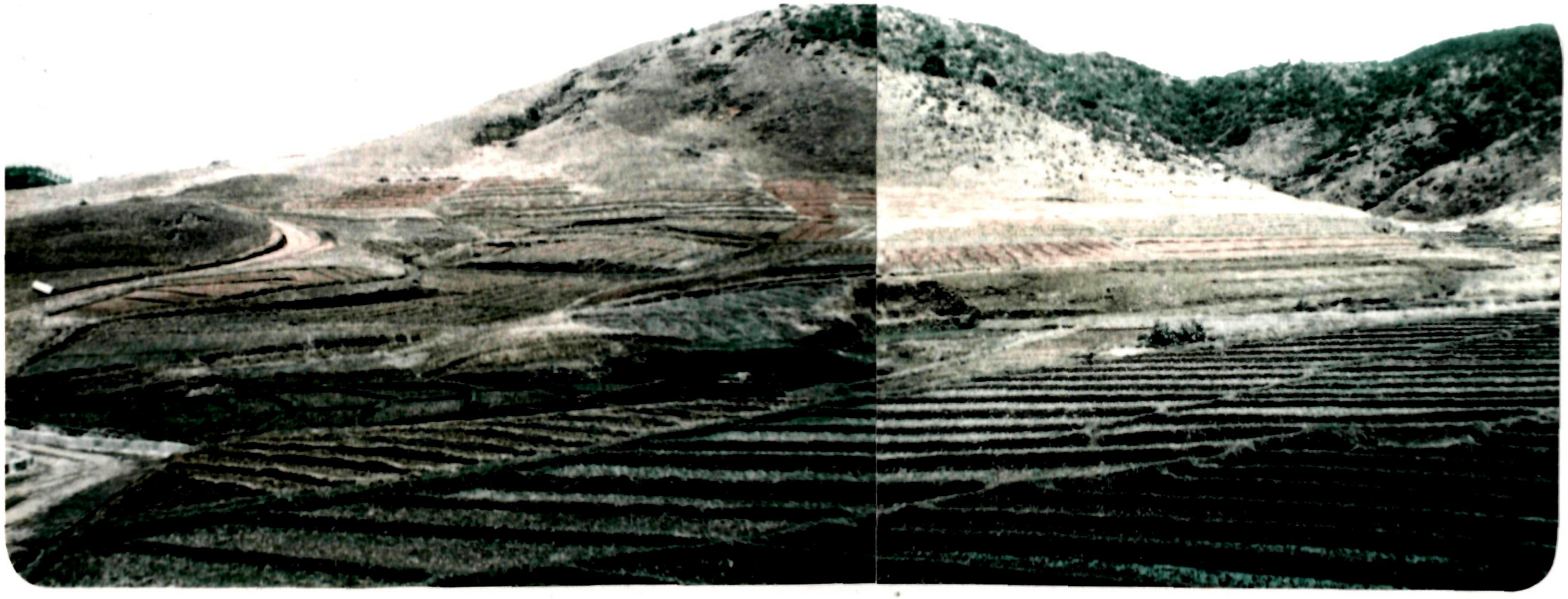
In the basin, all activities which generate marketable produce and/or monetary inflow have been included in this category and broadly involve the following ventures :

a) Industries
b) Agriculture
c) Horticulture
d) Diary Farming
e) Poultry and Livestock
f) Sericulture
g) Apiculture
h) Fisheries
i) Tourism

All of these activities have remained small scale or insignificant ventures or are in nascent stage of development, as far as economic growth in the basin is concerned. The main reason for this slack is remoteness, poor infrastructural facilities, inadequate technical and financial inputs and the socio-politico conditions in the region as a whole. However, the tea industry located in the terminal part of the basin received protection and comparatively better infrastructural facilities in the Assam plains therefore, it could develop into one of the most remunerative economic activity in the basin. At present, it occupies a very insignificant area confining around Nelli over the stabilised terrace plain covering 6.614sq.km (0.463%) in the basin. There is ample scope of expansion of this industry by bringing the low hills, slopes and monadnocks around Nelli - Amjonggaon under tea plantation. Such expansion would not only generate higher employment avenues but would also act as conservation measures on the fragile "palaeolandslide" lobes fringing the hills in the terminal part of the basin. Though tea plantation means deforestation but at the same time, it also means plantation of large "crown trees" within the tea gardens.

Except the tea industry, there is not any worth mentioning industrial unit within the basin. However, a small industrial township has recently been opened downstream of the Umiam lake. A few small industrial units for calcinated lime, bakery, tantalum etc. are already in production stage.

The agriculture, horticulture, diary farming are expanding though with a slow pace, due to prevalent land holding/tenure system, adherence to primitive methods and inadequate technical and financial inputs. In this mountainous tract, there is scarcity of agricultural plain land, as a result, there is little scope for agricultural expansion in the basin. There is a scarcity of agricultural land in the upland part of the basin. Therefore with increase in population, the farmers have started agricultural activities in the intermontane valleys, which have accumulation of fertile top soil washed down the slopes. But, the soil fertility is depleting fast due to continuing jhumming activities and attendant soil erosion (Plate-16). However, this scenario can be reversed by expansion of Horticulture, Diary, Poultry and Livestock activities. Remarkably, the climate and topography is suitable for expanding Horticulture and Diary based industries. These activities generate self employment, require low financial inputs and are environment friendly. As part of integrated rural development, these activities could be interfaced with Poultry - Livestock, Sericulture and Apiculture as well. The structural terraces occupying the elevation between 1500m to 1700m above mean sea level (Fig.3), fringing the Shillong township are ideally suitable for developing large scale "flower-beds" adding to tourist attraction and revenue generation. It would form part of conservation measures to reclaim degraded landscape besides promoting apiculture.



(Plate-16) : Cultivation in headwaters of intermontane valley. Note deforestation on ridge flank and soil wash (brown patches).

There are 33 bils (lakes) and permanent water bodies of varying sizes in the terminal part of the basin (Figs.24 & 27). The bils are scattered over an area of 22.576sq.km occupying the unstabilised terrace plains (Fig.27) and conspicuously form a wetland eco-system (Pearce and Turner 1990). The bils vary in size from 0.005sq.km to 0.736sq.km and covers cumulative area of 2.947sq.km. These bils are neglected and are hardly used for commercial fisheries at present.

As part of flood control measures in Assam Plains, check dams and/or reservoirs are to be constructed in all tributary basins of Brahmaputra river. Such check dams would meet multipurpose objectives - besides regulating peak discharges in the Brahmaputra river during monsoon period, they would provide canal irrigation facilities and captive fisheries as well.

Shillong, the capital of Meghalaya, known as the Scotland of the east is located in the southwestern part of the basin. It is one of the most picturesque centres in the entire northeastern India. The entire landscape around Shillong offers excellent tourist attractions. The magnificent Umiam Lake nestling in a bowl of captivating landscape is fast developing into a tourist resort.

Tourism means monetary inflow, generation of self employment, socio-cultural exchanges, regional cooperation and development. But, due to prevalent socio-politico situations in this part of the country, the tourist potential in the basin has remained unexploited. The infrastructural facilities for encouraging tourist is almost non existent.

The wetland in the terminal part is a multifunctional resource (Pearce and Turner 1990) and the bils or lakes therein form sites of aquatic and semiterrestrial biodiversity. Wetlands are recognised to have enormous capacity to absorb solar energy and are "collectors" of nutrients draining down the uplands. The resulting eutrophication builds "biocides" in aquatic food chain for waterfowls and fishes. (Firouz 1978; Schofield 1978).

The wetland eco-system attracts global protection and conservation under the "International Ramsar Convention, Iran" of 1971 (Caldwell 1991). Thus, the bils in the terminal part of the basin need to be converted into a "wetland park" and bird sanctuary to avoid its transformation into a biological desert by continuing silting and eutrophication. A bird sanctuary in the terminal part of the basin would also promote tourism as it would be directly on the Guwahati-Kaziranga National Park tourist circuit of Assam.

The wetland is approachable from Guwahati by NH-37 and lies close to Jagi Road Railway Station on Guwahati - Dibrugarh broadgauge section of NF Railways. Thus, the basin has ample scope for exploiting its tourist potential by upgrading the infrastructural facilities.

GEOHAZARDS IN THE BASIN :

Geohazards are all environmental "instabilities" including land degradation due to natural as well as man made causative factors. It damages physical, chemical or biological status of a land (Chisholm and Dumsday 1987; Panizza 1987). In its most simple meaning geohazards are like "homeostatic disequilibrium" as per the concept of landscape health (Ferguson 1994).

The geohazard assessment of a terrain includes evaluation of geological, geomorphological, hydrologic, topographic, forest and soil degradational processes. The aim is to identify the environmental "risks" in an area i.e., the vulnerability of the landscape to degradational processes. The information products so obtained are useful in the preparation of Geohazard Zonation Map. Such maps help in reclaiming degraded land resources and finally provide economic suitability data for integrated development and total catchment management (Martin and Lockie 1993; Johnson et al. 1994).

The various geohazards in the basin can be broadly categorised into the following two group.

(i) Terrain Inherited Geohazards
(ii) Man Induced Geohazards

This division is based on the fundamental terrain characteristics and the effects of development processes and "predatory" activities of man.

(i) **Terrain Inherited Geohazards**

The present study carried out in the basin has identified the following Terrain Inherited Geohazards (TIG).

(a) Ambient Soil Erosion
(b) Escarpments
(e) Floods
(f) Gorges
(e) High Dissection
(f) Palaeo-Landslides
(g) Reactivated Lineaments and Seismicity
(h) Steep Slopes
(i) Swamps - Water Logging

The above geohazards are the natural instabilities produced in the basin during its course of evolution and is a continuing process. These instabilities are infact, process - response systems under a set of geomorphic - geodynamic stresses. The various instabilities in the basin are depicted in the different, thematic maps.

It is abundantly clear that all the TIG are not distributed uniformly throughout the basin. The geohazards like escarpments, gorges, high dissection, steep slopes etc. are selectively spread over the Plateau Domain. Their development is controlled by the interaction of exogenetic processes with the lithology and tectonic grain of the basin. The polycyclic erosion and rejuvenation along structural discontinuties (lineaments) have produced localised relief and slope instabilities. The gradual northeast ward unloading of the "stepped topography" has produced the lowlands in the terminal part of the basin. The Kopili-Brahmaputra bankline oscillations and shallow ground water table are the chief architects for the recurring floods and swamps in this lowland.

In contrast, the microseisms and reactivated lineaments are the geodynamic processes of regional scale with manifestations throughout the basin. The causative sources of *these events are "endogenetic". Spatially, these sources are* "interbasinal" as well as "intrabasinal" as they are linked up with the "Global Plate Tectonics" and the tectonic fragmentation of the Shillong Massif (c.f. Chapter II).

An analysis of published earthquake data (Bapat et al. 1983; Sahu et al. 1988; Gupta et al. 1986; Gupta and Singh 1986; Chandra 1992; Chandrasekaran and Das 1992) revealed that though over 98% of the earthquake events of magnitude >3, from historical past (326 BC) to 1990 have epicentres outside the basin but, the tremors do affect the basin area. Earthquakes of magnitude less than 3 (microseisms) are frequently felt within the basin which certainly have localised causative sources, more often than not, related to interbasinal reactivated lineaments that may have extensions outside the basin boundary also.

The basin already has signatures of two devastating earthquakes with magnitude above 8. The earthquake of 12th June, 1897 and 15th August, 1950 with epicentres outside the basin caused large scale landscape modification and triggered large landslides throughout the northeastern India (Oldham 1899).

The identification of neotectonic movements in the basin (c.f. Chapter IV) and its location in the high seismic zone adds to the seismic vulnerability of the basin. It is also evident that the seismic vulnerability of the basin is not limited to the interbasinal epicentres only.

The palaeolandslides are mainly confined at the foot of the ridges bordering pediments and rock platforms. These are lobate shaped debris masses comprising assorted and exotic regolith moved downslope away from the source rocks. The palaeolandslides were triggered during the major earthquakes of 1897 and 1950. These lobate debris flows have invariably formed metastable hill slopes fringing the low lands around Amjonggaon-Nelli. Rare incidences of these are also seen in the uplands particularly at the foot of the spurs in the intermontane valleys (Plate-10).

These palaeolandslide lobes are potential geohazards in the basin. They look passive like any other mound or hillock. But, being located in high rainfall and seismically active area, any undercut in these "fossilised" landslides would destabilise them making them prone to movements. Moreover, these palaeolandslides have their provenance in the upper slopes therefore, all segments of the slopes above the palaeolandslides become vulnerable and hazardous.

The operation of natural geomorphic processes degrade positive relief areas by denudation ultimately unloading the topography through ambient soil erosion which is a very slow process. The whole process of topographic unloading is a part of "circulation of matter" and energy under atmospheric conditions. In the basin, due to geological and hydrological heterogeneity, the ambient soil erosion is not uniform and consistent. However, this erosion always remains within the resilient capacity of a terrain unless this equilibrium is disturbed by anthropogenic activities.

(ii) **Man Induced Geohazards**

The unplanned, indiscriminate and unscientific land resource utilisation induces various geohazards in an area. These "Man Induced Geohazards" (MIG) always overtake the "Terrain Induced Geohazards" (TIG) resulting in enhanced degradation of geoenvironment. As a consequence, the resilient capacity of the terrain is jeopardised and the terrain starts converting into "wasteland" if suitable remedial measures are not implemented in time.

In the basin, the impact of man on geoenvironment is immensely felt. His predatory activities have degraded the environment variously beyond the basin's resilient capacity. A paradoxical situation exist in the basin wherein, the quantum of degradation is not compatible with the existing industrial base and density of population. The various degradational processes in the basin are the result of over exploitation of land resources which have caused a number of geohazards in the basin. Broadly, the Man Induced Geohazards (MIG) in the basin can be categorised into following groups :

a) Deforestation
b) Waste Dispersion
c) Landslides
d) Quarrying and Landscape Scarring
e) Upland Erosion
f) Silting of Umiam Lake
g) Air-Water Pollution

The cumulative effects of MIG essentially ends up in vigorous soil erosion leading to "desertification" processes and wasteland generation (Prasad 1988).

Deforestation

The basin has large deforested patches spread over 37.80% of the area. Moreover, number of relict forest patches are seen within the forest covered areas (Fig.30). These relict forest patches vary in size from 0.008sq.km to 2.63sq.km and signifies clusters of thin canopy cover. This is the initial stage of deforestation due to timbering/logging (Plate-12). In contrast, the deforestation due to Jhumming produces completely deforested patches(Plates-17 & 18). An interesting feature of relict forest is that when it occurs within the forest covered areas, it means depredation whereas its occurrence in deforested patches signify protection and conservation of the leftover thin canopy covers. In the former case, the growth of relict forest is injurious to the overall heath of the forest while in the latter case, its presence and growth indicate conservatory measures.

(Plate-18) : Deforestation on the ridges. Note development of gully indentations into the ridge flanks.

(Plate-19) : Development of minor rills due to anthro-pogenic activities in the uplands. Note age of pine trees (recent afforestation).

The deforestation due to logging jhumming and public encroachment (urban and rural) has induced changes in landuse pattern in the basin. Forests, though a renewable resource, has not been exploited in a sustained way. The public ownership (Table-54) of forests has led to the rapid and indiscriminate exploitation as it provides easy remuneration with low financial inputs in an industrially poor basin. The changes in the degradation of forest in the basin can be seen by the comparison of the forest status map of the last 50 years (Figs.29 & 30).

The total deforested area in the basin has not changed considerably during the period but, the health of the forest has not been the same. The degraded forest cover areas in the basin have reduced the carrying capacity of the soil as well as it has accentuated soil erosion which is clearly seen by the development of microrelief features like gullies, rills etc.

It is not possible to separate out deforestation due to timber exploitation and Jhumming in absence of basic data. However, in the basin, Jhumming activity is very less as large patches of forest have already disappeared in vicinity of the villages.

It is worth mentioning that the primary forest in the basin has almost disappeared and its place has been taken over by secondary, and tertiary forest cover. As a result, large patches of deforested land is visible on the slopes and forests older than 35-40 years are seldom seen.

In the degraded forest areas of the basin, the soil erosion is taking place mainly in the following ways.

a) Sheet Wash
b) Rill Wash
c) Gully Erosion
d) Rain Drop Impact Induced Erosion
e) Concentrated Flow

The cumulative effect of the soil erosion by the above mentioned ways is far more than the ambient soil erosion thereby accentuating silting of Umiam lake as well as the sluggish Kopili river in the downstream. The silting of Kopili river ultimately causes recurring floods in the lowlands at the terminal part of the basin.

The immediate effect of forest degradation has reduced soil moisture retention thereby reducing soil cohesion and increasing surface runoff. The onset of sheet wash over incohesive soil profiles has initiated rill and gully formation (Plate-19) channelising concentrated flows. Thus the deforestation has increased landscape vulnerability to soil erosion particularly in the upland segments with high dissection, high relief and high slopes. The rill and gullies invariably have disproportionate discharges and are like "misfit" streams. It indicates development by vigorous erosion under concentrated or channelised flows.

Waste Dispersion

"Waste" in most simple language, is the useless, unwanted, unused or discarded materials comprising solid, liquid and gas components. The disposal of waste is of immediate concern to the town planners, architects, administrators, environmentalists and ofcourse, the common public, as a whole.

Waste dispersion is basically an urban problem linked to the rising consumerism. It is mainly a waste disposal constraint and is not only confined to the third world countries only but, also to the developed nations. The agencies involved in waste disposal invariably opt for inexpensive operations as nobody wants to spend money on materials which they consider worthless, as a result, the waste dispersal commences.

In the area the waste dispersion and disposal are essentially restricted to the Shillong Urban Agglomeration only located in the southwestern part of the basin. The rapid expansion of Shillong in terms of population and area during the last 100 years has created stresses on the civic amenities.

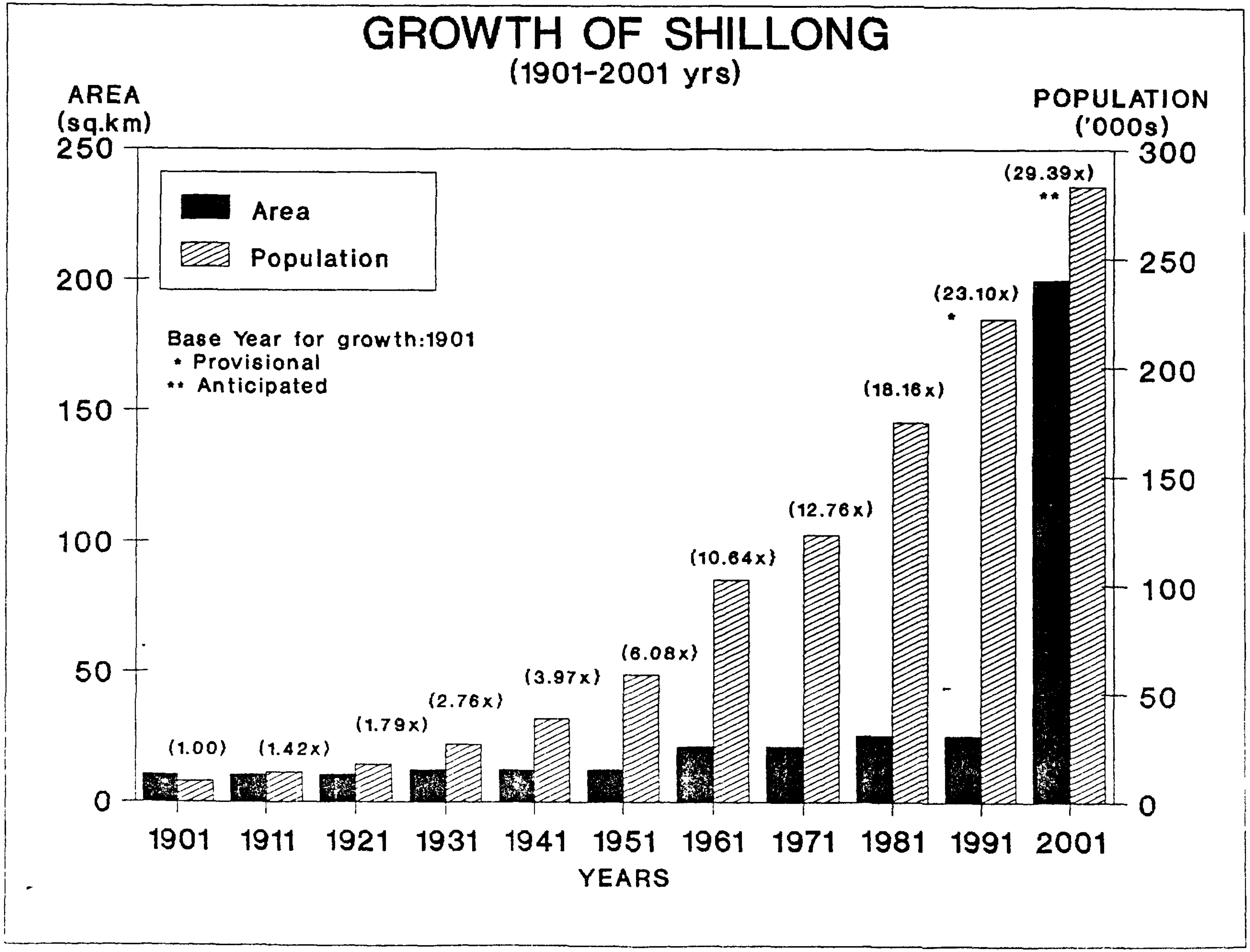
The growth of Shillong over 100 years (1901-2001) is given in the Table (57) and is shown in the Fig.(31). During the period 1901-1951, the urban area around Shillong increased by about 1.18 times and the corresponding population grew over 6 times. This growth has resulted due to inclusion of Shillong Cantonment in the urban centre in the 1931 census. The towns of Mawlai and Nongthymmai had been included in the urban limits of Shillong in 1961. As such the urban area increased by 2.05 times and the corresponding population grew 10.64 times with reference to 1901 as base year. In 1981 census, the towns of Madanrting and

TABLE-57

URBAN GROWTH PATTERN OF SHILLONG AGGLOMERATION
(after Tayeng 1982, Anon 1992)

Name of Town	Area in sq.km	No. of house-holds	Population and Growth Rate (Decadal growth rate % in brackets)										
			1901	1911	1921	1931	1941	1951	1961	1971	1981	1991*	2001**
Shillong U.A.	25.40	33,978	9,621	13,639	17,203 (26.13)	26,536 (54.25)	38,192 (43.93)	58,512 (53.20)	1,02,398 (75.00)	1,22,752 (19.88)	1,74,703 (42.32)	2,22,273 (27.23)	2,82,798 (27.23)
1. Madanrting	2.11	1,182	-	-	-	-	-	-	-	-	6,165	8,927 (44.80)	12,926 (44.8)
2. Mawlai	6.14	3,593	-	-	-	-	-	-	8,528	14,260 (67.21)	20,405 (43.09)	30,442 (49.19)	45,416 (49.19)
3. Nongthymmai	2.93	4,349	-	-	-	-	-	-	10,084	16,103 (59.69)	21,558 (33.82)	26,816 (24.39)	33,356 (24.39)
4. Pynthorumkhrah	2.02	2,244	-	-	-	-	-	-	-	-	10,711	14,322 (33.71)	19,150 (33.71)
5. Shillong Cant.	1.84	1,321	-	-	-	5,236	7,458 (42.44)	4,756 (-36.23)	11,348 (138.60)	4,730 (-58.32)	6,620 (18.89)	11,075 (33.71)	14,808 (33.71)
6. Shillong M.	10.36	21,289	9,621	13,639	17,203 (26.13)	21,300 (23.82)	30,734 (44.29)	53,756 (74.91)	72,438 (34.95)	87,659 (21.01)	1,09,244 (24.62)	1,30,691 (19.63)	1,56,346 (19.63)

* Provisional Census data
** Anticipated



GROWTH OF SHILLONG
(1901-2001 yrs)
AREA
(sq.km)
POPULATION
('000s)
Area
Population
Base Year for growth:1901
* Provisional
** Anticipated
250
200
150
100
50
0
300
250
200
150
100
50
0
(1.00)
(1.42x)
(1.79x)
(2.76x)
(3.97x)
(6.08x)
(10.64x)
(12.76x)
(18.16x)
(23.10x)
*
(29.39x)
**
1901
1911
1921
1931
1941
1951
1961
1971
1981
1991
2001
YEARS

Fig. (31)

Pynthorumkhrah were added in the urban area and the whole area was renamed as Shillong Urban Agglomeration with six towns. The agglomeration showed an overall areal growth of 2.45 times and population growth of over 18 times with reference to the base year. The provisional census data of 1991 has indicated a population growth of over 23 times with reference to the base year and no further areal growth of the Urban agglomeration.

During the period 1901-1991, the waste generation capacity of the town has increased may fold due to changing lifestyle patterns, increased inflow of diversified consumer goods and new trends in packaging and marketing strategies. It has drastically changed the per capita waste generation and has also concentrated it to the urban sprawls.

To evaluate the magnitude of the waste generation in the town, selected sampling of waste was done. The waste is a very heterogeneous material and its constituents vary from place to place depending upon the source of waste generation and season of the year therefore, sampling was done at number of source points and was spread over a period of time. A total of 144 samples were drawn from "trash bins" during February - April'93 and August - October'93 from the following localities in and around Shillong Agglomeration.

a) Bara Bazar
b) Laban
c) Laitumkhrah
d) Madanrting
e) Malki
f) Mawlai

g) Motinagar
h) Nongmynsong
i) Nongthymmai
j) Police Bazar
k) Pologround
l) Umpling

About 1 cu.m of waste was drawn from trash bins twice a month when the bins were full with trash. These materials were weighed and classified into various groups depending upon the nature of the constituents. They were further sorted out into broad categories based on the similarity of waste materials. This helped in identifying the sources and nature of the different kinds of waste materials.

At present, the waste generated around Shillong is disposed in the following three ways :

a) disposal by individual householders into various streams passing through the towns,

b) Intermittent burning in rubbish bins located in the towns,

c) shifting of waste to trenching ground for self decay.

The quantity of waste thrown into various streams is estimated to be around 10 tonnes per day. All around settlements trash is seen thrown on the backyard slopes and pushed into the streams below (Plate-20). In absence of a sewerage system the households discharge their "refuse" into the different streams passing through the towns. Moreover, the septic tanks wherever installed also discharge the muck into the adjoining streams. This primitive way of disposal not only degrade the aesthetic

((Plate-20) :
Garbage filled streams passing through the Shillong Urban Agglomeration.

(Plate-21) : Garbage dispersion (trenching ground) down the valley slopes to the Umiam lake depression.

beauty of the town but, also pollute the air-water system and the Umiam Lake which is the repository of all streams draining the towns.

The trash burnt in the bins is of the order of 2 tonnes per day and the waste transformed ash is ultimately dispersed into the air - water system of the towns.

Presently, the shifting of waste to trenching ground is done by three agencies depending upon their area of jurisdiction:

a) The Shillong Municipality.
b) The Syiem of Mylliem
c) The Shillong Cantonment Board.

The Shillong Municipality is maintaining a trenching ground of 18 acres near village Mawiong in Riat Khawan Reserve Forest (Fig.30) since 1938 on lease. The site is being used for dumping waste (garbage and night soil) by the Municipality as well as the Syiem of Mylliem. The waste disposal at the trenching ground is not mechanised and the waste is simply pushed down the valley opening into the Umiam Lake (Plate-21). The trenching site has become a breeding ground for rodents, flies and other parasites. It is a potential source of spreading contagious diseases through the waste handling workers. The average daily quantity of waste dumped by the Municipality and the Syiem of Mylliem is of the order of :

a) Garbage : 42 tonnes
b) Night Soil : 3200 gallons (about 14,500 litre)

The Shillong Cantonment Board throws the waste behind Garrison Engineer's office, into the Um Shirpi stream (Plate-22), a tributary of Wah Ro Ro which joins Wah Umiam, upstream of the Umiam lake. At present, the Cantonment Board disposes off about 72 trucks load of waste of 300 c.ft (8.4 cu.m) capacity each per month.

The perspective plan for Shillong envisages development of over 200sq.km area into Shillong Urban Agglomeration with its northern fringe touching Barapani and the southern fringe glancing Laitkor village. This expansion as well as continuing population growth trend indicates an anticipated spatial growth of over 19 times and population growth of over 29 times by the year 2001 with reference to the base year (1901). These rising trends and availability of diversified consumer goods would generate disproportionate waste and waste handling problems scattered over a much larger area.

The whole operation of waste disposal in Shillong Urban Agglomeration is very primitive. The collection, transportation and disposal of the waste are unscientific and ill managed. The collection sites i.e. the rubbish bins and disposal site are in appalling conditions, and the work-force has to work under most unhygienic conditions. During the study, it was found that the waste generated in the town was being dispersed into the Umiam lake through the drainage network and directly from the Riat Khawan trenching ground. Moreover, the leachate generated is

(Plate–22) : Garbage disposal into the Um Shirpi stream, a tributary of Umiam River upstream of the lake.

percolating through the soil and rocks contaminating the ground water sources.

Recent studies carried out by National Environment Engineering Research Institute (Anon 1991) for solid waste management in Shillong, revealed the composition of waste, collected from the few refuse bins as given below :

a)	pH	:	7.328
b)	Organic Matter	:	54.36% to 69.53%
c)	Carbon	:	31.53% to 40.33%
d)	Nitrogen	:	0.54% to 0.83%
e)	Phosphorous	:	0.15% to 0.27%
f)	Potsh (K_2O)	:	45.30% to 71.28%
g)	Carbon/Nitrogen Ratio	:	45.30% to 71.28%

This composition of the waste is suitable for composting and which could be a source of income as well. The biggest problem of waste disposal is that everyone generates waste but, its disposal remains the most neglected aspect of urban development everywhere. No one wants to put money in products which are labeled "waste". So, one of the important constraint in waste management is lack of funds. But, if the town is to be saved from the heaps of waste and its dispersal, scientific waste disposal mechanism is to be established forthwith. At the same time, the use of non-biodegradable materials like, plastics and other synthetic consumables are to be discouraged. These are found to have long distance dispersal capacities and can survive in subsurface indefinitely.

Landslides

It is one of the MIG which is by and large associated with developmental (constructional) activities which modifies the slope segments particularly making the profiles steeper in sections. This causes slope instability with a tendency to fall as and when the equilibrium is disturbed. The landslide prone areas are conspicuously confined within the Shillong Group of rocks especially where the dips are steeper.

In the basin, the developmental activities are mainly concentrated in the southwestern part in and around Shillong Agglomeration. Therefore, the incidences of landslides are also concentrated in this part of the basin. However, where the Shillong Group of rocks have horizontal to subhorizontal disposition and the slope segments gentler, the landslides are absent or rare. But, along steeper slopes and steeper dips the rock fails at times during rains in vicinity of settlements. It is due to the "daylighting" of bedding and joints by excavations for constructional activities along which the rock fails due to increased pore water pressure during monsoon.

The arterial roads running through the basin have been constructed without due recognition of the slope profiles and "rheological" properties of the rocks consequently landslides and slumps are frequently associated with them. Abrupt steep slope cuts in excess of 60^{o} all along the road networks have made the slope profile unstable which causes frequent landslides (Plate-8 & 9).

The landslides in the basin are the result of unplanned development ignoring geomorphic characteristics of the terrain. They contribute large quantities of sediments into the Umiam drainage network which could be avoided by suitably modifying road alignments and "grading" the slope profiles. It would also cut down recurring expenditure on maintenance of landslide prone road sections.

Quarrying and Landscape Scarring

The basin has Quaternary deposits in less than 5% of the area. As a result, the constructional activities depend for their building materials upon the hard rocks only. The insignificant Quaternary deposits can hardly support any building material demands. The requirements of cobble - gravel - boulder etc. are met from crushed rocks and the resulting sand sized material is used in place of river sands. Moreover sand requirements are also supplemented from weathered and altered friable Quartzite of Shillong Group (Plate-2) as well as weathered Gneisses.

Since the building or construction materials are commodities of "low price and high volume", they are to be procured usually not far from construction sites. As a result, large number of rock quarries have cropped up around Shillong, within the urban limits, to meet the demand of construction materials. Studies carried out in the basin revealed presence of 15 to 20 regular and intermittent working roadside quarries within the Shillong Agglomeration. These quarries produce between 30,000 and 35,000 cu.m of construction materials annually, with 1600 to 2500 tonnes of unusable muck.

These quarries not only destroy aesthetic beauty of the landscape by "land scarring" but also induces landslides. The quarries within the settlements at times undercut the ledges and spurs making the slopes vulnerable to landslides thereby exposing life and property to man induced geomorphic risk.

The huge annual quantity of muck generated during quarry operations adds to the sediment load in the component basins and contribute additional sediments in the Umiam lake. The operations of quarries cannot be stopped in the basin for want of construction materials. At the sametime, the minerals and mining regulations remain non operative due to the existing land holding/tenure system in the state. These quarries though are not large scale operations but, due to deployment of unscientific methods and the total disregard to mineral and mining regulations, are serious geohazards in the basin.

<u>Upland Erosion</u>

It is one of the most fundamental and universal process occurring on hill slopes. Management of soil and water resources in hill areas is a very complex problem in comparison to plain areas. The uplands in general have higher rates of erosion mainly due to higher relief, higher stream gradients and higher deforestation. The deforested areas accelerate soil erosion as the areas do not get "canopy" protection resulting in higher "raindrop impact" induced soil erosion (Plate-16). Nevertheless soil erosion is a serious problem in all kinds of terrain.

Certain estimates are available indicating the seriousness of the problem of soil erosion. Randhawa (1980) has reported that 50% of agricultural land (80 m ha), 35% of the forest land (20 m ha), 86% of the cultural wasteland (15 m ha), 95% of permanent pasture and other grazing land (14 m ha), 75% of the fallow land (15 m ha), 24% of land under trees and grooves (1.0 m ha) and 44% of the total geographical area of India (145 m ha) are subjected to severe erosion.

As estimated 6000 m tonnes of soil and along with it more than 6 m tonnes of nutrients are lost every year (Gautam, 1980). This is more than the total amount of fertilisers used by the country at present. This is a great waste of the natural resources when we consider that in nature, it takes 100 to 400 years or more to generate 1cm of top soil and 3,000 to 12,000 years to generate 30cm layer of soil.

Sediments from erosion cause downstream sedimentation by filling distant reservoirs and nearby road ditches. Upland erosion is a diffuse process having widely varying rates over a landscape. Therefore, direct measurement of upland erosion at a number of sites is impractical. Physically, erosion is difficult to measure and variability of climate requires that at least 10 years of data be collected under best conditions to obtain an accurate measure of annual erosion (Foster 1988).

The suspended sediment load of rivers does not give the correct erosion rates of the uplands because, it does not take into account the bedload component in the rivers (Emmett 1984; Walling 1988). Such data on global basis is readily available (Walling op.cit.).

Global maximum sediment yield of 25,600 tonnes per sq.km per year is reported from Dali river China from a drainage area of 96.10 sq.km. Values of less than 1.0 tonnes per sq.km per year is reported from several rivers of Poland. According to Walling (1988) such sediment yield data does not provide meaning-ful information about on-site rates of erosion and soil loss within a drainage basin because only a fraction of the soil eroded within a drainage basin reaches the basin outlet and is represented in the sediment yield.

Upland erosion in the basin is the most important Man Induced Geohazard (MIG). The present study has identified following kinds of erosion in the basin.

(a) Sheet Erosion
(b) Rill Erosion
(c) Gully Erosion
(d) Concentrated Flow Erosion
(e) Stream Channel Erosion

The upland erosion varies with landuse, nature of lithology and structure, vegetation cover and economic activities in a terrain. An idea of total upland erosion can be had from published data estimated for analogous areas. Lal (1977) reported from the highlands with hilly catchments under forest covers in Malaysia a soil erosion rate of 245 cubic meter per sq.km per year. Similarly, the soil loss in Thailand under uncultivated forest is reported to vary from 6.4 to 7.5 tonnes per sq.km per year from the Peninsular Malaysia region. Morgan (1979) reported erosion rates of 670 to 1090 tonnes per sq.km per year from highly dissected highlands upto an elevation of 2000m under equatorial monsoonic climate (annual rainfall 1750 to 2510mm).

In India, Singh and Singh (1981) have reported upland erosion rate of 1885 tonnes per sq.km per year from 40 to 50% slopes under natural mixed forest. Singh and Singh (op.cit.) reported erosion due to development of roads, expansion of habitation etc. of the order of 6720 tonnes per sq.km per year from the hill regions of Northeastern India. Such huge erosion though alarming, often goes unnoticed as the eroded material is efficiently transported to lower levels or main drainage systems. Landslides along the roads and erosion from earthfills are the main problems which are frequently occurring in the basin due to road development. Most of the hillside road cuttings in the basin are steep and the slope profiles are modified by cuts in excess of 70^{o}. This poses serious erosional problems. Singh and Singh (op.cit.) reported erosion rate of 2410 tonnes per sq.km per year from 60^{o} slope on roadsides.

Singh (1987) has reported erosion rates 0.002 tonnes per sq.km per year to 5 tonnes per sq.km per year under different landuse, from Byrnihat (north of Umta) near Assam-Meghalaya border.

Recent studies carried out by water and power consultancy services (Anon 1990) in the upper reaches of the basin have given the following rates of erosion in different landuse.

(a) Forest Covered Areas	:	52 tonnes per sq.km per year
(b) Residential Areas	:	1885 tonnes per sq.km per year
(c) Jhum Cultivation	:	4095 tonnes per sq.km per year
(d) Orchards	:	390 tonnes per sq.km per year
(e) Roadsides	:	241 tonnes per sq.km per year
(f) Steep Stream Bank	:	300,000 tonnes per sq.km per year

It is seen that the erosion rates within the basin show large fluctuations. The variation in the erosional rates in the basin reflects microlevel changes in basin vulnerability to erosional processes. The present study revealed that all the component basins are not equally vulnerable.

<u>Silting of Umiam Lake</u>

One of the chronic problems associated with man made lakes is the loss of effective capacity due to silting and Umiam lake is no exception. The Umiam lake was constructed as a part of a hydroelectric project near Barapani to harness the hydel potential of Umiam river. Construction of this hydroelectric project in the basin where there was hardly any human activities prior to this project provided ample opportunities to the local people in their development and upgradation of economic conditions. This initiated construction of road networks, cultivation in new areas, deforestation, new settlements etc. These activities by and large have ignored geomorphic attributes and mushroomed in an uncontrolled pattern resulting in accelerated soil erosion. This in turn, has increased sediment flow in the streams going into the reservoir thereby decreasing the storage capacity and utility of the reservoir.

The catchment of the reservoir is 221.44sq.km. with 24.25km length of Umiam river and 14 component basins feeding it. (c.f. Fig.24). The catchment of the reservoir has highest anthropogenic activities in the entire basin as the Shillong Agglomeration is located in this part of the basin and heavy upland erosion is the main contributor of silting.

Recent hydrographic surveys conducted in the reservoir (Anon 1990) revealed reduction in the reservoir capacity as given below.

(a) Original capacity at 981.46m above m.s.l. : 18,142ha.m in 1965.

(b) Present capacity at 981.46m above m.s.l. : 16,697ha.m in 1990
Reduction in capacity in 25 years : 1445ha.m

(c) Rate of Silting per year per sq.km area of the catchment = 0.261 ha.m per sq.km per year 1445/25x221.44

In a period of twenty five years since impounding, the capacity of the reservoir has been reduced by 1445ha.m. In other words, the annual silt deposition in the reservoir from the catchment is 57.80ha.m. Assuming 1 ha.m silt to be equivalent to 14639 tonnes, the annual silt deposition in the reservoir at present works out to be 84,61,34.20 tonnes.

The silting in the reservoir has altered the dead storage level as well as the live storage level. The amount of storage in the reservoir provided for silting is called "dead storage" and the storage above dead storage is called the "effective storage" or "live storage".

The Umiam lake was constructed in 1965 with a gross storage capacity of 18142ha.m (1,47,000 acre ft.) at maximum reservoir level at 981.46m above m.s.l. The minimum reservoir level was kept at 960.12m above m.s.l. to have a dead storage of 3949ha.m (32,000 acre ft.). But during the last twenty five years, the silting has altered these capacities as given in Table (58).

TABLE-58

CHANGES IN STORAGE CAPACITY OF THE UMIAM LAKE

Level	Original Capacity ha.m	Present Capacity ha.m	Difference ha.m
Dead Storage Level	3949 (32,000)	3101 (25130)	848 (6870)
Live Storage Level	14193 (1,15,000)	13596 (1,10,167)	596 (4833)
Total	**18,142 (1,47,000)**	**16,697 (1,35,297)**	**1445 (11,703)**

Remarks : Figures in brackets are in acre ft.

At the present rate of silting i.e. 57.80ha.m annually, the present dead storage capacity (3101ha.m) of the reservoir will be filled in another 53.65 years. However, due to ongoing developmental activities and concomitant deforestation, the upland erosion is expected to rise in the catchment. Therefore, life of the dead storage level would be certainly less than the predicted life unless upland erosion is checked.

As per the authorities of Meghalaya State Electricity Board (MeSEB) under whom the hydroelectric project is functioning, the reservoir was designed assuming a silt load of 0.036ha.m per sq.km per year from the catchment area. But, at present the silting rate has been found out to be 0.261 ha.m per sq.km per year which is 7.25 times more than the assumed rate indicating very high increase in erosion of the upland during the last twenty five years.

A survey of 21 reservoirs in the country has revealed silting at the rate of 0.0851 ha.m per sq.km per year against designed inflow of 0.0302ha.m per sq.km per year (Randhawa 1980). It indicates 2.82 times more sediment accumulation than the designed inflow. In comparison to this rate of siltation (0.0851 ha.m per sq.km per year), the silting of Umiam (0.261ha.m per sq.km per year) is 3.06 times more which is alarming.

The sediment deposited in the reservoir can be removed by a variety of mechanical and hydraulic methods such as excavation, dredging, siphoning, draining, flushing etc. But all these methods are extremely expensive and almost impractical. The most relevant and economic approach would be to control sediment inflow in the feeder stream of the Umiam lake, i.e., Umiam River. In the component basins of Umiam river forming the catchment area of the lake and over which the Shillong Agglomeration is sprawled the Man Induced Geohazards (MIG) are to be reduced for checking upland erosion. Therefore in the component basins nos. 1-5 & 44 to 52, the developmental activities should not ignore the geomorphic attributes and associated geomorphic risks and aggravate the landscape degradation, the chief cause of upland erosion.

GEOHAZARD ZONATION IN THE BASIN

Identification and spatial distribution of geohazards are useful for planning, designing and execution of developmental schemes such as roadways, railways, power transmission lines, building construction etc. to have minimum environmental degradation. It also helps in mitigation of geohazards and in formulating reclamation strategies for degraded landscape.

The Umiam basin is at the threshold of development. Therefore, a geohazard zonation map would be helpful to prioritise utilisation of land resource in different parts of the basin. Hence, a new, simple quantitative microlevel approach for Geohazard Zonation Map (GZM) has been developed based on numerical ratings of various geomorphic, geologic attributes and geohazards in the basin. Similar numerical rating schemes are utilised in rockmass classification (Barton et al. 1974; Bieniawski 1979) as well as land evaluation and land capability classification (Diamond 1984; Negi 1991).

In the numerical rating, equal rank has been given to each attribute and geohazard present in the area. The following 10 attributes and geohazards have been considered in the numerical rating scheme :

GEOMORPHIC ATTRIBUTES

(a) Absolute Relief (AR)
(b) Relative Relief (RR)
(c) Dissection Index (DI)
(d) Average Slope (SL)
(e) Drainage Frequency (DF)
(f) Drainage Density (DD)

GEOLOGIC ATTRIBUTES

(g) Lithology (LL)
(h) Geo-Structure (GS)

GEOHAZARDS

(i) Deforestation (DT)
(j) Erosional Vulnerability (EV)

All the attributes have been classed into 5 categories in ascending order. The ranking to each attribute is assigned on the basis of their estimated significance in causing geo-environmental instability in the basin. The minimum ranking is given 1 and the maximum is 5 as shown in Table (59).

Ranking of Geomorphic Attributes

The spatial distribution of different categories of each attribute has been computed in each component basin and the

TABLE-59

RATING OF ATTRIBUTES AND GEOHAZARDS IN THE BASIN

Ranking Value	ATTRIBUTE CATEGORY AR (m)	RR (m)	DI	SL ( )	DF (No/km)	DD (km/km)	LL	GS	GEOHAZARD CATEGORY DT (%)	EV
5	>1600	>500	>0.8	>30	>12	>8	UT	>0.4	>50	>8
4	1200-1600	300-500	0.6-0.8	20-30	9-12	6-8	ST	0.3-0.4	40-50	6-8
3	600-1200	200-300	0.4-0.6	10-20	6-9	4-6	SG	0.2-0.3	30-40	4-6
2	200-600	100-200	0.2-0.4	5-10	3-6	2-4	PG	0.1-0.2	20-30	2-4
1	<200	<100	<0.2	<5	<3	<2	GC	<0.1	<20	<2

interfluve area and the weighted ranking of each component basin is then calculated.

Ranking of Geologic Attributes

Broadly, the basin has following five lithotypes, distributed throughout the basin in well defined sectors (Fig.6).

Unstabilised Terraces (UT)
Stabilised Terraces (ST)
Shillong Group (SG)
Granitoid Plutons (PG)
Gneissic Complex (GC)

These lithotypes have been assigned ranking 1 to 5 depending upon their relative vulnerability to weathering and erosion. The Gneissic Complex is least vulnerable in the basin and has been assigned rank value of 1 while the Unstabilised Terrace is highly vulnerable, hence, has been ranked 5. The spatial distribution of the different lithotypes have been computed for each component basin and the interfluve area and the weighted ranking of each component basins is computed.

The Tyrsad - Barapani shear zone is the major geostructure running along the axial part of the basin but, only affects some of the component basins and part of interfluve area. The shear zone has affected the lithotypes over a width of about 500m making them highly vulnerable to weathering and erosion. Since, this is a linear feature and the effects of shearing die out away from the shear zone, its influence remains confined to its intercepts in the component basins through which it passes. The area (length x breadth) in each component basin affected by the shear zone is computed and divided by the area of the respective component basin giving the weighted rating for the whole component basin. These ratings have been classed into five categories viz., >04,0.3 - 0.4, 0.2 - 0.3, 0.1 - 0.2 and <0.1 The less than 0.1 category has been assigned ranking value of 1 and greater than 0.4 category has been assigned ranking of 5

Ranking of Geohazards

The deforested patches in each component basin as well as interfluve area has been computed and converted to percentages of deforestation. It varies from less than 20 per cent to greater than 50 per cent. Accordingly, minimum ranking of 1 is assigned to less 20 per cent deforestation whereas ranking of 5 is assigned to greater than 50 per cent deforestation.

The erosional vulnerability of the basin is its vulnerability to geomorphic processes and is due to the complex interaction among geologic, climatologic, fluvial inhomogeneities and anthropogenic activities as a process - response system. The analysis of the 54 morphometric parameters carried out in each component basin (c.f. Chapter-V) revealed predominence of certain parameters over others in inducing higher erosion. The correlation analysis indicated presence of clusters of these parameters in the component basins, which varied from less than 2 to more than 8 and have been classed into 5 categories. The less than 2 category has been assigned ranking value of 1 whereas greater than 8 category has been given ranking of 5.

Zonation Index

The Zonation Index is the total ranking in a component basin divided by the minimum ranking of a component basin in the area. It signifies areas with similar geoenvironmental instabilities in comparison to the area of the least geoenvironmental instability in the basin.

The total ranking of all the attributes and geohazards has been computed for each component basin and interfluve area. The total ranking varies from 18.45 in component basin no.83 to 32.65 in component basin no.31. This means that the component basin no 83 has least instabilities in the whole Umiam basin. Therefore, all component basins and the interfluve area have been compared with it, and the total ranking values have been normalised with respect to its value of 18.45 i.e. the total ranking of each component basin has been divided by 18.45 to get the Geohazard Zone Rank Value. This zone rank value varies from 1 to 1.77 and the same has been classed into 5 Geohazard Zones varying from less than 1.15 to greater than 1.60. These Geohazard Zones have also been assigned qualitative status varying from very low to very high (Table-60) and their spatial distribution is shown in the Geohazard Zonation Map (Fig.32), and discussed below.

Very Low Geohazard Zone

It occupies largest area in the basin covering 498.05 sq.km (34.84%). Conspicuously, it is confined as large patches in the central and terminal part of the basin. Incidentally this is

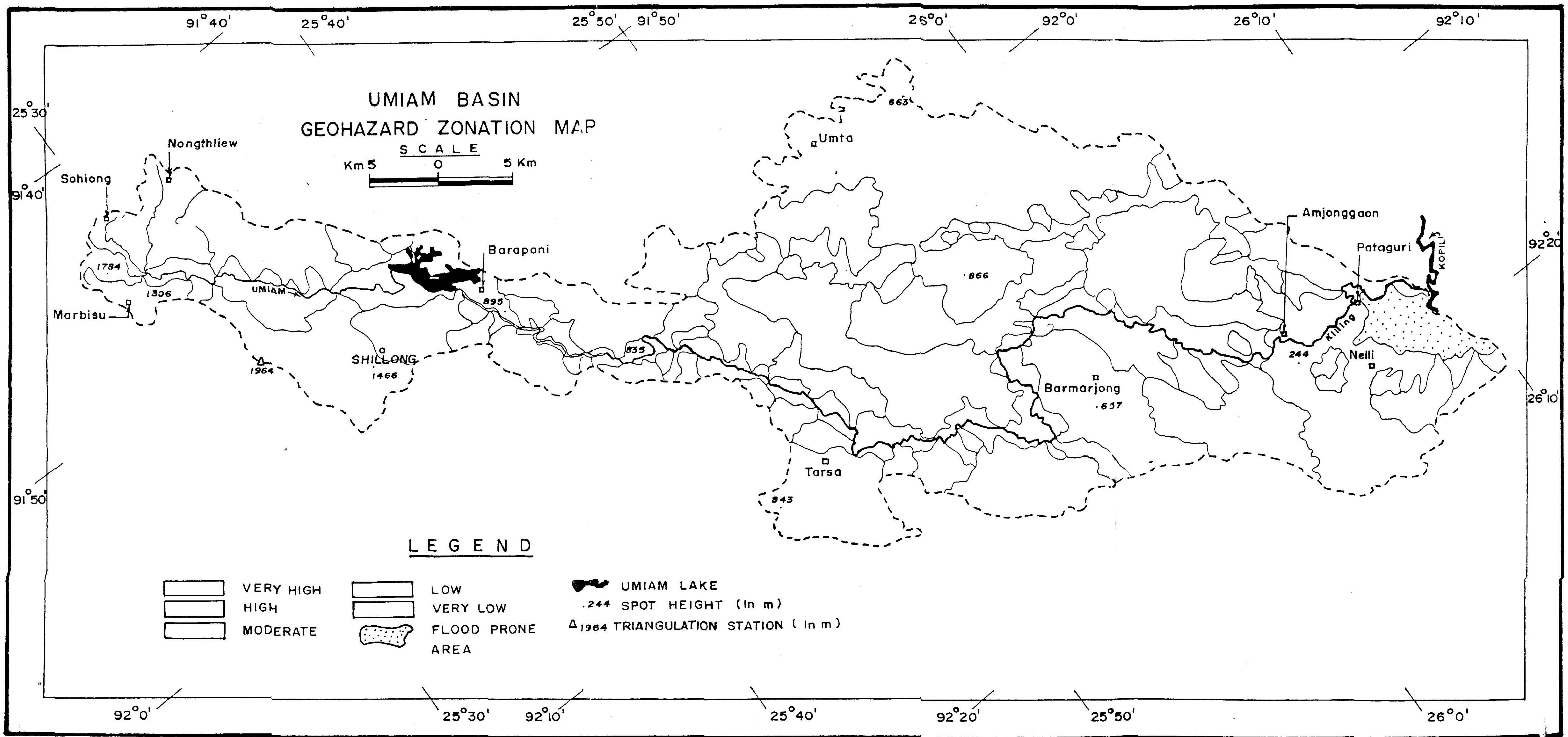

UMIAM BASIN
GEOHAZARD ZONATION MAP
SCALE
Km 5 0 5 Km
Nongthliew
Sohiong
Marbisu
1784
1306
UMIAM
1964
Barapani
895
SHILLONG
1466
835
663
Umta
866
Tarsa
843
Barmarjong
.657
Amjonggaon
Pataguri
KOPILI
Killing
244
Nelli
91°40'
25°40'
25°50'
91°50'
26°0'
92°0'
26°10'
92°10'
25°30'
91°50'
92°20'
25°30'
92°10'
25°40'
92°20'
25°50'
26°0'
LEGEND
VERY HIGH
HIGH
MODERATE
LOW
VERY LOW
FLOOD PRONE AREA
UMIAM LAKE
.244 SPOT HEIGHT (In m)
Δ1964 TRIANGULATION STATION (In m)

Fig.(32)

the area with poor infrastructural facilities and least developmental activities. The area is scattered around near Tarsa, Umta, Amjonggaon and Nelli. This zone is characterised by lower elevations, relief, slope and deforestation. However, in the terminal part of the basin, this zone is prone to water logging and periodic flooding which is the result of backwaters from Kopili river during rains. The older terraces around Nelli supports tea plantation and patches of reserve forest. There is ample scope of enlarging the tea plantation over the hill slopes as part of landscape conservation measures.

TABLE-60

GEOHAZARD ZONE RANKING IN UMIAM BASIN

Serial No.	Zone Rank	Area sq.km	Cumulative Area	Area %	Cumulative Area	Category Group
1.	>1.60	201.85	201.85	14.12	14.12	Very High
2.	1.45-1.60	244.32	446.17	17.09	31.21	High
3.	1.30-1.45	299.74	745.91	20.97	52.18	Moderate
4.	1.15-1.30	188.55	931.46	12.98	65.16	Low
5.	<1.15	498.05	1429.510	34.84	100.00	Very Low

Low Geohazard Zone

It is by and large scattered downstream of Umiam lake occupying an area of 188.55 sq.km (12.98%). Remarkably, it forms discrete patches near Umiam lake, Tarsa, southeast of Umta, Barmarjong, west of Amjonggaon and east of Nelli. This area is mostly contiguous to very low Geohazard Zone and also lacks infrastructural facilities. It occurs as smaller patches in comparison to very low geohazard zone.

Moderate Geohazard Zone

This zone occupies an area of 299.74sq.km (20.97%) and stretches as discrete patches from Sohiong - Nongthliew in the southwest to near Nelli in the northeast. This zone occupies peripheral parts of Shillong Agglomeration. It signifies the onset of landscape degradation due to anthropogenic activities.

High Geohazard Zone

It covers an area of 244.32 sq.km (17.09%) and is distributed broadly in two segments in the basin. The first segment is confined mainly in the Plateau Domain from Marbisu in the southwest to west of Tarsa in the central part of the basin. The second is confined mainly in the Hill Domain as narrow strip from southwest of Umta to west of Amjonggaon and southeast and northeast of Barmarjong. Remarkably large part of Shillong Agglomeration is confined in this zone. At present, main developmental activities are concentrated in the plateau part of this zone which has highest infrastructural facilities in the whole basin. This zone demarcates areas in the basin which have acquired terrain induced as well as man induced a instabilities.

Very High Geohazard Zone

It covers an area of 201.85 sq.km (14.12%) in the basin and occurs as a narrow strip along the Umiam river right from north of Marbisu to near Amjonggaon. This zone is characterised by steep slopes, high dissection and high relief. It is zone of extensive rill erosion. The terrain inherited and the man induced geohazards are maximum in this zone.

The Umiam lake depression forms part of this zone where the hydroelectric project expansion activities are concentrated at present. At the same time an industrial complex is also coming up downstream of the lake. The location of these developmental activities in this very high geohazard zone would further induce vulnerability to the terrain.

The Geohazard Zonation Map is useful for planning the developmental schemes in the basin. The execution of these schemes in areas of minimum instabilities would cause least geoenvironmental stresses in the basin.

GEOHAZARD MITIGATION

The present study has identified more than 52 per cent of the area in the Umiam basin to be under moderate to very high geohazard zone. It implies that more than half of the basin has geoenvironmental instabilities or imbalances. The high to very high geohazard zone is the most fragile segment in the basin and the moderate geohazard zone acts as a buffer between it and low to very low geohazard zone. The land resource utilisation beyond the moderate zone should not be encouraged. Road and power transmission networking are the two developmental activities most injurious to the "health of the landscape" and always extend beyond the actual nodes of development. Therefore their alignments should be planned for minimum passage through moderate to very high geohazard zones.

The geoenvironmental imbalances in mountainous tracts always have serious repercussions in the plains below in the form of silting of river beds and recurring floods as a consequence.

The terrain characteristics in the basin have impeded growth of industrial base or sustained economic activities and employment generation. *This has led to widespread "logging"* (deforestation) as the local inhabitants find it to be highly remunerative with little or *no* financial inputs. Primitive agricultural practices on barren hill slopes with low productivity and attendant high soil erosion under tropical monsoonic conditions is gradually transforming the "degraded landscape" into a "wasteland".

The existing environmental protection regulations remain inoperative in the area due to prevailing land tenure-holding/ownership system. As a result, all developmental activities and land resource utilisation in the basin proceed with total disregard to the different provisions of environment protection laws and regulations. The land resource utilisation should not only be economically viable in short run but, also not environmentally degradational in the long run (Ghildyal 1991). However, reverse is the scenario in the Umiam basin where land resource utilisation is causing extensive land degradation and the various man induced instabilities like landslides, deforestation, land scarring, vigorous upland erosion etc. have cropped up.

The developmental processes in the basin have largely been concentrated around Shillong Agglomeration as a result highest geoenvironmental degradation is confined around Shillong. The land scarring by quarries within the Shillong Agglomeration needs to be stopped and the quarry operations should be shifted outside the urban limits. The rapid urbanisation around Shillong has not been provided with commensurate waste disposal system. The present waste disposal operations are serious threat to the Umiam lake and surrounding areas. The use of waste into non-conventional energy alternatives, composting, recycling etc. is to be integrated with other developmental activities in the basin.

The developmental activities should be dispersed throughout the basin so that the resource base could be utilised in a sustained way to generate local employment and to ease pressure on land around Shillong. The project cost of all developmental activities should also include cost of reclamation of the degraded landscape and not only the cost of inputs. The development in the basin should also proceed with the concept of total catchment management (TCM) i.e. as per terrain characteristics, resource base and status of geohazards in the area. The Terrain Inherited Geohazards (TIG) like gorges, escarpments, steep slopes high relief, high dissection etc. in the basin cannot be avoided or eliminated. They are part of process response systems related to the evolution of the basin. But, Man Induced Geohazards (MIG) by and large have originated in response to unplanned and overexploitation of natural resources which need to be retarded in the basin.

The seismic proneness makes the basin vulnerable to earthquake hazards. The dwellings, the multistoried R.C.C. buildings and superstructures should include aseismic designs. Moreover, construction of dwellings along valley slopes need to be discouraged and a complete moratorium be imposed for construction along these slopes to avoid loss of life and property during earthquakes. The terrain characters would be a serious hindrance to rapid relief and rescue operations in case, an earthquake event like of 1897 or 1950 magnitude strikes again, with the present population growth and dwelling sprawls along slopes.

Economic activities linked to agro-diary-horticulture based small scale industries should be encouraged in the rural areas with co-operative marketing facilities. This should have ancillary supporting activities like fisheries, livestock, sericulture, apiculture etc. at village level. Such economic activities have minimum geoenvironmental degradational effects, generate self employment and promote conservation in mountainous and hilly tracts. It would be disastrous to have heavy industries in this fragile basin. However, environment friendly industries like electronics, computer hardware, software etc. should be encouraged to develop here.

The deforested patches in the basin should be brought under afforestation schemes with multitier vegetation. The presence of relict forest patches (Fig.30) within the deforested area should be the nodal points to expand the afforestation. At the same time the relict forest patches within the forest cover areas which signify the centres of forest degradation, should be stopped forthwith to protect ongoing deforestation.

In absence of river borne sands, cobbles, boulders etc. the quarrying of rocks for substituting the demand of construction materials cannot be stopped but, if silting of Umiam dam is to be checked the diversion of quarry waste into the drainage lines is to be stopped by enforcement. Similarly, the grades of slope segments cut by the road networks are to be maintained for greater slope stability so as to avoid recurring landslides - slumps in the basin.

All geohazard mitigation actions should aim in lowering the zone ranking of the geohazard zones while promoting development in the basin. The objective of environmental protection should not be misconstrued as "anti development" but environment friendly development.

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SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSION

The geomorphic attributes and geomorphic risks of an area form an important database for sustainable development and minimum geoenvironmental degradation. The indiscriminate and unscientific land resource utilisation leads to environmental deterioration. Many of the environmental problems relate to the interactions between man and natural resources. Environmental management focuses total attention to an integrated approach for rational utilisation and conservation of land-water resources.

Environmental degradation as part of normal denudational processes cannot be avoided. But, unplanned anthropogenic activities often accentuate these processes resulting in imbalances beyond the resilient capacity of the terrain. Therefore, the knowledge of geomorphology of an area to be harnessed is of paramount importance for environmental management of natural resources.

In view of this interrelationship between geomorphology and environmental management, the present study has been undertaken in the Umiam basin to study the cause and effects of ongoing degradational processes, their mitigation and resource utilisation for sustainable development.

The Umiam basin covers an area of 1429.510sq.km and is confined to the eastern part of the Shillong Massif. The basin exposes by and large the Proterozoic Shillong Group of rocks, Proterozoic Granitoid Pluton and the Precambrian Gneissic Complex. The geomorphic evolution of the basin is linked up with the tectonic history of the Shillong Massif which is the northeastern extension of the Peninsular Indian Shield. The Massif is a horst forming plateau block uplifted to its present height of 600m to 1900m above m.s.l. since Jurassic.

The basin is spear-head shaped and its configuration is controlled by the distribution of the different lithotypes and the structural grain. The Granitoid Plutons have restricted the lateral enlargement in the upper reaches of the basin. At the same time, the NE-SW trending Tyrsad-Barapani shear zone running along the axial part of the basin has induced rapid downcutting within the Shillong Group of rocks accentuating headward erosion. This has conspicuously caused elongation in the upper reaches of the basin. The basin is traversed by criss-crossed lineaments with history of reactivation as evidenced by structural adaptation of the drainage lines within the basin.

The basin experiences tropical monsoonic climate and represents "Selva climate process system". The physical weathering in the basin is subordinate to the chemical weathering. The high rainfall and plateau nature of the terrain is conducive to deep chemical weathering. As a result, the soil mantle is thick and lateritic due to excessive leaching.

Modification of natural slope profiles during the road developments and building construction activities induces slope instability in the weathered rocks causing landslides/slumps particularly in Shillong Group of rocks. This is a serious geohazard in the steeply dipping Shillong Group of rocks in vicinity of reactivated lineaments and Tyrsad-Barapani shear zone.

The terrain analysis of the Umiam basin reveals manifestation of fragmental or remnantal shapes arising due to polycyclic denudation.

The elevation within the basin varies from 60m in the northeast to more than 1900m in the southwest. In general, the absolute relief analysis depicts a staircased physiography in the basin. The longitudinal profiles reveal a "eight step" landscape indicating gradual unloading of physiography towards northeast.

There is a remarkable concentration of high relative relief aligned parallel to Umiam river. This marks the gorge section of Umiam entrenched in the Shillong Group. The other concentration of high relative relief in the central part as well as in the northeastern fringe of the basin is collinear with the Tyrsad-Barapani shear zone cutting through the basin.

The dissection index in the basin also indicates existence of peneplanation surfaces with superimposition of fluvial cycles. In general, the Granitoid Plutons have higher dissection index than the Shillong Group of rocks indicating the removal of overlying Shillong Group of rocks from the Granitoid Plutons and superimposition of dissection index over their irregular surfaces, marking sporadic and periodic high erosion. The low dissection index over the Shillong Group of rocks suggests that the Cretaceous - Tertiary sediments were stripped from over the Shillong Group only recently which is a consequence of Quaternary erosional process. The terminal part of the basin covering Quaternary sediments has least dissection index which is a reliefless lowland formed of Umiam-Kopili-Brahmaputra oscillations. The plain has signatures of Neotectonic movements in the form of micro-scarps, terraces and palaeolandslide lobes.

The average slope distribution revealed the presence of very high steep slope over Umiam gorge section. It also occurs as isolated patches which coincides with the trace of the Tyrsad-Barapani shear zone cutting through the basin. The low land at the terminal part of the basin has lowest slope category.

The drainage frequency categories reveal a peaked grid frequency distribution between 3 nos. per sq.km and 12 nos. per sq.km. Above 12 nos. per sq.km category is clustered in the Shillong Group of rocks and sporadically over the Nongpoh Pluton as discrete patches. Inspite of being part of very high rainfall region, very low areal distribution of this category suggests presence of higher secondary permeability and low concentrated flow. The drainage analysis also reveals that the channel segments have very spectacular structural control. The clusters of high drainage density category incidentally falls in the deforested terrain signifying higher channelisation of run-off due to deforestation.

The correlation among the six geomorphic attributes viz., Absolute Relief, Relative Relief, Dissection Index, Average Slope, Drainage Index and Drainage Density shows that no single parameter has controlled the development of other parameters significantly which is typical of plateaus. But, due to local geological inhomogeneity like reactivated lineaments - rejuvenation, the parameters do depict sharp dependencies over small segments of the terrain.

The Umiam is a seventh order stream with 120 component basins varying in order from third to sixth. It rises from south of Shillong and joins Kopili river near Dharamtul in the northeast. The Umiam suffers a fall of 1801m from its source to mouth and the whole course is divisible into seven segments at points of abrupt change in gradient. The longitudinal profile of Umiam also shows cascading nature conforming to the general stepped physiography of the basin. The steps in the profile are the manifestations of pulses of Active Tectonics.

Morphometric analysis reveals highest number of third order basins over the Granitoid Pluton with smaller area and perimeter than that over Shillong Group of rocks. It indicates easy erodibility of the Shillong Group of rocks by the drainage network. The component basins in their headwater zones do not show influence of geostructure but in their lower reaches, particularly when the basin has enlarged, they depict strong N-S and E-W elongations oblique to the formational trends. These skewed alignments indicate effects of Active Tectonics in basin development. To evaluate basin development, twentynine morphometric parameters defining indices of drainage network, basin geometry, intensity of dissection and relief have been used. The analysis reveals localised vigorous headward enlargement of component basins. Incidentally, such vigorous erosion is confined in areas of heavy deforestation and basins with reactivated lineaments.

The correlation of nineteen morphometric parameters for all third, fourth and fifth order basins was studied. The analysis reveals that all nineteen parameters do not depict interdependency and have not contributed equitably in the development of drainage hydraulics. The third, fourth and fifth order component basins do not have identical parameter groups with positive or negative mutual correlation. The basin areas and parameters do not increase proportionately with rise in drainage density and drainage frequency in the same order component basins. It is suggestive of topographic unloading rather than basin enlargement i.e. presence of vigorous erosional conditions in the component basins.

Broadly, the basin is divisible into Alluvial Domain, Hill Domain and Plateau Domain with distinct landforms and denudational imprints. The Alluvial Domain is confined in the terminal part of the basin in and around Amjonggaon, Nelli and Pataguri and forms a part of Umiam-Kopili-Brahmaputra bankline oscillations. As a result, it has multiple Holocene-Pleistocene terraces. The younger terraces are flood prone while the older terraces are stabilized and support settlements and tea plantation. The Hill Domain is part of the uplands commencing south of Amjonggaon and extending upto the central part of the basin. It represents exhumed topography with overprinting of fluvial cycles. As a result, the landscape has lost its plateau appearance but, the accordance of summits is still persisting preserving its plateau character. The Domain is conspicuous with rounded and irregular domal topography expressed over the Granitoid Plutons. Strong structural adaptation of streams along lineaments as well as the warped gneissosity peripheral to the Granitoids and fold traces is conspicuously seen in this Domain. The Plateau Domain extends from near the central part of the basin to its headwaters. The imprints of polycyclic rejuvenation and erosional surfaces are very well evident in this Domain compared to Alluvial and Hill Domains.

The Umiam lake occupies a NE-SW trending linear depression in this Domain, northeast of Shillong. The construction of this lake has modified the hydrologic factor in the stream regimen. The lake acts as a local base level impeding the bedload carrying capacity of the river.

The geomorphic characters in the basin reveal presence of various geomorphic risks like escarpments, gorges, steep slopes, palaeolandslide lobes, reactivated lineaments, swamps, flood prone areas, bankline oscillations etc. These risks cannot be avoided but their recognition helps in suitably planning developmental schemes for harnessing the natural resources in the area for sustainable development. The concept of sustainability emphasises on optimal resource utilisation with inbuilt conservation measures. In fact, sustainable development is the objective of geoenvironmental management. In its most simple meaning, it is like a "resource budget" i.e., an inventory of resources, an inventory of existing geohazards, the likely geohazards at the time of exploitation of resources and mitigation and conservation measures.

The Umiam basin is at the threshold of development. Unfortunately, the developmental activities have so far largely remained concentrated in the southwestern part of the basin, centred around Shillong Agglomeration. The various environment protection regulations are not being enforced under the prevailing landholding system in this part of the country. As a result, the resource exploitation and the developmental schemes have extensively degraded the landscape in the basin by Man Induced Geohazards (MIG) like deforestation, land scarring, upland erosion, silting of Umiam lake, waste dispersion, landslides etc. As a result the MIG has overtaken the Terrain Inherited Geohazards (TIG) in the basin due to unplanned and over exploitation of resources.

The identification of different geomorphic risks and geohazards have been utilised to prepare Geohazard Zonation Map of the basin based on numerical ranking system. This map is useful for rationalising land resource utilization and developmental planning. The basin is divisible into five Geohazard Zones viz., very low, low, moderate, high and very high. Over 52% area of the basin falls under moderate to very high Geohazard Zones indicating the fragile status of the basin. The area suitable for resource exploitation is restricted to very low and low Geohazard Zones only with minimum Man Induced Geohazards.

Recommendations

To check further geoenvironmental degradation in the basin as well as to reclaim the degraded landscapes, following strategies are suggested.

(1) Large tracts in the basin are in the process of transforming into wastelands due to unplanned and over exploitation of natural resources. The resource base potential of the basin should only be harnessed as per terrain characteristics so as the Man Induced Geohazards in the basin do not overtake the Terrain Inherited Geohazards.

(2) The infrastructural facilities net and the developmental activities to be spread throughout the basin with emphasis on generation of value added end product resource utilisation. Promotion of heavy industries should be discouraged in the dissected hilly upland and small scale environment friendly industrial base should be preferred. This calls for introducing agro -forestry - horticulture, diary - livestock, poultry, fisheries, apiculture, sericulture and tourism industries in the basin. The whole aim is to upgrade the socio-economic conditions of the inhabitants of the basin by resource utilisation and activities not injurious to the landscape health of the basin.

(3) The land holding/tenure system in this part of the country gives little or no scope for enforcement of environment protection laws thereby; promoting only indiscriminate land resource utilisation. This single factor has introduced wide spread geoenvironmental degradation in the basin. The present land tenure system needs to be suitably amended for conservancy of natural resources and reclamation of degraded landscape i.e. to promote sustainable development.

(4) The development in the entire basin should be conditioned by the Geohazard Zonation Map. Resource exploitation should be avoided in high to very high Geohazard Zones and further enlargement of such zones to be checked by creating a buffer over the Moderate Geohazard Zone. It implies that the moderate zone requires spread of landscape reclamation and conservation measures immediately.

(5) All developmental schemes introduce geoenvironmental degradation of one kind or the other. Since, environmental protection has not to be anti development therefore, it should be mandatory for all developmental schemes to include cost of landscape conservation and reclamation.

(6) The unplanned growth of Shillong Agglomeration in the moderate to high Geohazard Zone is to be checked. The waste dispersion in the Umiam lake should be controlled forthwith by modernising waste disposal system in the constituents of Shillong Agglomeration. Land scarring through indiscriminate quarry operations to be stopped within the urban limits to restore the aesthetic view. The quarry operations should be shifted outside the Shillong Agglomeration.

(7) All constructional activities in the basin should integrate aseismic designing in their structures against earthquake risks considering the seismic proneness of the area. At the sametime, a relief and rescue system should be evolved in the basin to become operative in the eventuality of an earthquake.

(8) The quarries and man made slope instabilities to be minimised to reduce siltation in the Umiam lake. Mining regulations to be enforced and slope profile modifications should be graded for landslide management.

(9) Upland erosion should be checked by encouraging multitier canopy covers through afforestation schemes with peoples participation and social forestry. Logging/Lumbering of immature trees to be totally banned in the area and the reserve forest coverage to be increased in the basin.

(10) Social awareness to geoenvironment to be spread and environment protection to be encouraged as part of personal hygiene ethics.

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