

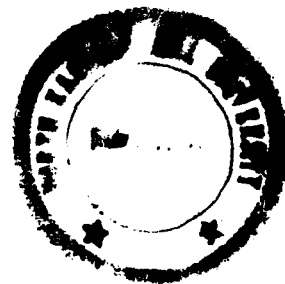
**SLOPE MASS MOVEMENTS AND ASSOCIATED SOILS IN
EAST KHASI AND JAINTIA HILLS OF MEGHALAYA**

ABSTRACT

UTPAL BARUAH

**THESIS SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY**

To



**DEPARTMENT OF GEOGRAPHY
SCHOOL OF ENVIRONMENTAL SCIENCES
NORTH-EASTERN HILL UNIVERSITY**

SHILLONG

SEPTEMBER, 1992

Sherris
eyes

DS
910.0254164
BAR

MEMO
Doc. No. 102495
Doc. by [signature]
Date: 7/21/94
Class. by [signature]
Sub. [signature]
Reviewed by [signature]

The Problem, Objectives and the Study Area :

Slopes are the basic of all landforms and for this reason alone commands the attention of physical geographers. In addition to soil formation slopes directly affect many of man's activities, viz., agriculture, land drainage and major construction which are associated with various kinds of land stability.

Studies on slopes are based on two important concepts viz., form and process. 'Form' applies to the morphology at a given moment of time, and 'process' applies to the happenings and agents active in changing the 'form'. The predominant attributes of hillslope are landform and its composition e.g. soil and rock. Among the various processes the importance of mass movement has been highlighted in many forums. Mass movement is the detachment and downslope transport of soil and rock material under the influence of gravity. The sliding or flowing of these materials is due to their position and gravitational force, but the mass movement is accelerated by the presence of water, ice and air. Thus mass movement considers movements of earth materials at all scales and at all rates. Mass movement occurs when the stresses acting on a hill or a valley side exceed the strength of the material involved. It is reported that the mass movement directly

depends upon the slope angle and strength of the materials. Consequently, the strength of the materials depends on many factors including the role of water. Water in the pore spaces between soil particles or in the cracks of rocks exerts pressure on the surrounding materials. Therefore, water holding capacity, plastic limit and liquid limit which are interdependent factors and are influenced by the texture of the material, are important factors in mass movement. Strength also depends upon its organic matter content, as higher organic matter content reduces cohesion of the soil particles.

Information as to such studies embracing the above factors causing different types of mass movement is very meagre. The main objective of the study will be, therefore, to identify form of slope and types of mass movements that occupy there on, to relate mass movement with slope elements and finally, to investigate relationships between the occurrence of unstable mass movement slopes and their associated soil, and between the occurrence of relatively stable slopes and their associated soils. To throw some light into these aspects, the present study is, therefore, undertaken in Meghalaya, which is famous for tropical monsoon climate having the highest rainfall in the world. The pattern of rainfall distribution is, however, not uniform throughout the year. Geologically, the study area is occupied mainly by

archean gneissic complex, sandstone, shales, limestone etc., which together with peculiar geomorphological setting pose an exclusive field for such study. For this purpose, various sites in East Khasi and Jaintia Hills districts, Meghalaya are included in the study.

Materials and Methods :

1. Physiographic material : Aerial photos of scales 1:60,000 using stereoscope have been interpreted for delineation of broad geomorphic units.

2. Identification of mass movement prone areas : Based on the knowledge gained from aerial photos of the locations having distress instability conditions, field observations are made to examine, identify the slopes and types of mass movements. Slope profile measurements were done with the help of abney level and pit was dug and soil samples were preserved for analysis.

3. Particle size analysis, water holding capacity, liquid limit, organic carbon and pH were determined for each sample as per standard method.

4. Based on severity, types of mass movements observed in this area are scored with numerals 1,2....6.

Description of Sites : Slopes and Soils :

Slope profile and soil analysis were undertaken in ten selected locations. They are Myllem, Ryngngain, Sohiong, Mawlat, Smith, Barnihat, Jarain, Bapung, Komrrah and Sonapur. The first six are located in old hard rock zone of granites and gneisses. The first five offer dominantly natural landscape. Centrally located Barnihat is a localised areas of Jhum cultivation. The other four are localised areas in the southern fringe lying on the younger soft rocks : sandstone, shales and limestone.

RESULTS & DISCUSSION :

Based on severity, types of mass movement observed in the present investigation are arranged as Topple > wedge slide > rockslide > talus creep > soil creep > sheetwash and scoring with numerals 1,2,3,4,5 and 6 were allowed to indicate progressive increase in severity respectively. The highly significant and positive relationship ($r=0.77$) observed between gradient and severity of mass movement in the present study suggest that with increase in gradient severity of mass movement increases.

However, severity of mass movement does not depend solely on the steepness of the slopes rather slope length and

shape of slope come into play in the mass movement. In the present investigation, highly positive and significant ($p=1\%$ $b=.085$) relationship between slope length and severity of mass movement suggest that the increase in severity of mass movement along with parallel increase in slope length.

The above explanation lend support to observed slow mass movement e.g. talus creep, soil creep, sheetwash decrease with gradient form 60-3 %, where slope length of different sites varies from 15 m to 90 m. Increase of slope length with parallel decrease of gradient reduces in velocity of falling of soil and rock masses producing slow type of mass movement. The above results suggest that in rapid and moderate type of mass movement, gradient as explained earlier seems to play major role in determining mass movement irrespective of slope length.

In addition to above, the shape of the slope also plays a vital role in occurrence of different types of mass movement. Three different types of slopes were identified. These can be arranged in order of severity of mass movement as rectilinear > convex > concave. It is found that slow mass movement like sheetwash, soil creep occur in convex slope; topples, wedge slide, rockfall occur in the rectilinear, while there is trace mass movement in the concave slope.

However, geology of the existing rocks might have also played role in the severity of mass movement. It is observed that mass movement e.g. topples, wedge slide, rockfall confined to areas (Mylliem, Ryngngain, Sohiong, Mawlat and Barnihat) developed from hard rock types like granite and gneissic complex, while slow mass movement like soil creep, talus creep occurred on soft rock zone (Bapung, Jarain, Sonapur, Komrrah)viz, sandstone, shale etc. The reason may be attributed to variations in heat penetration between types of rocks. But in case of Smith, the above observation does not hold good. Smith, which occurred in hard rock zone, experiences only mass movement viz. sheetwash and soil creep which can be attributed to low gradient.

The study reveals the following important soil properties as regulated by slope.

(i) Thickness of A horizon shows an inverse relationship with gradient.

(ii) Soil colour depends upon their position on slope profile interacting with organic carbon content and local drainage condition. For example, soils of Ryngngain C with high organic carbon gives rise to very dark grayish brown colour (10 YR. 3/2). While imperfectly drained soils of low organic carbon of Komrrah E give rise to yellowish brown

colour (10 YR. 5/6).

(iii) Proportion of finer soil particle to coarser size distribution shows significant negative correlation with gradient. Variation in the ratio amongst in soils are explained by accumulation due to mass movement, particle sorting, shape of slope, aspect, land clearing and management practices.

(vi) Organic carbon tended to decrease with increase of slope. Variation in the above is explained by erosion and mass movement, drainage condition, aspect, clearing of natural vegetation, human disturbances and microbial activities.

(v) Both water holding capacity and liquid limit behaved the trend of either finer soil particles or organic matter content.

(vi) pH distribution does not show any relationship with gradient.

AMU Library
Acc. No 102495
Acc. by [signature]
Date 7/5/94
Class by
Sub. heading by
Author
Described by

**SLOPE MASS MOVEMENTS AND ASSOCIATED SOILS IN
EAST KHASI AND JAINTIA HILLS OF MEGHALAYA**

UTPAL BARUAH

THESIS SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

To



DEPARTMENT OF GEOGRAPHY
SCHOOL OF ENVIRONMENTAL SCIENCES
NORTH-EASTERN HILL UNIVERSITY



SHILLONG

SEPTEMBER, 1992

Geo.

DS
910.0254164
BAN

MEMO
Acc. # 102495
Dec 24
Date 7/5/94
Clerk [Signature]
Sub by [Signature]
Date [Signature]
Transcribed by [Signature]

22/9/95

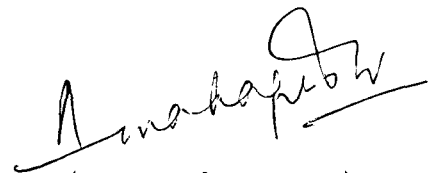
Dedicated to my Parents
Mr. Saroj Kumar Barua
Mrs. Saila Barua

Dr. A.C.Mohapatra,
Professor & Head,
Department of Geography,
School of Environmental Sciences,
NEHU, Shillong - 793014.

September 20 , 1992

This is to certify that the dissertation, titled "Slope Mass Movements and Associated Soils in East Khasi and Jaintia Hills of Meghalaya," submitted by U. Baruah, Doctoral candidate is a bonafide study to the best of my knowledge and belief. Quotations and references to works of other authors have been duly acknowledged.

The dissertation can now be placed for evaluation.



(A.C.Mohapatra)

A. C. Mohapatra

HEAD

Department of Geography
North-Eastern Hill University
Shillong-793014.

CONTENTS

	Page No.
Acknowledgment	i
Preface	iv
List of Figures	vi
List of Tables	viii
Chapter I	
Introduction	1
Chapter II	
Materials and Methods	24
Chapter III	
Description of Sites : Slopes and Soils	34
Chapter IV	
Discussion	96
Chapter V	
Summary and Conclusion	111
Appendix	116
Bibliography	118

ACKNOWLEDGMENT

This thesis was prepared under the supervision of Dr. A. C. Mohapatra, Professor and Head, Department of Geography, Shillong. His valuable comments and suggestions at various stages of the work have improved and enriched this study. I express my deep sense of gratitude to him.

I express my deep sense of gratitude to Professor S.K. Chandra, Jawaharlal Nehru University, New Delhi, for his valuable suggestions and guidance, in preparation of the thesis.

In the preparation and completion of this work, I owe a debt of gratitude to Dr. G.S. Chamuah and Dr. A.K. Maji, Scientist of National Bureau of Soil Survey and Land Use Planning, ICAR, Jorhat, who have greatly helped me at every stage of this work. Without their constant help, encouragements and valuable suggestion, this work would not have been possible.

I express my sincere thanks to Dr. H.K. Chamuah and Mr. E. Shanpru, Soil Survey Wing, Department of Agriculture, Meghalaya, for their help in carrying out the field work.

I am grateful to Dr.J.L. Sehgal, Director, National

Bureau of Soil Survey and Land Use Planning, ICAR, Nagpur, for sanctioning the leave to undertake this study.

I express my sincere thanks to Dr. N.P. Goel, Dr. B.S. Mipun, Dr. S. Sarmah and others of Department of Geography, NEHU for co-operation at various stages.

In addition to these, I thank to Prasanta Dutta, Atul Kalita, D.R. Gogoi, Shyamali Chetia, Dilip Dutta, Durga Dutta, Puspa Dutta and L. Barchetia, NER Centre, NBSS & LUP, ICAR, Jorhat for their help.

I would like to thank my uncle, Sjt. G.D. Bhagawati and aunt, Sjta. L. Bhagawati for what all they have done for me, but for their help, this work could not have been completed, I am grateful to them.

My family has been especially helpful in all my endeavours. I express my heartfelt gratitude to my father and mother, Mr. & Mrs. S.K. Baruah for their warm encouragement, my wife Anuva, and children, Rajarshi and Priyanki, for their moral support and patience throughout the research work.

(ii)

Finally, I express my sincere thanks to Miss Advicy Nongrum for typing the manuscript.

Department of Geography

NEHU, Shillong - 14

Date : 30.9.92

Utpal Baruah

(UTPAL BARUAH)

PREFACE

Writing a doctoral dissertation is at the same time a rewarding experience, a sense of fulfillment and at the same time an exasperating affair, particularly in the mid-stream of life with compelling and competing demands on time and energy. However, the unending search for laws, theories and explanations, a journey of self exploration while exploring the world of nature is, after all, what all doctoral research aims at. I am not sure if such lofty aims have been fulfilled or not but this journey in the quest of knowledge is certainly rewarding.

Study of mass movements can commonly be grouped under the category of 'weathering,' 'slopes' and 'soil mechanics'. Of late, the study of mass movement especially landslides, together with the associated technique of soil mechanics, has grown into a major branch of slope geomorphology. There are many studies where emphasis was made on the stability of slopes against landsliding. But mass movement studies embracing pedogenic aspect are rather very few in the international scenario. In this thesis a modest attempt has been made to bridge the challenging gap on some selected mass movement prone areas of East Khasi and Jaintia Hills of Meghalaya.

(N)

In the process of the study and compilation till the present state, help from many quarters have come which have been duly acknowledged. Omission, commission and errors, wherever they are in the text are the sole responsibility of the author only.

Dated the 30th September, 92.

Shillong.

Utpal Baruah

U. Baruah

Scientist (SG)

National Bureau of Soil

Survey and Land Use

Planning, ICAR,

Jorhat - 785013.

LIST OF FIGURES

Number	Title	Page No.
1.1	Constituents of Slope forms	2
1.2	Location of Study area	7
1.3	Monthly distribution of rainfall and temperature in Shillong and Cherrapunji	10
1.4	Altitudinal zones	11
1.5	Natural drainage and catchments	13
2.1	Physiography - East Khasi and Jaintia Hills	25
3.1	Location of Myllem	35
3.2	Form of hillslope, Myllem	37
3.3	Trend of soil characteristics at Myllem	40
3.4	Location of Ryngngain	42
3.5	Form of hillslope, Ryngngain	44
3.6	Trend of soil characteristics at Ryngngain	46
3.7	Location of Sohiong	48
3.8	Form of hillslope, Sohiong	50
3.9	Trend of soil characteristics at Sohiong	52
3.10	Location of Mawlat	53
3.11	Form of hillslope, Mawlat	55
3.12	Trend of soil characteristics at Mawlat	57

3.13	Location of Smith	59
3.14	Form of hillslope, Smith	61
3.15	Trend of soil characteristics at Smith	63
3.16	Location of Barnihat	65
3.17	Form of hillslope, Barnihat	67
3.18	Trend of soil characteristics at Barnihat	69
3.19	Location of Jarain	71
3.20	Form of hillslope, Jarain	73
3.21	Trend of soil characteristics at Jarain	75
3.22	Location of Bapung	77
3.23	Form of hillslope, Bapung	78
3.24	Trend of soil characteristics at Bapung	81
3.25	Location of Komrrah	83
3.26	Form of hillslope, Komrrah	85
3.27	Trend of soil characteristics at Komrrah	87
3.28	Location of Sonapur	89
3.29	Form of hillslope, Sonapur	91
3.30	Trend of soil characteristics at Sonapur	93

LIST OF TABLES

Sl. No.	Table No.	Caption /	Page
1.	1.1	General stratigraphic sequence of geological formations	8
2.	2.2	Range of soil depth and its description	32
3.	2.3	Types of mass movements and their scores	33
4.	3.4	Soil characteristics of Myllem	41
5.	3.5	Soil characteristics of Ryngngain	47
6.	3.6	Soil characteristics of Sohiong	51
7.	3.7	Soil characteristics of Mawlat	58
8.	3.8	Soil characteristics of Smith	64
9.	3.9	Soil characteristics of Barnihat	70
10.	3.10	Soil characteristics of Jarain	76
11.	3.11	Soil characteristics of Bapung	80
12.	3.12	Soil characteristics of Komrrah	88
13.	3.13	Soil characteristics of Sonapur	95
14.	4.14	Sites showing gradient, length, shape, mass movement, rock types and thickness of 'A' horizon.	96
15.	4.15	Correlation matrix between soil variables and average gradient	109

CHAPTER - I

INTRODUCTION

1.1. The problem:

Slopes are the basic of all landforms and for this reason alone, it commands the attention of physical geographers (Clark and Small: 1982). In addition to soil formation (Jenny, 1941), slopes directly affect many of man's activities, viz. agriculture, land, drainage and major construction activities etc. which are associated with various kinds of land instability. Understanding the mechanisms of slope development constitute a vital task for the applied geomorphologist. Studies of the slopes highlighting relationship between pedology and geomorphology have been strengthened through several innovative works. (Pandey et al. 1967; Roy et al. 1967; Wooldridge, 1949, Twidale, 1959). They stress the need to study the processes and forms of slope development and their relationship with soil morphological and genetic properties.

Studies on slopes are based on two important concepts viz. form and process. 'Form' applies to the morphology at a given moment of time, and 'Process' applies to the happenings and the agents active in changing the 'form'. Young (1972), distinguished the form and process in terms of descriptive

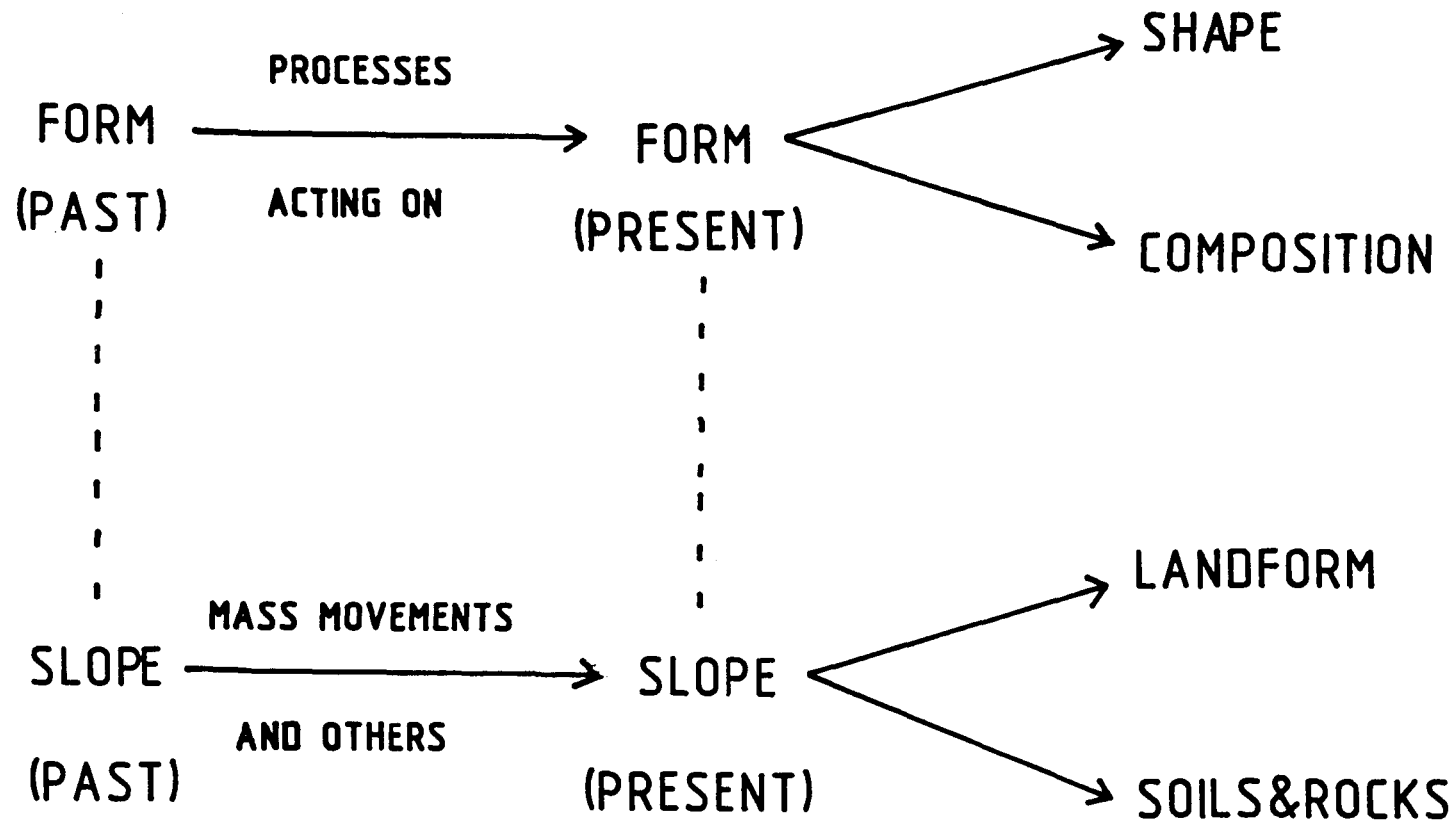


FIG.1.1. CONSTITUENTS OF SLOPE FORMS

and genetic approaches. The form of a slope may be divided into elements or sections of uniform gradients, separated by breaks of slope i.e. point at which the angle of the slope changes.

Processes operating on slopes include weathering and mass movement resulting in the present landform, which can be shown in Fig.1.1.

The Figure 1.1 elucidates that an important attribute of hill-slope is landform and its composition of soil and rocks. Among the various processes, the importance of mass movement has been highlighted in many fora. Mass movement is the detachment and down slope transport of soil and rock material under the influence of gravity. The sliding or flow of these materials is due to their position and gravitational force, but the mass movement is accelerated by the presence of water, ice and air. Thus, mass movement considers movements of earth materials at all scales and at all rates. Therefore, the slow downslope creep of soil and rock fragments, as well as, the rapid movement of large landslides over long distances are both mass movements (Chorley et al. 1985). Mass movement occurs when the stresses acting on a hill or a valley side exceed the strength of the material involved. It is reported that the mass movement directly depends upon the slope angle and strength of the materials. Consequently, the strength of the materials depends on many factors including the role of water. Water in the pore

spaces, between soil particles or in the cracks of rocks exerts pressure on the surrounding materials. Therefore, water holding capacity, plasticity limit and liquid limit are interdependent factors (Baver, 1972) and are influenced by the texture of the material which are important factors in mass movement (Chorley et al, 1985). Strength also depends upon its organic matter content, as higher organic matter content reduces cohesion of soil particles (Kuntze, 1967).

1.2: Objectives:

Information as to such study embracing the above factors causing different types of mass movements is very meagre. The objectives of the study therefore, are :

(i) to identify the form of the slope and types of mass movements that occupy there on;

(ii) to relate mass movement with slope elements and finally;

(iii) to establish a relationship of associated soil properties with relatively stable and unstable slopes as effected by the said mass movements.

1.3: Approaches :

Before going into the details of the methodologies as per the objectives, it is necessary to understand the major approaches to the evolution of slopes.

1.3.1. The slope Evolution Approach :

This is concerned with the historical development of the slope, its evolution to its present day form and forecasting of the future slope forms. However, there are

problems associated with this approach, such as to reconstruct the initial form to the present slope in relation to time sequence. It is believed that the oldest slopes are the gentlest and the younger slopes are appreciatively steep. A theory of slope decline to be applied to the area of study is far from easy, though in some instances it can be done crudely (Small, 1985).

1.3.2. The Process-form Approach :

The approach is based on a reasonable assumption that there is a direct causal relationship between the processes of weathering, transportation, erosion and deposition of soils and the form and gradient of slopes. The immense variety of slope forms and the steepness observable in the field is regarded as the outcome of the processes of denudation operating in varying combinations and with different degrees of relative effectiveness in areas of different rock types, structure, climate, vegetation, relief etc. Processes operating on slopes are generally very slow. For very precise and accurate assessment at all stages, it is necessary to know about the nature and speed of operation. Secondly, it is not easy to demonstrate that all the slope processes have any direct effect on the form of denudational slopes. Thirdly, one of the most teasing problems associated with the process-form approach is that in majority of instances, slopes are not the product and of the present day process. Lastly, process-form approach is concerned with the

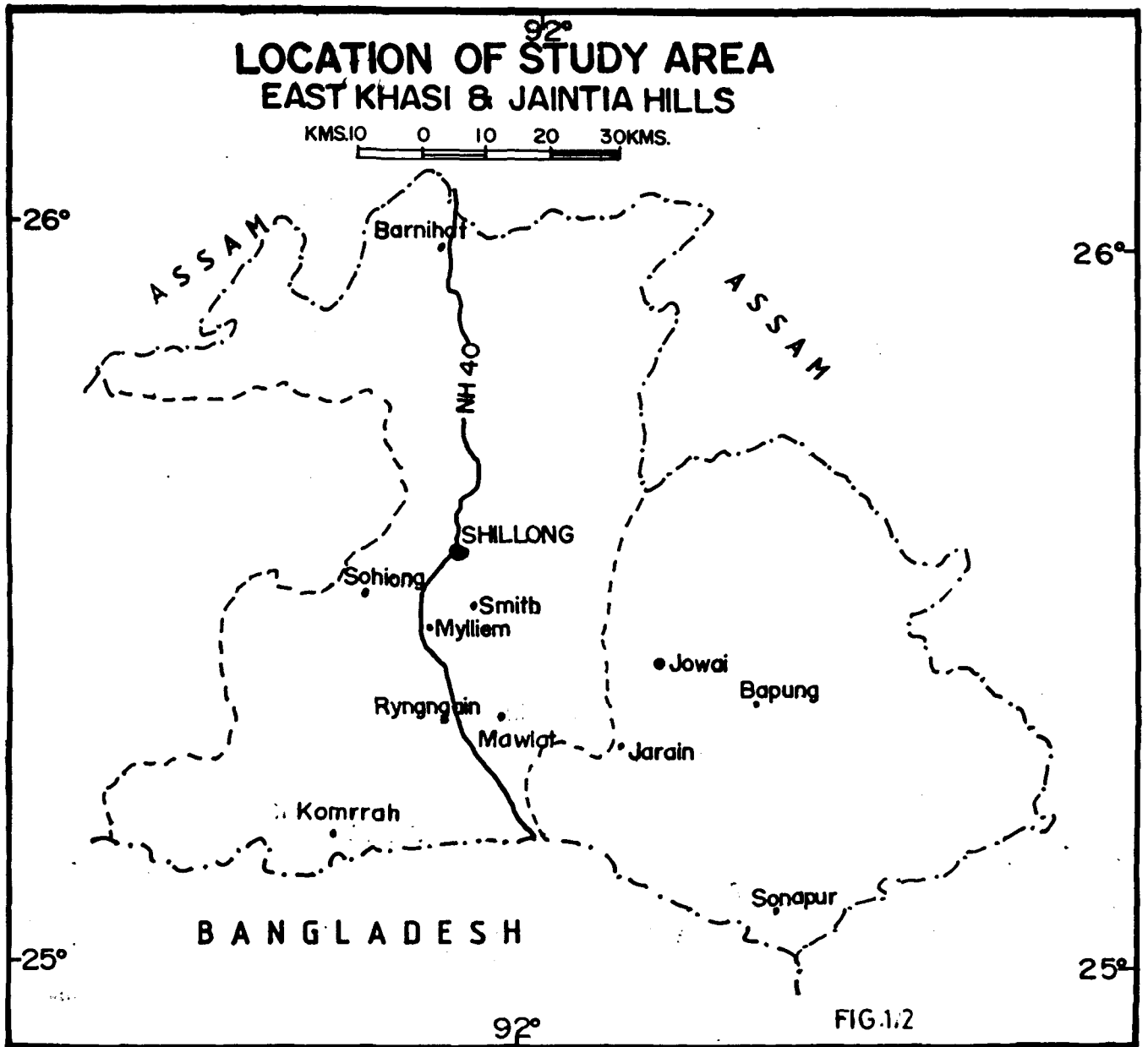
concept of climatic geomorphology.

The above discussion reflects the view that formulation of theories of slope evolution remains largely a speculative task, although modern techniques, such as age stone orientation, pollen analysis, study of land mollusca, etc. are utilized to overcome the difficulties faced in relating form to process. Nevertheless, present form and process can be observed during the survey and evidence of past processes can be derived from evidences. In the present study, therefore, a process-form approach is adopted considering the inherent difficulties like the complexities of processes, the slowness of form change and micro-level spatial diversity of the environmental conditions.

1.4: Brief Description of the Study Area :

Study pertaining to slope mass movement and associated soils and problems arising out of it has hardly been dealt within India. The State of Meghalaya is famous for tropical monsoon climate with the highest rainfall zone in the world. The rainfall distribution is however, not uniform throughout the year, which has a great impact on the strength of the soils. Geologically, the state is occupied mainly by Archean gneisses, sandstones, shale, limestone etc., which together with the peculiar geomorphological setting poses as an exclusive field for such a type of study.

Various locations in the East Khasi Hills and Jaintia Hills districts, Meghalaya, were included in the study. They



are situated between 25° 5' to 26° 6' N latitudes and 91° 20' to 92° 47' E longitude and bounded by Kamrup and Nowgong districts of Assam to the north, Bangladesh to the south, North Cachar and Karbi Anglong districts of Assam to the east and West Khasi Hills district of Meghalaya to the west. A location of the two districts are shown in Fig.1.2.

1.4.1 Geology :

Geological investigations made in Meghalaya has been systematically reported in Miscellaneous publications of GSI, 1974 and are presented in a tabular form.

Table 1.1

General Stratigraphic Sequences of Geological Formations
(Khasi and Jaintia Hills)

Geological Age (1)	Group Name (2)	Formation name (3)	Rock Types (4)

GROUP : SYSTEM			
Quarter-Recent 1	Newer alluvium (thickness not known) 1	Unclassified	Sand, silt & clays

	Pleistocene 1 (1)	Older alluvium (thickness not known)	Unclassified Sand, clay, pabble, gravel and boulder deposits.

-----Unconformity-----			
Tertiary or Eocene	Jaintia group	Simsang formation	Silts- sand stone alternations, sand.
Mesozoic	27(65)	Shella	Alternation of sandstone limestone.

1	2	3	4
		Langpur Formation	Calcareous shale, sandstone, limestone.
Secondary or Mesozoic 180	Upper Cretaceous 75 (140)	Khasi group Mahadek formation Bottom conglomerate formation Jadukata formation	Arkose (glauconitic) Conglomerate, arkose Sandstone Conglomerate alternations
-----Unconformity-----			
secondary Mesozoic	of Jurassic 60(200)	Sylhet Trap	Basalt, alkali basalt, rhyolite acid tuff.
-----Unconformity-----			
Precambrian or Archean	Precambrian (2500)	Intrusives (Acid & basic)	Porphyritic and coarse granites pegmatite, aplite quartz vein epidiorite, dolerite, basalt
		Shillong group	Quartzite, phyllite, conglomerate
-----Unconformity-----			
	Archean (2500)	Gneissic complex	Biotite, gneiss biotite hornblende gneiss granitic gneiss migmatite, mica schist, sillimanite-quartz schist, biotite-granulite, amphibolite, pyroxene-granulite, etc.

Source : G.S.I., Miscellaneous Publication, No. 30, Shillong, 1974.

* Figures without brackets show the total duration of the Group or System in millions of years, while those within brackets show the lapse of time from the beginning of the particular era or period to the present.

MONTHLY RAINFALL AND TEMPERATURE DISTRIBUTION

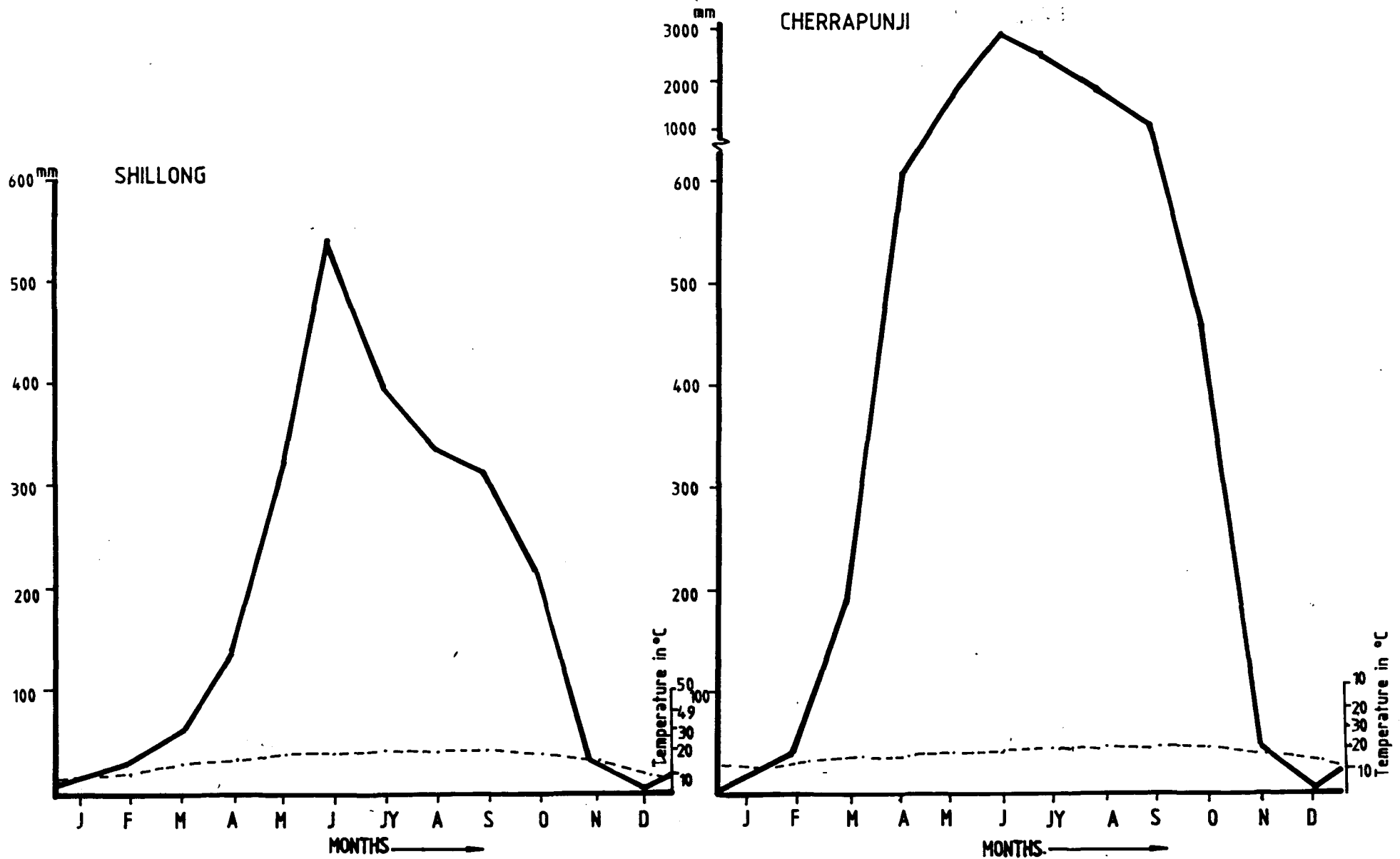


FIG. 1.3

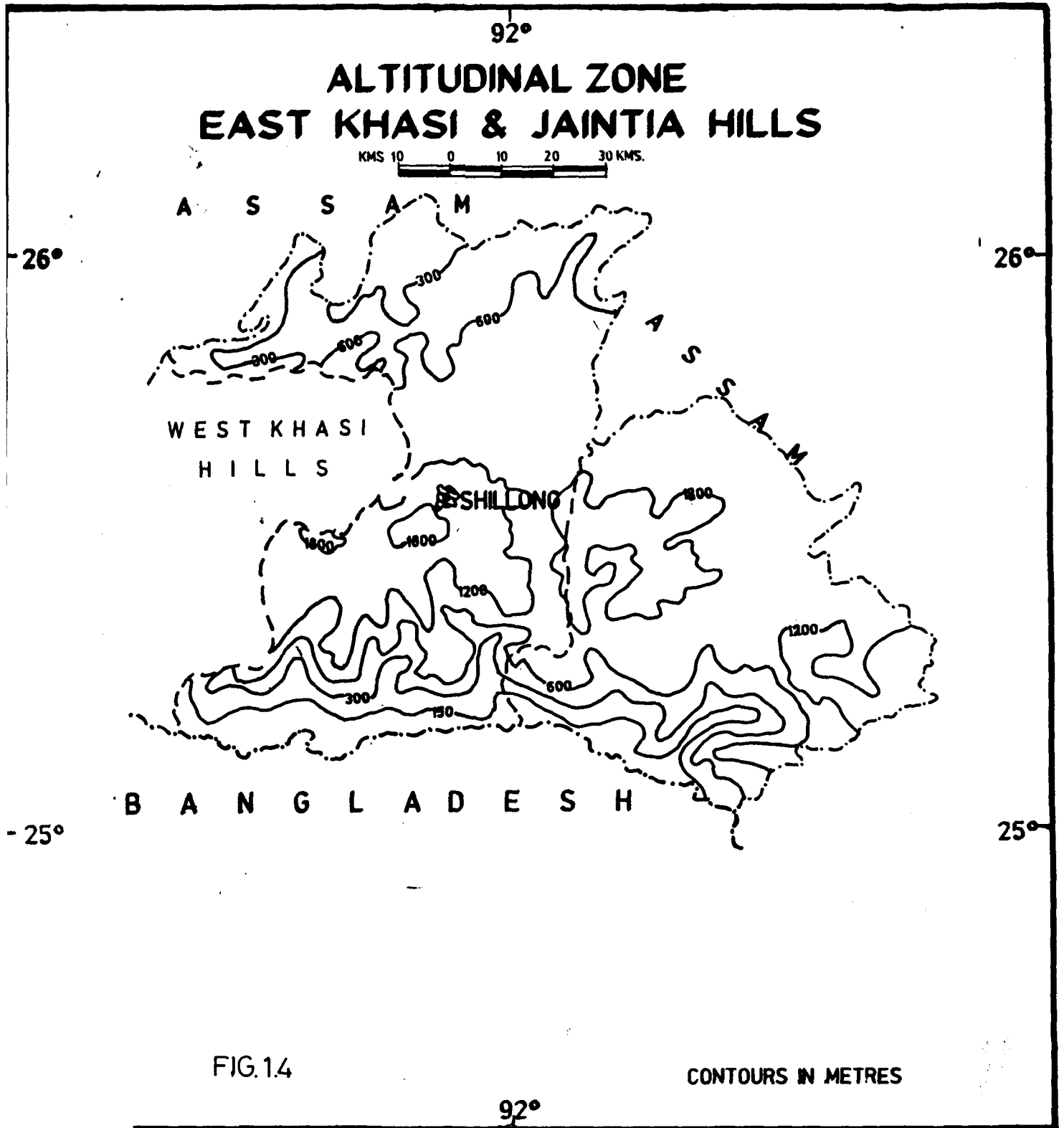


FIG.14

CONTOURS IN METRES

The gneissic complex is apparently overlain by the Shillong series in the Precambrian times, when the central part i.e. East Khasi Hills and central Jaintia Hills were developed into a trough over which the sediments of Shillong group of rocks were overlaid.

1.4.2. Climate :

Overall the climate of the districts is characterised by moderately high to high precipitation, moderate to high humidity and low to moderately high temperature. The climate is mostly governed by altitude and south west. Average monthly rainfall and mean maximum and mean minimum temperature are given in Appendix-I.

As in other parts of the region, Meghalaya is a typical example of the influence of monsoonal climate, by far the greater quantity of rainfall occurs due to the south-west monsoon days (June to September) and the post monsoon effects (October to November) by the retreating monsoon. Fig. 1.3 shows monthly distribution of rainfall and temperature in the station viz. Shillong and Cherrapunji.

1.4.3 Relief and Drainage :

Study of contours reveal that 1200 m contours demarcate the Central Plateau comprising Shillong, Nongstoin and Jowai town. However, there are three patches between Shillong and Nongstoin which are above 1800 m contour m.s.l. (Fig. 1.4). This zone above the 1200 m acts as the watershed from where

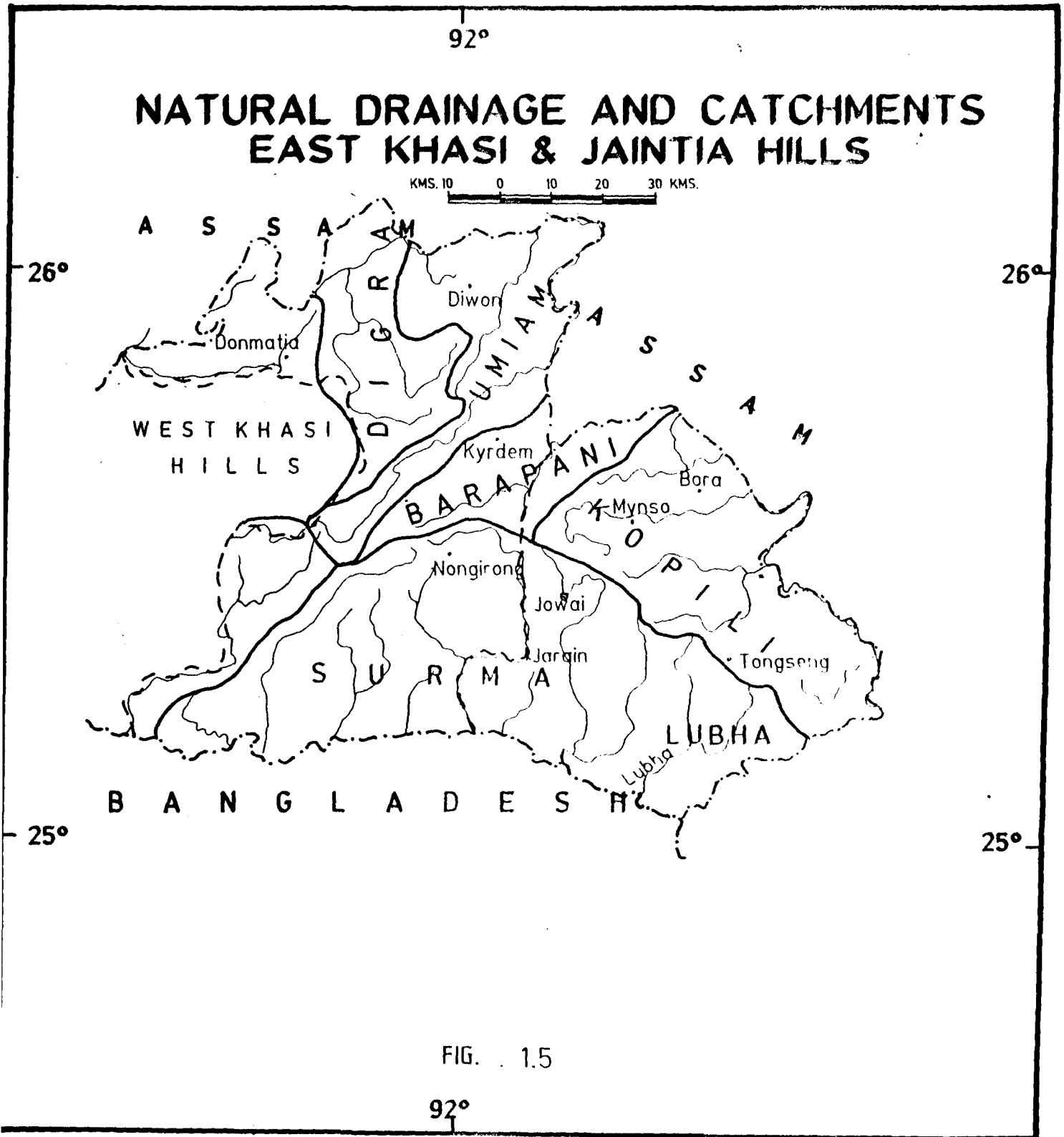


FIG. 15

92°

the tributaries like Kopili, Umiam, Digra, Khri and Umtrew flow towards the north to Assam valley and Surma, Jadukata and Lubha rivers to the south towards Bangladesh. The northern rivers flow to the Brahmaputra and southern rivers flow to Meghna (Fig. 1.5).

The subtributaries of Umiam form a rectilinear drainage pattern in NE-SW direction, Khri's tributaries in NW-SE direction, Jadukata and Kapili in NE-SW direction and tributaries of Surma flow in N-S direction. The rectilinear pattern of all the drainages is a distinctive feature of Shillong Plateau. Most of them have extraordinarily straight courses, evidently along joints and faults. The magnificent gorges scooped out by the rivers of south part of Khasi and Jaintia Hills are the result of massive headward erosion by antecedent streams, along joints of sedimentary rocks. The relief drops down rather abruptly both in north and south towards the Brahmaputra and Meghna valley respectively.

1.5: Review of Literature :

Mass movement is an exogenetic slope forming process and comprises all such gravity induced movements except those in which the materials are carried directly by transporting media such as ice, snow, water, or air. This process is termed as mass transport (Hutchinson, 1968). He stated that in Nature, both the processes are so much intermingled that it is difficult to visualise one process from the other. On the basis of geology, climate and topography, Hutchinson

classified mass movements into eight broad categories and further sub-divided them into twenty four divisions. Further, he pointed out that in every slope, gravity produced shearing stresses exist, which increase with slope inclination, and the height and weight of the slope forming material. Carson and Kirkby (1972) classified mass movements under seven groups according to mechanisms (heave, slide and flow) and moisture content.

The process of instability or mass failure in soils has been largely neglected by geomorphologists until very recently. It is true that Sharpe as long ago as in 1938, produced a classification of mass movements and since then, his ideas have been presented in almost as a text book in geomorphology. Instability processes in soil masses have not changed substantially till the works of Ward (1945), Skempton (1948) and Terzaghi (1950). Terzaghi described mechanism of landslides in application of geology and engineering practices.

Paleolandslide studies often focus on establishing chronologies for major mass movements, many of which can be related to the tectonic process as evident from Curry and Melhorn (1990), Fillion et al, (1990) and Campbell and Evans (1990) have undertaken studies at various sites in America and Canada. Curry and Melhorn (1990) propose tectonic subsidence as a factor determining in the landslides of the development of Summit Lake Basin. Brusden and Jones (1974)



studied the form and evolution of an active complex on the Dorset Coast. They identified two mechanisms namely, viz. rotational landslide and block disruption. Chorley et al (1985) also showed the relationship between mass movement and tectonic processes and summarised that where relief, slope inclination, rock types and climatic conditions are favourable, mass movements can dominate the landscape. However, within the landscape, mass movement can occur at position dependent on aspect, slope configuration, slope angle and of course, zones of weak rock and closely jointed rocks. O'Loughlin (1972) working in the coastal range of British Columbia reported that most landslides do not occur on the steepest slopes; rather slopes of intermediate inclination are most susceptible. He observed, most landslides originate on slopes between 31° and 39° in the mountains. Slopes steeper than 40° are rocky and lack soils that are involved in mass movement. Chorley et al (1985) cited that in Los Angeles Mountains the soil slips occur most frequently between 26° and 45° . On gentler slopes, the gravitational forces are not adequate to produce slippage, and on steep slopes rainwash and other erosion processes have kept the soils thin and rocky, thereby preventing mass movement.

Carson and Kirkby (1972) visualised that a strong well jointed rock mass is likely to pass through three phases; an initial phase while the cliff face is replaced by a scree slopes a second phase with the change from a scree slope to a

taluvial slope; and a third phase during which the ultimate soil mantled slope emerges. The number of phases of instability which occur in a landscape depends very much on the history of disintegration of the rock material although other elements such as the climate may also be important. They are of the opinion that cut in the rocks are fractured and jointed so much that they are virtually cohesionless, but because of the high density of packing, the angle 'Fi' is about 43° - 45° . Such slopes contain relatively large voids and probably do not develop pore pressures greater than atmospheric pressure. The stable angle of slope thus, corresponds with the 'Fi' value of the material in the dense state. This angle is common in shale badlands. Strahlar (1950) noted that many slopes in the Verdugo Hills occurred at this angle. Similar is the case of an angle ranging between 33° - 38° slopes mantled by the same type of materials as in the case of 43° - 45° with looser state of packing. The 'Fi' value of this material is much lower, and approximates to the angle of repose. However, the slopes of 25° - 28° results in taluvial slope and slopes of 19° - 21° develop a higher percentage of sand slopes and it is assumed that the pore pressure pattern plays a dominant role. Goudie (1990) has defined both rapid and slow mass movement processes and mentioned that only one aspect of slope geometry is significant in stability i.e. slope angle.

Statham (1976) presented a model for the scree slope accumulation. He found that most scree slopes have a

straight upper slope and a basal concavity. This is due to the exponential distribution of particle travel distances, producing an exponential wedge of materials on the accumulation slope. Secondly, the angles of straight scree slopes are usually lower than the angle of repose because of movement of fallen particles moving over a scree becomes sorted since small particles experience greater resistance to motion on the rough surface. Thus, smaller particles are more easily trapped in depressions.

Weathering and rock character are important factors in determining mass movement type and frequency. Durgin (1977) related mass movement to the weathering of granitic rocks during the erosional evolution of a granitic terrain. He recognised four stages of granitic weathering; fresh rock, corestone, decomposed granitoid and saprolite. According to Durgin, fresh rocks subjected to rockfalls, rockslides and block slides are controlled by fractures. The corestone stage is characterised by rock rockfall avalanches. Decomposed granitoid is characterised by debris-flows, debris-slides and saprolite is vulnerable to slumps and earthflows. Durgin states that failures in granitic rocks are most common in stage four, which is achieved in areas of intense chemical weathering. Therefore, mass movement will be important in the humid tropical areas of the world.

Varnes (1978) has summarised the causes of mass movements under two broad headings (i) factors that contribute to increased shear stress and (ii) factors that contribute to

reduced shear strength. Under (i), he lists five main factors, viz. (a) Removal of lateral support, (b) Surcharge, (c) Transitory earth stress, (d) Removal of underlying support and (e) Lateral pressure and under (ii) he puts four main factors, viz. (a) Weathering and other physico-chemical reactions, (b) Changes in intergranular forces due to water content (porewater pressure), (c) Changes of structure and (d) Organic factors. He further elaborates the causes with a detailed list of factors.

Prior (1968) made a detailed study where the composite mudflows are divided morphologically into three parts, viz. a source area, flow track zone, and a depositional toe zone. Earthflow, displaying viscous fluid deformation, is a part of the study of landslides. Crozier (1969), studied the factors of earthflow in Eastern Otago. He took the climatic parameters viz., soil moisture, evaporation and rainfall. He found that variations of earthflow movement are most closely associated with variations of rainfall during winter and the early spring period when evaporation and temperature are lowest and soil moisture is high.

Schum (1956) has studied the role of creep and rainwash in south Dakota. The broadly rounded interfluves are interpreted largely due to creep. Kirkby (1967) has proposed a theoretical model of soil creep using soil mechanics principles. He found that relative magnitudes of soil creep was due to various important agents in the order of soil

moisture, freeze-thaw, burrowing animals and temperature changes.

Recently Terwilliger (1990) added vegetation as another important factors in controlling large mass movements. He identified a link between vegetation on shallow (less than 1 m) slips due to soil water modification in the Transverse Ranges, California. Further he suggested that the depletion of soil water by vegetation and associated lower saturation rates including mass movements is not always correct. Sidle (1985) stated that natural factors influencing the stability of forested hills slope are considered as geologic/geomorphic factors, soil properties, hydrologic factors, vegetative factors and seismicity. These may act synergistically to initiate or accelerate soil mass movement.

The effect of micro climatic variations are also important. Rice et al (1969) in southern California found that the greatest frequency of slides occur on north facing slopes because in this area of Mediterranean climate the north facing slopes are brush-covered, whereas the south facing slopes are grass covered. The deeper root systems of the brush render the north facing slope less resistant to mass movement. Therefore, the effect of aspect changes in the different climatic zones.

The mass movement is generally abundant in concave slopes and rare in convex slopes (Subramaniam and Rao, 1986). They reported that majority of landslides are occurring in the

S and SE facing slopes due to differences in micro-climatic conditions occurring in different aspects of the slopes. The S and SE facing slopes have relatively a larger duration of sunshine to which they are exposed. Consequently the retention capacity of moisture in the subsoil is less and therefore, the growth of vegetation is also correspondingly less. This is evident from interpretation that forest areas restricted to north facing and west facing slopes in this zone.

Lanyan and Hall (1983) predicted higher landscape instability at the areas with high moisture status. Patto et al (1978) found that bonding of soil materials increase with organic matter but high level of organic matter can lead to soil weakness (Kuntze 1967). Bell & O' Sullivan (1987) showed that the shear strength decrease with the increasing water content causing instability of surface materials.

Studies on soil slope relations:

The cause of sequential changes during the development of a soil profile depends on the environment. The relationship between the slope and soil profile development on different slope forms have been reviewed by Beckett (1968). He outlined the slope development phenomena with soil detachability and transportability and stated that in a given landscape the most nature soils will occur on the sites of least gradient.

Furley (1966) showed a close relationship between organic carbon, pH, texture and nitrogen and slope gradient. He reported that organic carbon percent, pH and nitrogen percent decrease with increasing slope gradient both in calcareous and acid soils of Oxford, however, the trend differed with the soils developed from different parent materials and also between upper slope and lower slope. However, Perling (1959) observed decrease in pH and increase in organic carbon with decreasing gradient in chalk soils.

Lateron Furley (1970) made another valuable study on relationship between slope from and soil properties developed over chalk parent materials taking transects represented by quite a sizeable number of soil profiles and their physical and chemical properties of the surface horizons (5-10 cm) provided evidence for interpreting the effect of the length and angle of slope. Multiple regression analysis showed that the combined effect of slope angle and distance down-slope is responsible for much of the variation observed in soil properties.

Pennock et al (1987) established relationship between landform elements and soil morphological properties and found that the thickness of the A horizon showed increased in manner of shoulders < backslope < level < footslope elements.

Gerrand (1990) has carried out hillslope analysis in different parts of England, where he found that relationships do exist between soils and landforms but the idea that many

slopes are integrated along their entire length is not necessarily true. Individual components of slopes possess soil characteristics that appear to be related to the morphological nature of those components but the slopes as a whole, do not possess integrated soil systems. Different parts of the slopes appeared to set independently.

CHAPTER - II

MATERIALS AND METHODS

2.1: Physiographic Material :

Aerial photos of scale 1:60,000 using stereoscope have been interpreted for delineation of geomorphic units and identification and demarketing landscapes, major towns, rivers etc. The major geomorphic units were transferred and presented on 1:1000,000 scale map (Fig. 2.1), and these are described as follows :

(1) Steep Hillslopes with Escarpments and Gorges:

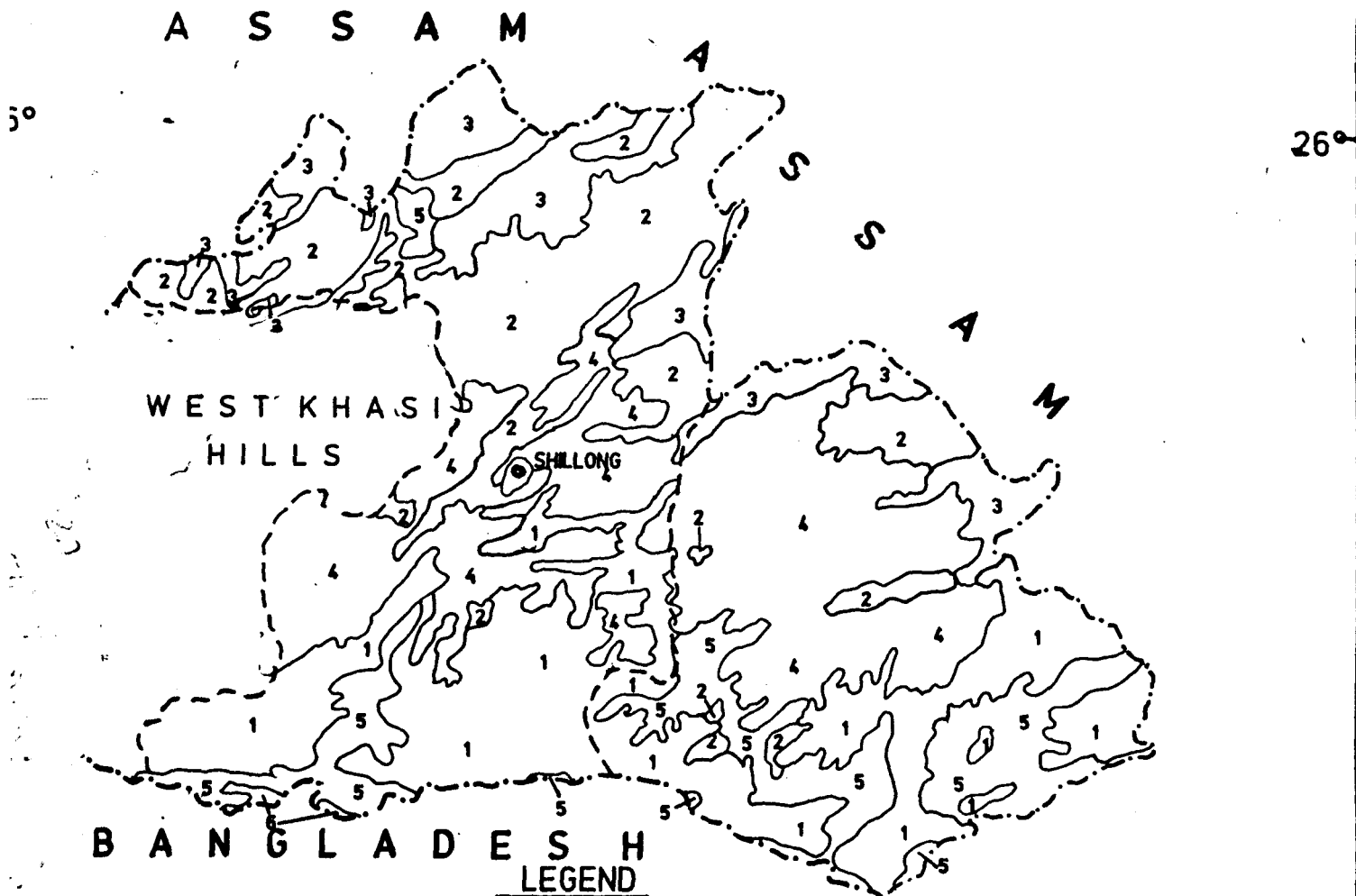
This unit is delineated on the basis of steepness of slope which is above 25 per cent ($>14^{\circ}$). These are highly dissected, folded and faulted with escarpments and gorges. The relief is excessive and irregular, and surface run off is rapid. The surficial materials are skeletal with abundant coarse fragments. The natural vegetation is mostly of tropical moist deciduous types.

(2) Moderate to Steep sloping hills with Ridges & Furrows:

Slopes varying in steepness from 15 to 25 per cent with moderate folds are the main characteristics of this unit. Here, dissection by streams is moderate and relief is subnormal to excessive with rapid run off. Vegetation types

PHYSIOGRAPHY EAST KHASI & JAIINTIA HILLS

KMS 10 0 10 20 30 KMS



LEGEND

- | | |
|---|--|
| <p>1. Steep hill slopes with escarpment and gorges</p> <p>3. Moderate to steep sloping hills with criss cross pattern</p> <p>5. Gently to Moderately steep, rolling ferrain</p> | <p>2. Moderately steep hills with ridge & furrow</p> <p>4. Plateau with low amplitude & moderate slopes</p> <p>6. Valley</p> |
|---|--|

FIG. 2.1

are similar to the first group as observed in this unit. The surficial materials are generally skeletal, comprising 30-40 per cent of boulders.

(3) Moderately Steep Hills with Crisis-cross Pattern.

The severity of all tonal characters on this landform are slightly less as compared to the previous unit. The steepness of slope varies from 8-15 per cent and is moderately to highly dissected. Relief is excessive and runoff varies from rapid to very rapid. It is covered with tropical moist deciduous forest. The land surface of this unit is skeletal with boulders covering 30-40 per cent of this area.

(4) Plateau with Low Amplitude and Moderate Slopes:

The major table-land of Meghalaya is covered under this unit. The altitude of this area ranges from 1200-1800 metres from m.s.l. On the table-land, there are however, hillslopes of moderate steepness and low amplitude. The streams make moderate dissection. The runoff varies from medium to rapid and is covered with subtropical pine forests with few patches of open shrubs.

(5) Gently to Moderately Steep Rolling Terrain:

There are many patches of gently to moderately steep-rolling terrain in the southern part of the plateau, mainly the tributaries resulting out of the side cuttings of streams. Occurrence of these are also not uncommon in

precipitous zones. The steepness of slopes varies from 3-8 per cent, and relief is subnormal to normal. The runoff is medium to rapid and the natural vegetation is tropical moist deciduous.

(6) Valley :

Along the Southern border of the districts of East Khasi Hills and Jaintia Hills along Bangladesh, normal valleys are formed. They are gently sloping to plain (0-3 per cent) with normal relief and gentle runoff. The surficial materials are coarser in nature.

2.2: Identification of Mass Movement Prone Areas :

Based on the knowledge gained from aerial photos of the locations having acute instability conditions, field observations are made to examine and identify different mass movements. The classification is made according to Hutchinson (1968).

(i) Site analysis : Geomorphological site analysis was carried out at each field observation and detailed information was collected about mass movement conditions of slopes and their associated soils. Geomorphological 'sites' have been identified by differentiating slopes into near-planar or regularly curved segments. This is done along measured slope profiles, aligned in the direction of maximum gradient, with equally spaced observation points at 5-15 m intervals, depending on terrain complexity and scale of

analysis. A slope segment less than 15m. size is excluded in this study considering it as local irregularity (Wright, 1973) within the site.

(ii) Slope profile measurements at each site are done with the help of 'abney level' and a pit was dug upto 'A' horizon at each site, one pit upto lithic content at each location and soil samples were collected and preserved for analysis. Important morphological characteristics, e.g. colour, texture, structure etc. were noted as per procedures outlined by All India Soil and Land use Survey (1971).

(iii) Slope : Gradient is measured with the help of two equal lengths of ranging poles placed at a specified distance. The angle of inclination viewed by abney level is the gradient. (Gardiner and Dackombe, 1983) which in many cases is expressed to its equivalent slope percentage. A list of gradients with its corresponding slope per cent is appended in Appendix-II.

2.3: Soil Texture :

Particle size analysis : Soil particle size varies from size limit 0.002 to 2 mm. in diameter and is determined based on Stoke's Law. The Stoke's equation is :

$$V = g \cdot a^2 (D-d) / 18 \eta$$

where V= the rate of fall cm per second,

g= acceleration due to gravity, cm/sec.²

a= diametre of the particle, in cm.

D= Density of the particle, g per cc

d= density of the fluid, g per cc
 n= co-efficient of viscosity of the fluid, poises

The individual soil particles are dispersed in water after removal of organic matter by standard method (Piper, 1950). Particles larger than 0.02 mm. in diameter are separated out by wet sieving. The other particles are determined by pipetting out measured amount of aliquot depending on the specified setting time and depth. It requires 5 minutes for particles 0.02 mm. and 5 hours 30 mins, for clay.

2.4: Water Holding Capacity :

Finely ground soils sieved through 2 mm. mesh were used in Keen & Reckzowaski's Box for determining WHC (Piper, 1950). WHC is calculated with the following formula :

$$\text{W.H.C.} = \frac{Y-Z-W}{Z-X} \times 100$$

where Y = Weight of soil saturated with water in a keen box,
 Z = Weight of the oven dried soil in a keen box,
 W = Weight of moisture absorbed by filter paper,
 X = Weight of the keen box with the filter paper.

2.5: Liquid Limit :

The liquid limit is measured by an apparatus known as Mechanical Liquid Limit Apparatus (Singh, 1966). About 120 gm of the specimen are mixed thoroughly with distilled water to make a paste which is then placed in the brass cup of the liquid limit apparatus and is levelled with a spatula. A

groove is cut with Casagrande grooving tool. By turning the handle of the apparatus once, the cup is raised by 1cm, and falls back again on the hard rubber block provided. The grooved pat in the cup is shaken at a uniform and constant rate of two blows per second. The number of blows required to close the groove through a distance, in 1.25 cm. are noted. The soil is immediately removed from the cup and kneaded. The blow count is recorded again. The difference in two successive blow counts should normally be within ± 2 . The water content of the soil paste is then determined. The test is repeated with different moisture content. A plot is made of the number of the number of blows to log scale versus Water content to natural scale. The liquid limit is read corresponding to 25 blows on the abscissa.

2.6: Organic Carbon :

Organic carbon content of the soil was determined using Walkley-Black method (Piper 1951). Organic carbon in soil samples is oxidified by dichromate-sulphuric acid and the amount of dichromate which remains is determined by titration with standard ferrous solution. The Walkley-Black procedure uses the heat of dilution of sulphuric acid to provide the temperature required. The difference of ferrous ammonium sulphate between control and soil containing sample are used to calculate the organic carbon per cent as follows:

Organic carbon in soil as per cent

$$OC = 10(V1-V2)/V1 \times 0.003 \times 100/wx1/0.77x(100+m1)/100$$

Where V1 = Volume of ferrous solution, blank, ml
 V2 = Volume of ferrous solution, sample, ml
 m1 = air dry moisture, ground sample, per cent

2.7: Soil pH :

pH is determined in a 1:2.5. soil : water suspension using pH meter.

2.8: Soil Structure :

Soil structure refers to an arrangement of soil particles. It is considered as one of the most important properties of soil. However, it is not possible at this stage to determine the stability index in the laboratory. The soil structure is simply used as a morphological character in describing the soils from the field observation. In the field, its size (very fine, fine, medium, coarse, very coarse), grade (structureless, weak, moderate, strong) and type (angular, crumb, columnar, prismatic, platy, angular blocky, subangular blocky, single grain or massive) were observed as per the guidelines of AIS & LUS (1971).

2.9: Soil Depth :

The depth of soil is of vital importance for plant growth and for establishing the chronosequence of profile development. In the present study, it gives a unique idea of steepness as well as mass movement prone sites. Soil depth

classes adopted in soil description is given below :-

Table - 2.2

Range of Soil Depth and its Description

Soil Depth (cm)	Description
< 10	Extremely shallow
10 - 25	Very shallow
25 - 50	Shallow
50 - 75	Moderately shallow
75 - 100	Moderately deep
100 - 150	Deep
> 150	Very deep

Source : Field Manual, Technical Bulletin 13, National Bureau of Soil Survey and Land Use Planning, ICAR, Nagpur.

2.10: Soil Colour :

Colour is one of the important characteristics of soils which, provides ready clue to soil conditions and several important soil properties. Soil colour is used in this study to describe the soil. The Munsell Colour Chart was used in the field and colours were assessed based on the hue, value and chroma. The hue is the dominant spectral colour and is related to the dominant wave length of the light, value refers to the relative lightness of colour and is a function of the total amount of light. Chroma is the relative purity or strength of the spectral colour and increases with decreasing greyness. (AIS & LUS, 1971).

2.11: Scorings of Mass Movements :

While undertaking a relational exercise of mass movement with some soil variables, it was felt necessary to quantify the different types of mass movements. Mass movement processes may be quantified in a time series observation which is not possible in a short time available in the present research work. However, according to severity of mass movements some scorings are allowed in the following way which are used in the appropriate places.

Table - 2.3

Types of Mass movements and their scores.

Types of mass movements.	Scores
Sheetwash	1
Soil creep	2
Talus creep	3
Rock slide	4
Wedge slide	5
Topple	6

CHAPTER - III

DESCRIPTION OF SITES : SLOPES AND SOILS

Slope profile and soil analysis were undertaken in ten selected locations (Fig. 1.2). These were Myllem, Ryngngain, Sohiong, Mawlat, Smith, Barnihat, Jarain, Bapung, Komrrah and Sonapur. The first six are located in old hard rock zones of granites and gneisses. The first five offer dominantly natural landscapes. Centrally located, Barnihat is a localised area of 'Jhum' cultivation on the northern periphery of Meghalaya. The other four are located in the southern fringe of the plateau, lying on the younger soft rocks i.e. sandstones, shales and limestones. Human interference through excavations of coal and limestones has provoked important changes in the cultural landscape of this zone.

3.1: MYLLIEM :

Myllem (Fig. 3.1), at 12km distant from Shillong is located between $25^{\circ} 29'$ to $25^{\circ} 30'$ N latitude and $91^{\circ} 49'$ to $91^{\circ} 50'$ E longitude. It falls within the physiographic unit number four (Fig. 2.1). It is a plateau with moderate slopes. Drainage pattern is dendritic to sub-parallel and seasonal in nature having main outlet to Umlew to the south. The elevation of the site ranges from 1700 to 1800 m from msl. In general, gradient is more than 50 per cent with more than 200

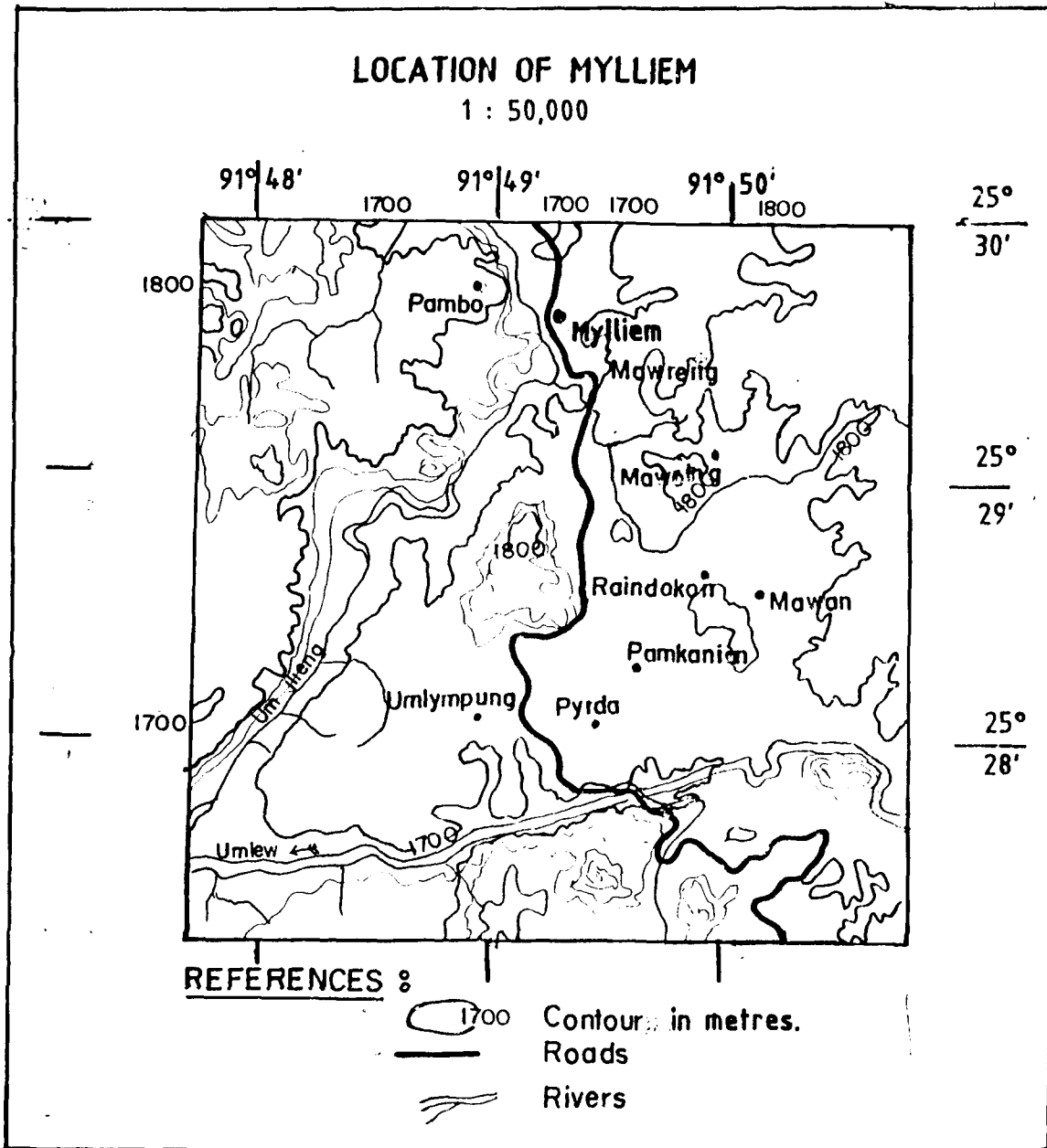


Fig. 3.1

m slope length. Erosion is severe with rapid surface runoff. Vegetation along river valleys and hillslopes are moderately dense, while it is sparse on hill tops. Pine trees are common on the summit.

Rock types are mostly granite, quartzite, quartz-mica schist of Shillong group and Khasi greenstones with Cretaceous sandstone cappings. The perphyritic granites are intrusive both in Shillong and Khasi greenstone group of rocks. Further the coarse granites are intruded into the perphyritic granite (Chakravorty & Das, 1982). Orientation of the dips are towards NW-SE direction. The foliations are also developed in the same direction and is more prominent at the contact of the two types of rocks. Numerous joints have developed within the pluton. Main joint is along the foliation plane and vertical, while others are across or oblique to the foliation plane.

Potato cultivation on terraces was intensive in early days but it is now abandoned due to landslides.

3.1.1: Slope Profile Analysis :

Slope profile analysis in the study area shows three distinct phases as depicted in Fig. 3.2. At A, slope summit extends upto 25 m length from the crest. It is full of dried grass and thinly spread pine trees. Soil cover is 85 to 90 per cent coupled with 10 to 15 per cent of rock outcrops of the size 120 x 150 cm² out of which 10 to 20 cm remain

FORM OF HILLSLOPE
MYLLIEM

Metres 5 0 5 10 Metres

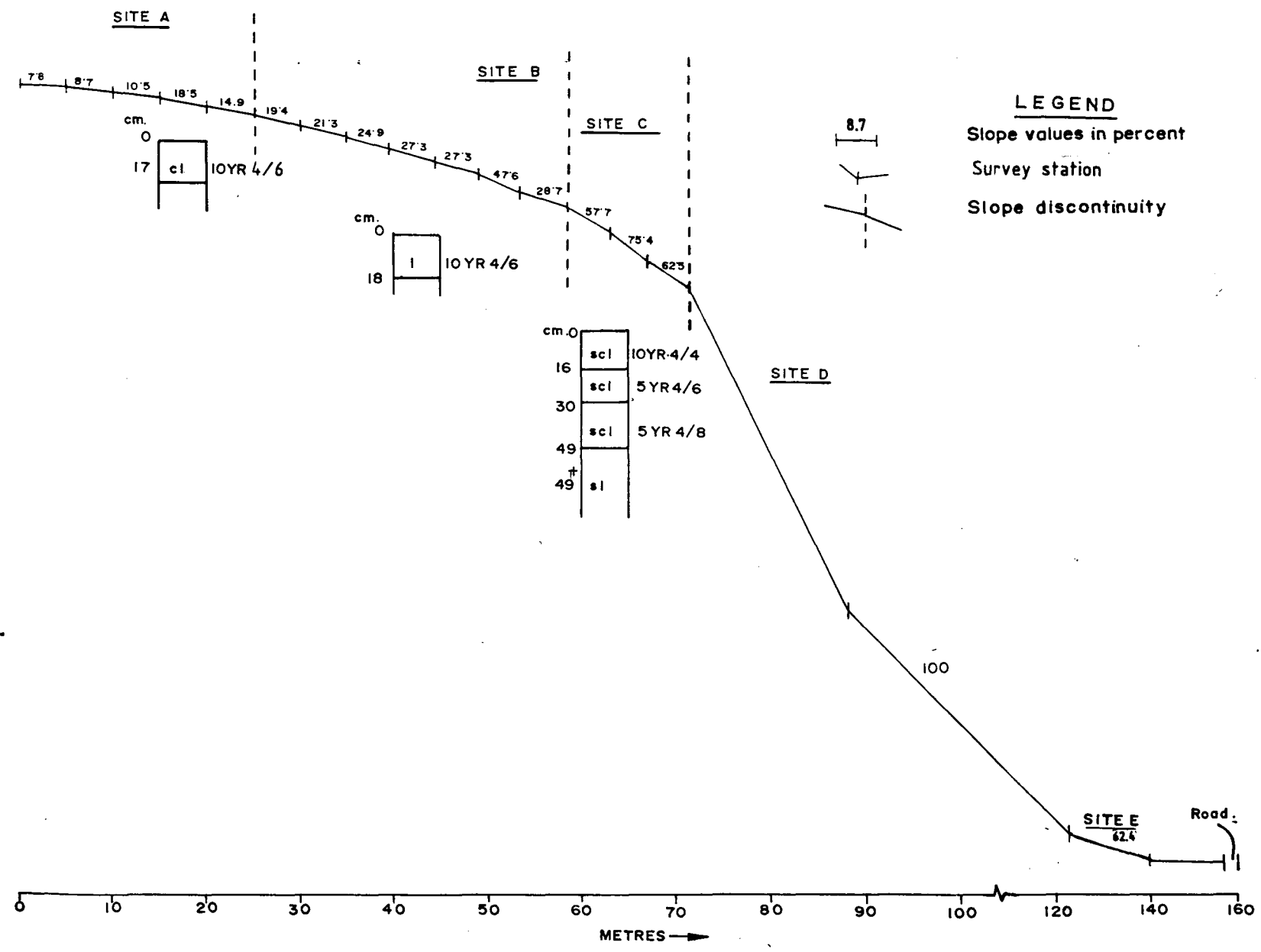


Fig. 3.2

exposed to surface. The slope extends from 7.8 to 18.5 per cent and are convex in nature. There are quite a number of hummock shaped structures measuring 120 to 150 cm in width and 210 to 300 cm in height. Slow mass movement like soil creep is observed at this site.

At B, slope with gradient 19.4 to 28.7 per cent extends upto 35 m length, out of which 5 m length was observed with exceptionally steeper gradient (47.6 per cent). It is a convexo-concave slope. The hillside drainage lines are the result of soil creep and talus creep on some concentrated line of rills and gullies with 10 cm wide and 8-10 cm deep at an interval of 60-90 cm. Rills and gullies are discontinuous because of stoney debris. There is also evidence of throughflow at the junction of the slope break.

Slope lengths of 15 m with gradient 57.7 to 78.4 per cent are observed at C. Pronounced gullies of 10 to 15 m in both width and depth are common. There are formations of tunnels and cappings of columnar shaped terracettes with rockfall, soil and talus creep type of mass movements. There are hummocks, highly prone to topples and slab slides.

Slope at D is a distinct free face and continues over 88 m length with 65^o of gradient. Gullies of the same size of C were also observed here. It is full of gravels, boulders, cobbles, and pebbles^{*}. There is a vigorous throughflow underneath. Boulders, even as big as 600 x 180 x 300 cm are

observed at 45^o slope. Formation of tunnels and terracettes are common.

The materials move downward from above, get deposited at E, which is a debris slope of 20 m length and gradually merges with the seasonal stream of 20 m wide wherein boulders, cobbles and pebbles are found scattered on its bed. There is hardly any space not covered by boulders, cobbles and pebbles.

3.1.2: Soil Analysis :

As shown in Table 3.4, soil depth at A and B extends upto 17 and 18 cm., respectively, while at C it extends upto 49 cm. Soil samples at D and E could not be collected because of free face and coverage of debris materials.

Soils at A are dark yellowish brown, clay loam, fine, moderate, sub-angular blocky. Soils at B have similar characteristics except the texture being loam. Soils at C are moderately shallow, excessively drained, dark yellowish

* Size Classes of Surficial Material

Size (cm)	Rounded/ Subrounded	Angular/ Subangular
> 25	Boulders	Blocks
> 7.5	Cobbles	Chunks
1.25-7.5	Pebbles	Flakes
Upto 1.25	Grits	Chips

TREND OF SOIL CHARACTERISTICS AT MYLLIEM

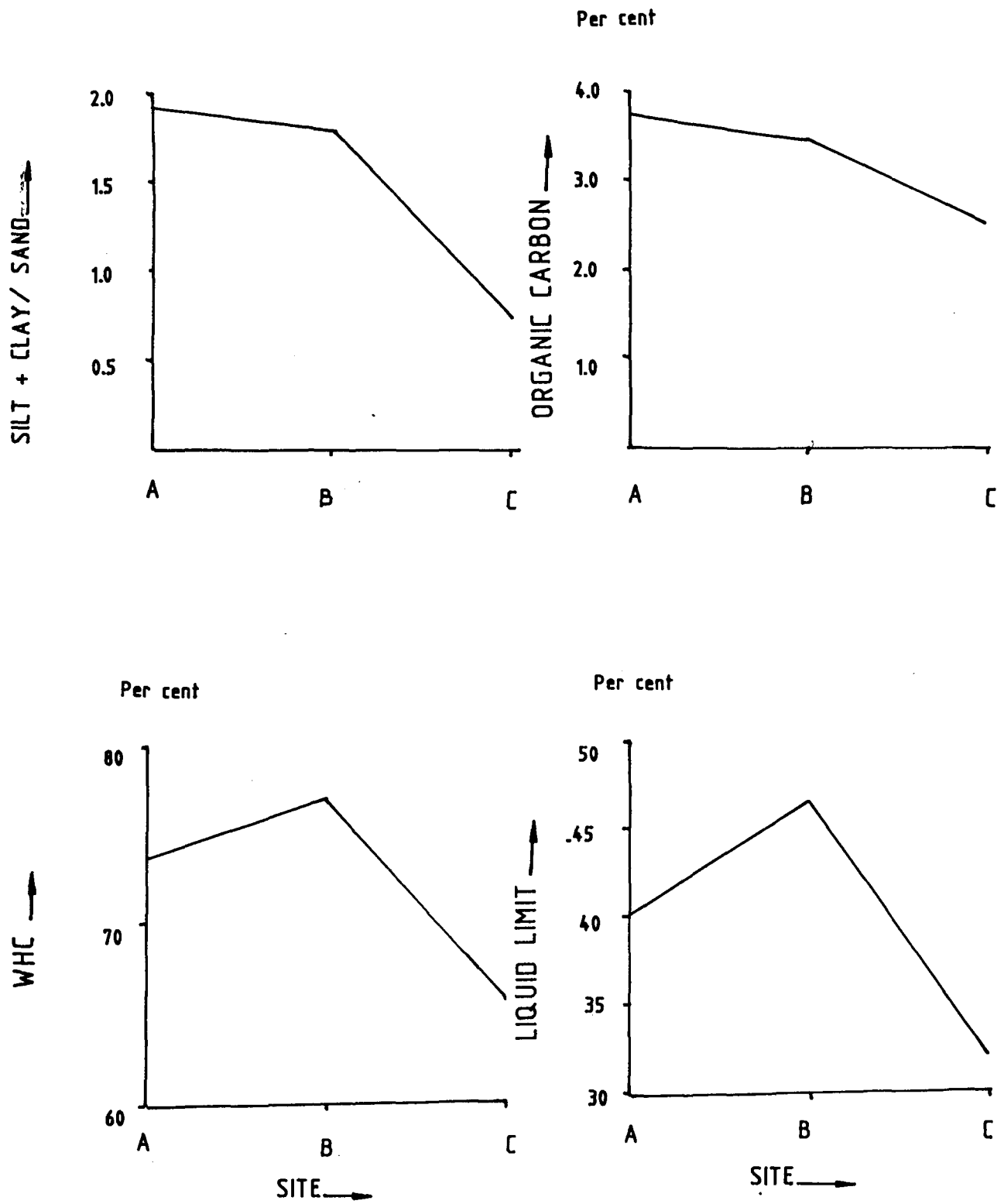


FIG. 3.32

Table - 3.4

Soil Characteristics of Myllem

Site	Average Depth Gradient (%)	Moist Colour	Sand (Si+C)/sand %	Org.C %	W.H.C. %	Liquid Limit %	pH		
1	2	3	4	5	6	7	8	9	10
A	12.1	0-17	10 YR 4/6	33.6	1.97	3.76	73.9	40.0	4.4
B	28.1	0-18	10 YR 4/6	35.4	1.82	3.46	77.5	46.5	4.4
C	65.2	0-16	10 YR 4/4	56.5	0.76	2.53	65.9	32.0	4.6
		16-30	5 YR 4/6	56.9	0.75	0.73	57.0	27.5	4.6
		30-49	5 YR 5/8	63.6	0.57	0.27	44.3	21.0	4.6
		49+	5 YR 5/8	77.5	0.29	0.12	36.6	19.5	4.5

Source: Estimated by the author.

brown, sandy clay loam very fine, weak, sub-angular blocky underlain by loam in the subhorizon. Soils of all sites are extremely acidic (pH 4.4 to 4.6). With increase in gradient from A to C (7.8 to 75.4%) there is gradual fall in finer soil fractions (silt and clay) including organic carbon (Fig. 3.3). Both WHC (Water Holding Capacity) and Liquid Limit (LL), however, showed slight increase at B, although the values sharply decreased at C corresponding with finer soil particles and organic carbon.

3.2: RYNGNGAIN :

Ryngngain is located between $25^{\circ} 21'$ to $25^{\circ} 22'$ N latitude and $91^{\circ} 52'$ to $91^{\circ} 53'$ E longitude (Fig. 3.4). It

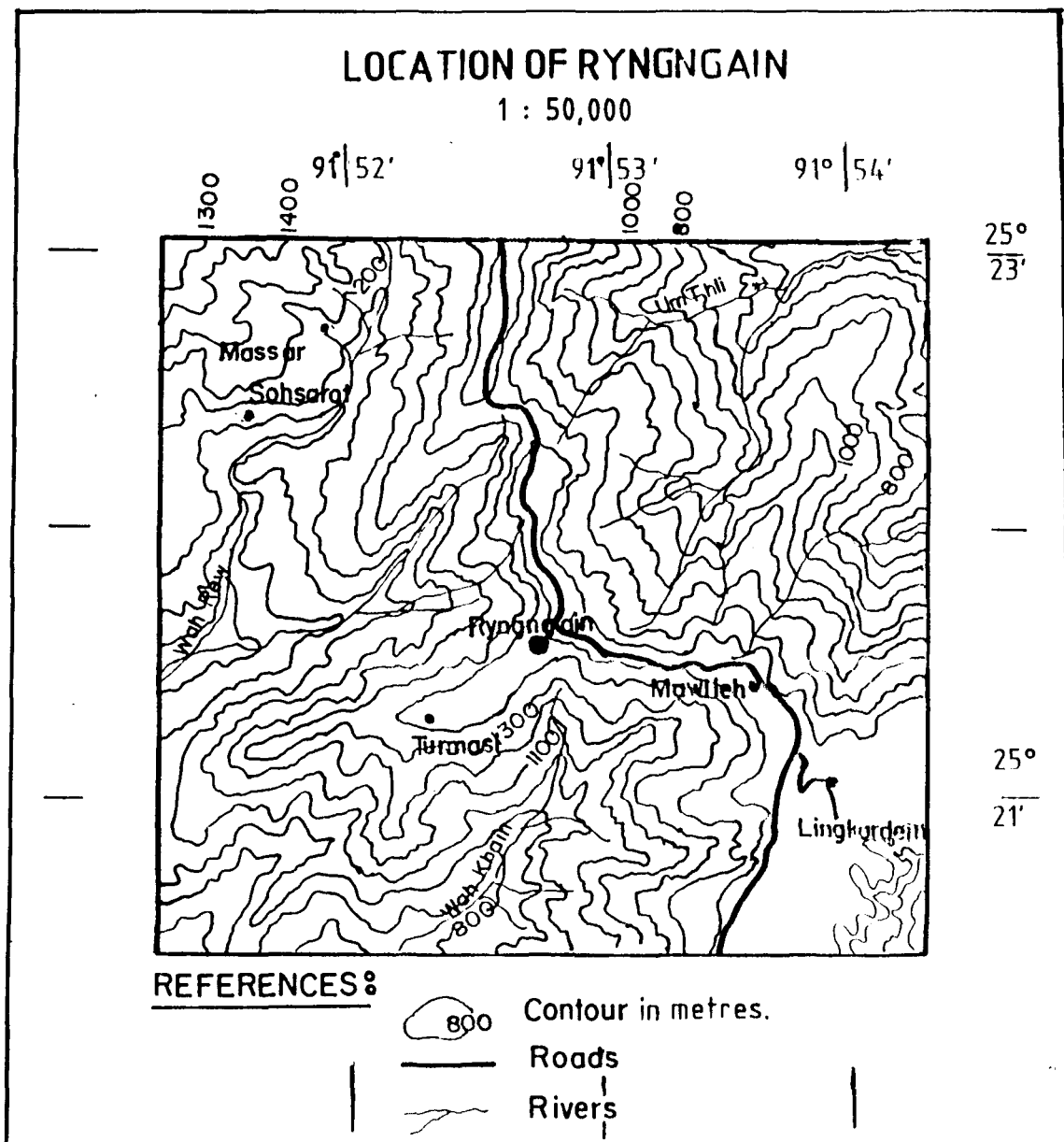


Fig. 3.4

falls within the physiographic division, Fig. 2.1. It is a dissected steep rocky hill, south facing, where a road from Shillong to Dawki runs. Presently, the road is under renovation and is being widened.

It forms part of a highly dissected tableland with several deep gorges and escarpments. The average height of tableland is 1200 m from msl and originates from the edge of the scarp face and extends upto the steeply sloping hill faces down below. The drainage pattern is dendritic to sub-parallel and recharge fully during the rainy season. In general, the gradient is more than 30-50 per cent, severely eroded with rapid runoff.

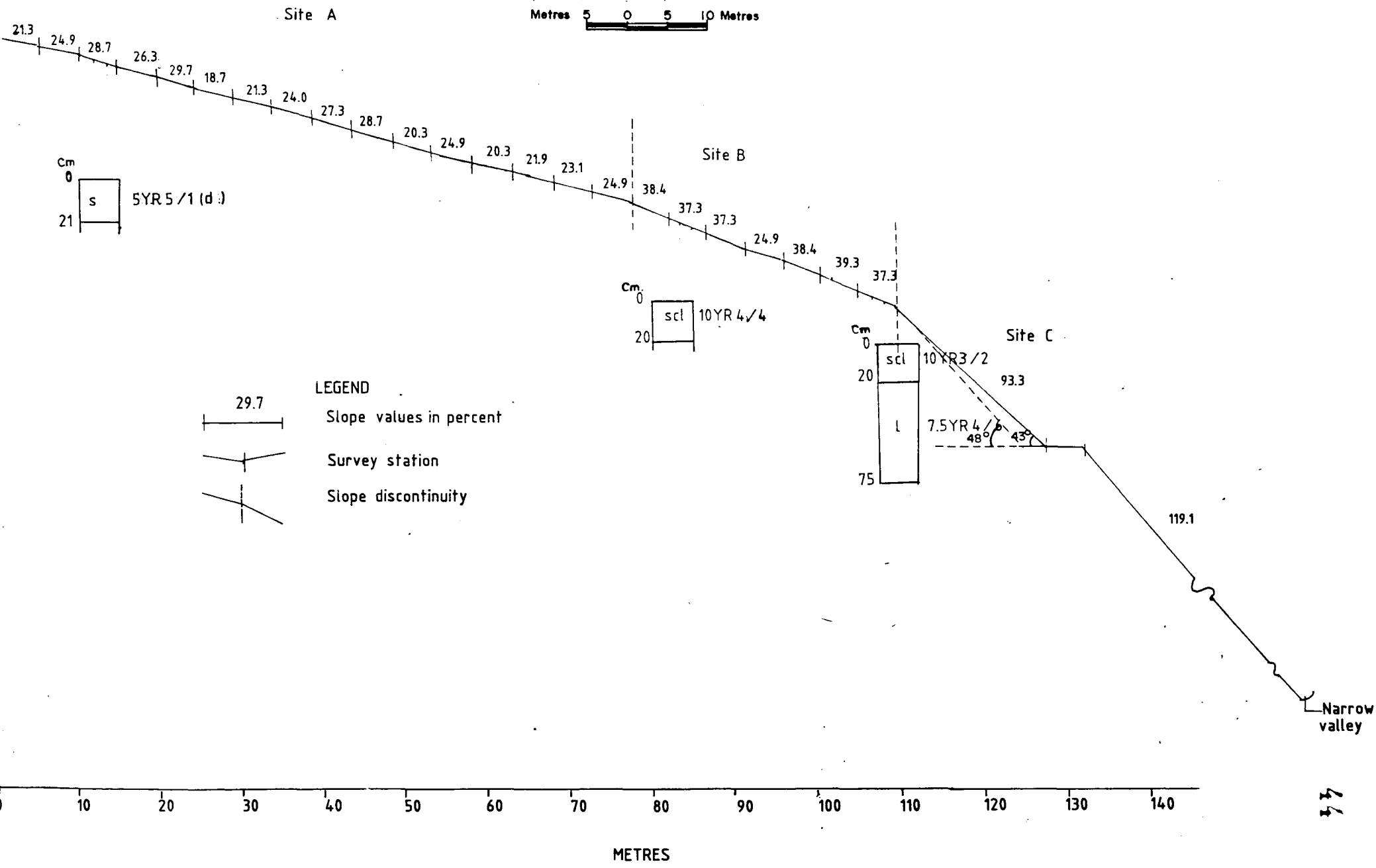
The rock type is horizontally disposed with medium to coarse grained sandstones and granitic gneisses. The joints are directed towards E-W, vertical joints and dippings are towards S-W. These widely spaced joints give rise to many blocks of large dimensions.

3.2.1: Soil Profile Analysis :

Three distinct sites were identified as shown in Fig. 3.5. Site A with 18.5 to 29.7 per cent gradient for a length of 80 m, consists of a series of near planar sites separated by smoother discontinuities. It is covered with dried grasses and orchids. The surface stoniness is 15 to 20 per cent with boulders of about 50 cm in diameter. The site is affected by slow mass movement, like soil creep and

FORM OF HILLSLOPE
RYNGNGAIN

Metres 5 0 5 10 Metres



METRES

Fig. 3.5.

partly, by sheetwash. Downslope, in B, the gradient is 37.3 to 39.3 per cent upto 35 m length with an exception of 24.9 per cent for 5 m. On this site exposed rocks are on the verge of breaking along the cleavages. Grass cover is thicker. The site is affected by mainly soil mass movement and partly by rock slide. Site C is having 93.3 to 119 per cent slope gradient for a length of 135 m with a 6 m wide road in between. The upper part of C, i.e. upto the road, suffers from rapid mass movement, like topples, slab slide, rock slide and rock falls. Surface materials viz. blocks, chunks and flakes of sandstone with few quartz are found. Downward the road the lower part, is covered with moderately a dense mixed forest. Large blocks of rocks with 50 to 75 cm in diameter are observed in this area.

3.2.2: Soil Analysis :

The soils at A is gray, sandy, coarse and single grained (Table 5). Soils at B are dark yellowish brown, sandy clay loam, medium, weak and subangular blocky. Soils at C are moderately shallow, excessively drained, very dark grayish brown, sandy clay loam, fine, single grained, underlain by strong browns, loam, fine, weak and subangular blocky. Soils are highly acidic throughout the slope profile.

A scrutiny of data in Table 3.5 shows that the finer soil fractions including organic carbon content increase from A to B, and thereafter, their values abruptly fall at site C

TREND OF SOIL CHARACTERISTICS AT RYNGNGAIN

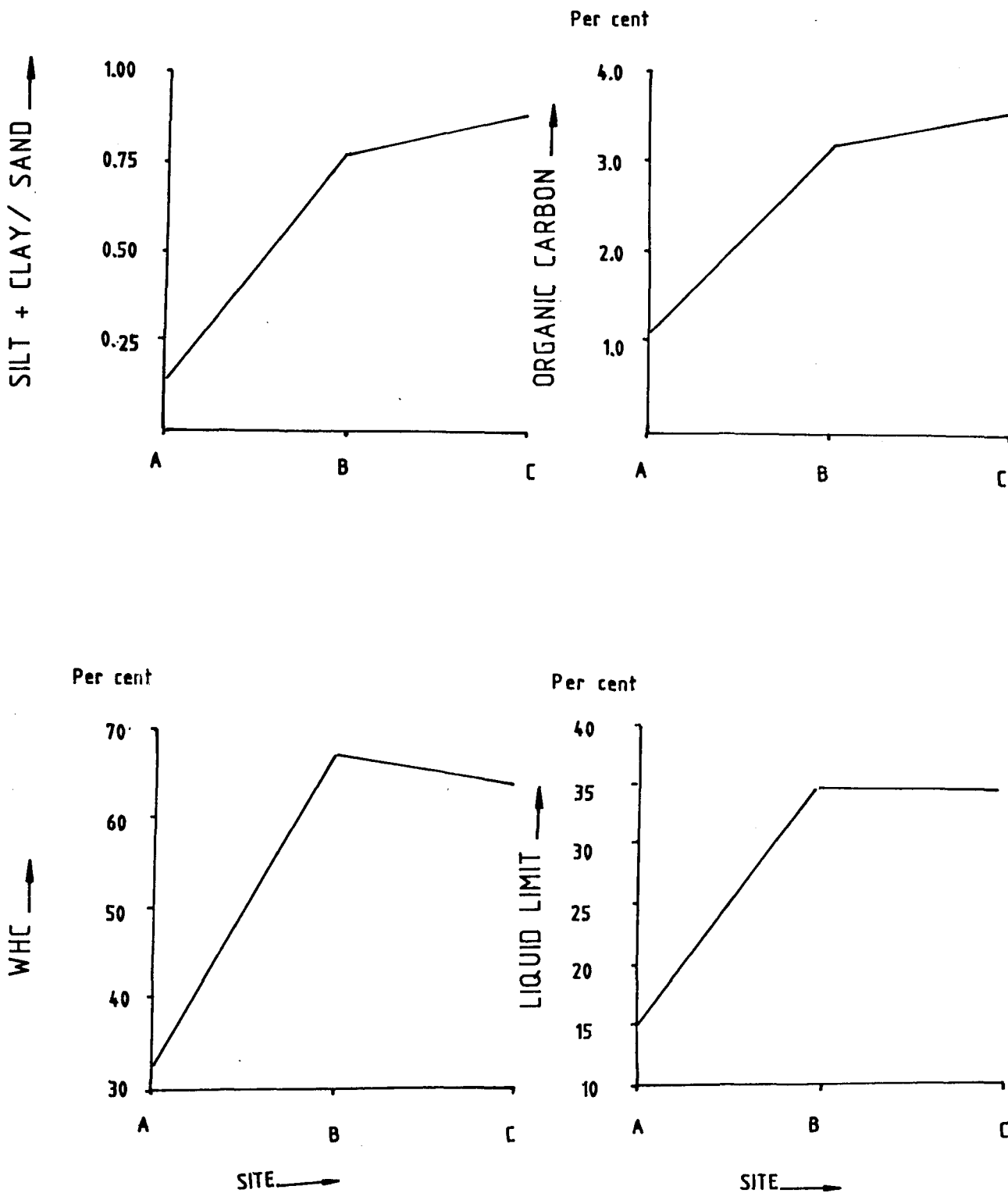


FIG. 3.6

(Fig. 3.6). The variations in both WHC and LL along slope profile A to B corresponded well to that of organic carbon; but no conspicuous change was observed at C.

Table - 3.5

Soil Characteristics of Ryngngain

Site	Average Gradient %	Depth (cm)	Moist Colour	Sand %	Si+C Sand	Org.C %	W.H.C. %	Liquid Limit %	pH
1	2	3	4	5	6	7	8	9	10
A	24.1	0-21	5 YR/1(d)	86.8	0.15	1.11	32.38	15.0	4.5
B	36.4	0.20	10 YR 4/4	56.3	0.77	3.23	67.38	35.0	4.8
C	106.2	0-20	10 YR 3/2	55.0	0.88	3.57	64.22	35.0	4.7
		20-75	7.5YR 4/6	46.1	1.16	1.01	57.12	32.5	4.6

Source: Estimated by the author.

3.3: SOHIONG :

Sohiong is situated between $25^{\circ} 30' N$ to $25^{\circ} 31' N$ and $91^{\circ} 40'$ to $91^{\circ} 44' E$ longitude at an elevation of 1760 m from msl (Fig. 3.7). It falls within the physiographic division, number two, Fig. 2.1. It is a highly dissected table-land with several gorges. The topography is marked by a steep to vertical scarp face. Eroded hill slopes have hill side drainage lines which are of dendritic to sub-parallel in nature. The runoff makes a slope wash on some concentrated line, generally rills and gullies. Due to continuous rock fall, a road has been diverted and the area is converted to a rock quarry.

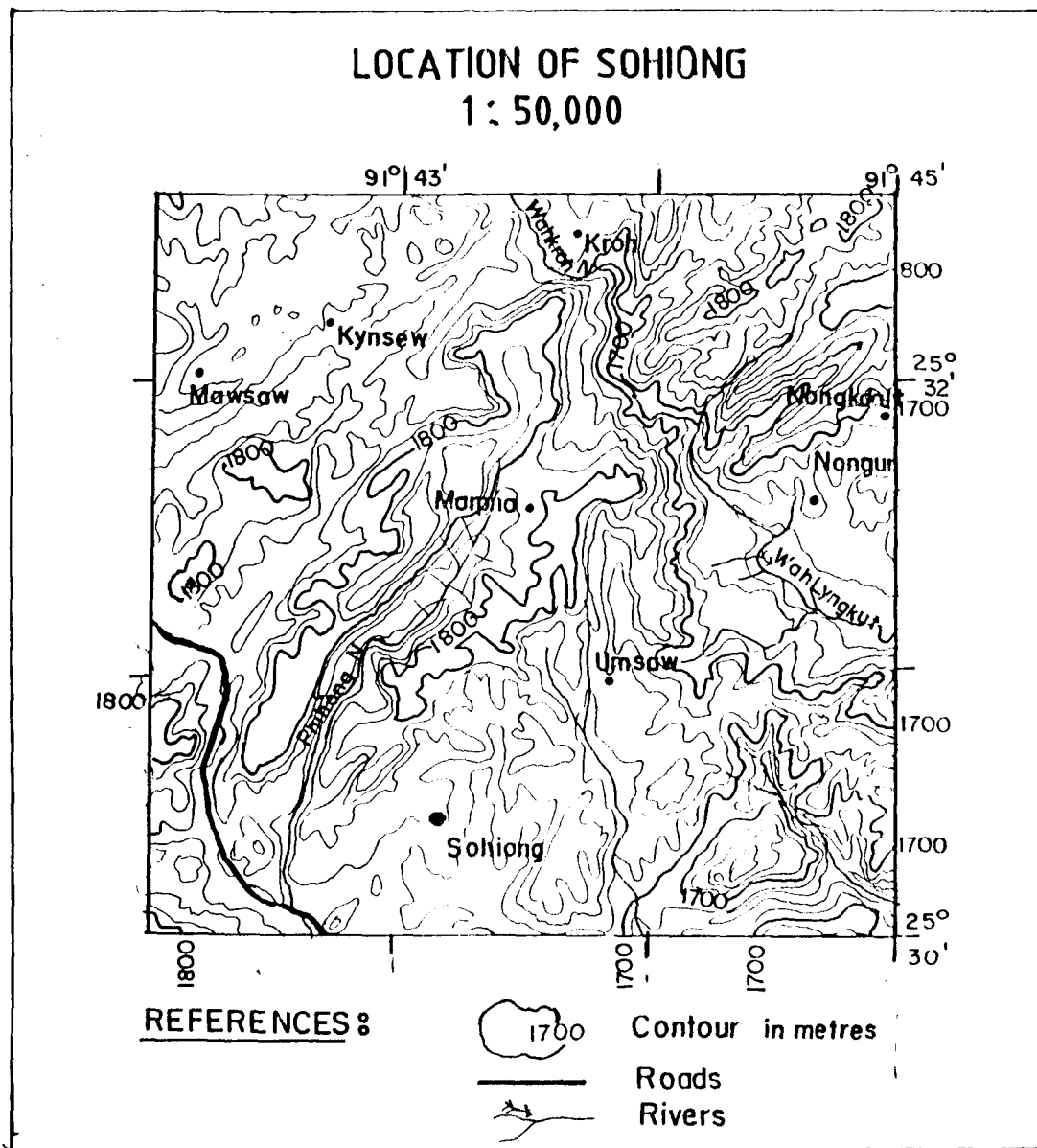


Fig. 3.7

Main rocks of the area are shale, sandstone and granitic gneiss. Rocks are horizontally to sub-horizontally disposed. Sandstones found here, are hard and medium to coarse grained in texture. Some joints are directed towards E-W, while others towards N-S. They are widely spaced giving rise to blocks of medium to large dimensions.

3.3.1: Slope Profile Analysis :

Slope profile analysis was carried out and three distinct sites were identified (Fig. 3.8). Site A is a summital convex with 13.4 to 28.7 per cent slope gradient. It is covered with grass and pine trees, though growth of these trees are not luxuriant. Evidence of sheetwash in A is found from the accumulation of small fragments at the base of the vegetation. Finer soil particles are washed down with little terracettes left behind. B is limited to 15 m length in the form of a free face, with gradient 44.5 to 48.8 per cent. At this site, some thin beds, commonly attached by differential weathering into discontinuous 'galleries' are observed. It perhaps corresponds to sandy beds separated by cohesive silt and clay and also by root bindings. The C is a free face with 70-87 per cent gradient of 90 m length. The upper part of C is susceptible to mass movements of translational type, viz. rock, slab, and detritus slide. Its surface is smooth and is covered with algae and mosses. There is formation of discontinuous rills and incipient gullies of 3 to 4 cm width and 1 to 2 cm depth. At the inflexion between 41^o and

FORM OF HILLSLOPE SOHIONG

Metres 5 0 5 10 Metres

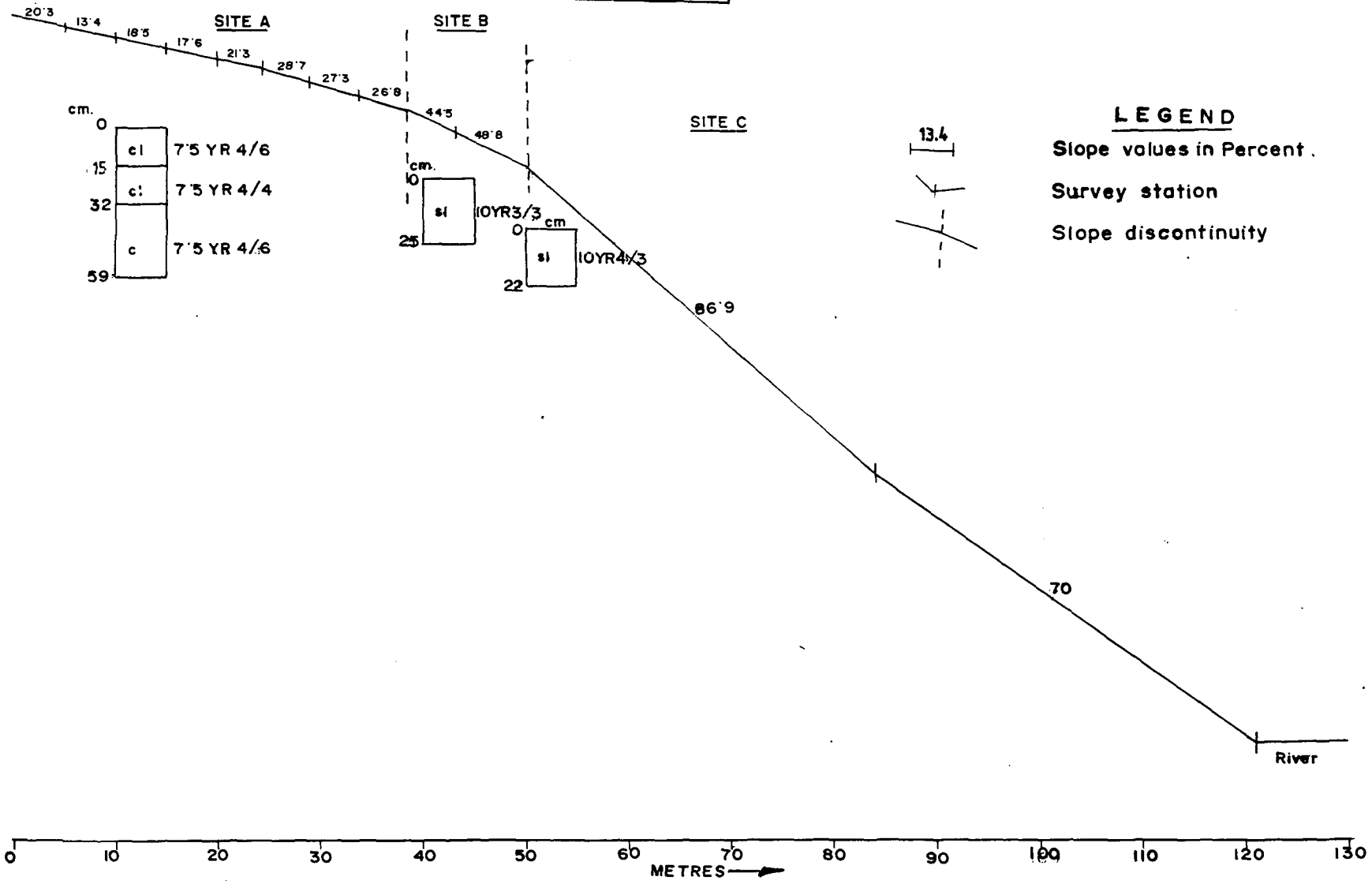


Fig. 3.2

35^o of this site, there is a huge accumulation of soil mass with trees, grass and other debris like boulders, cobbles, blocks and chunks with flakes and chips, which are washed away by rain and deposited over the base. Beyond C, a road with 6 m width was there. Now it is diverted away by about 20 m from the existing one. The old one is badly affected by rockfalls and other debris avalanches.

Table - 3.6

Soil Characteristics of Sohiong

Site	Average Gradient %	Depth (cm)	Moist Colour	Total Sand %	Si+C Sand	Org.C. %	W.H.C. %	Liquid Limit %	pH
1	2	3	4	5	6	7	8	9	10
A	21.7	0-13	7.5YR 4/6	38.3	1.61	2.69	64.76	37.0	4.9
		13-32	7.5YR 4/4	29.4	2.40	1.65	75.40	37.5	4.7
		32-59	7.5YR 4/6	17.5	4.71	2.27	57.14	37.5	4.7
B	46.6	0-25	10 YR 3/3	74.5	0.34	2.57	59.87	26.0	4.5
C	78.4	0-22	10 YR 4/3	67.0	0.49	3.38	61.84	27.5	4.5

Source: Estimated by the author.

3.3.2: Soil Analysis :

Soils collected at sites A, B and C are shown in Table 3.6. Soils of A are moderately deep, excessively drained, strong brown clay loam, medium, moderate and subangular blocky, underlain by dark brown to strong brown, clay loam to clayey, fine to medium, moderate and subangular blocky soils.

Particle size analysis shows that relative proportion of finer soil fractions to coarser ones decreased sharply

TREND OF SOIL CHARACTERISTICS AT SOHIONG

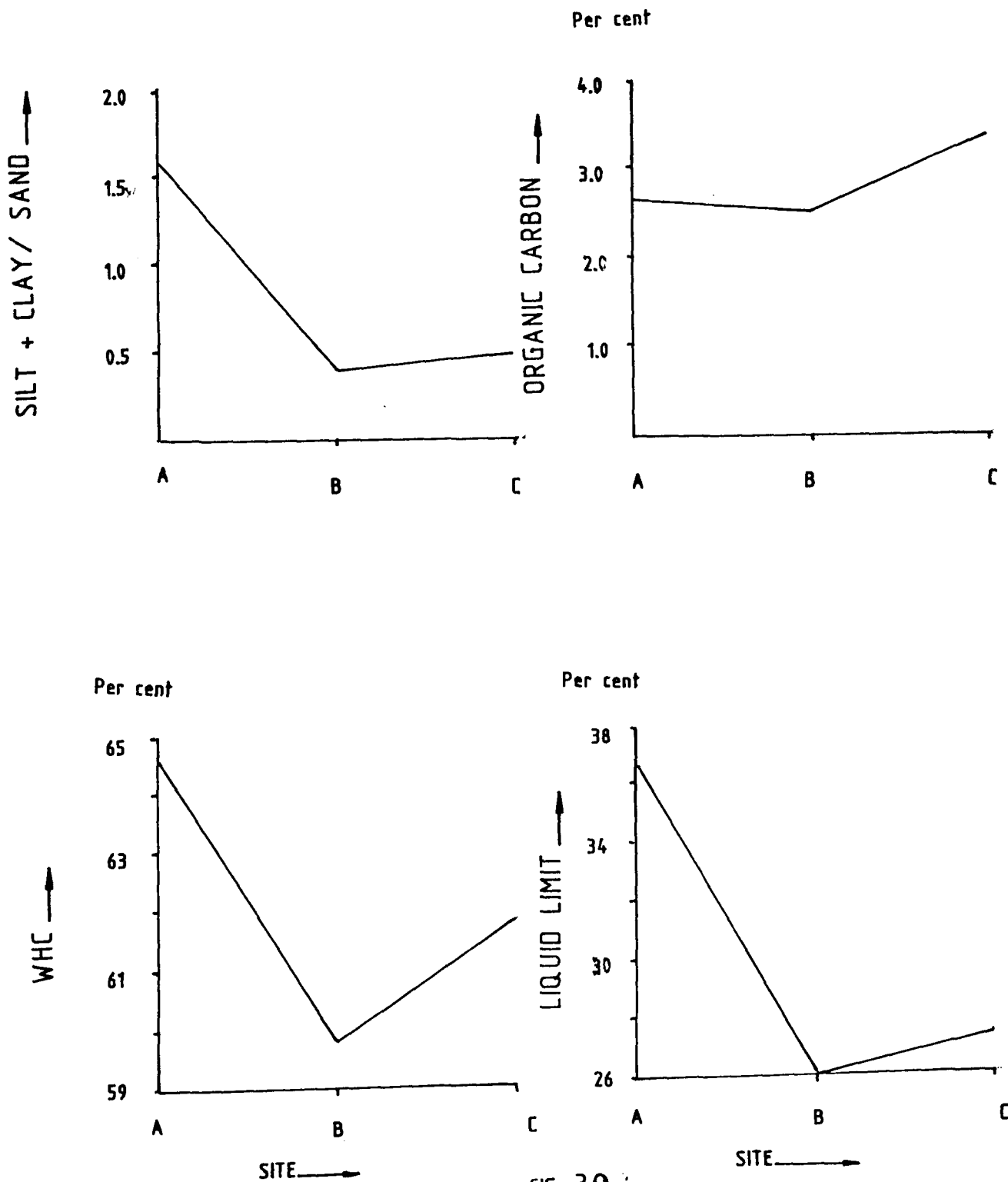


FIG. 39.

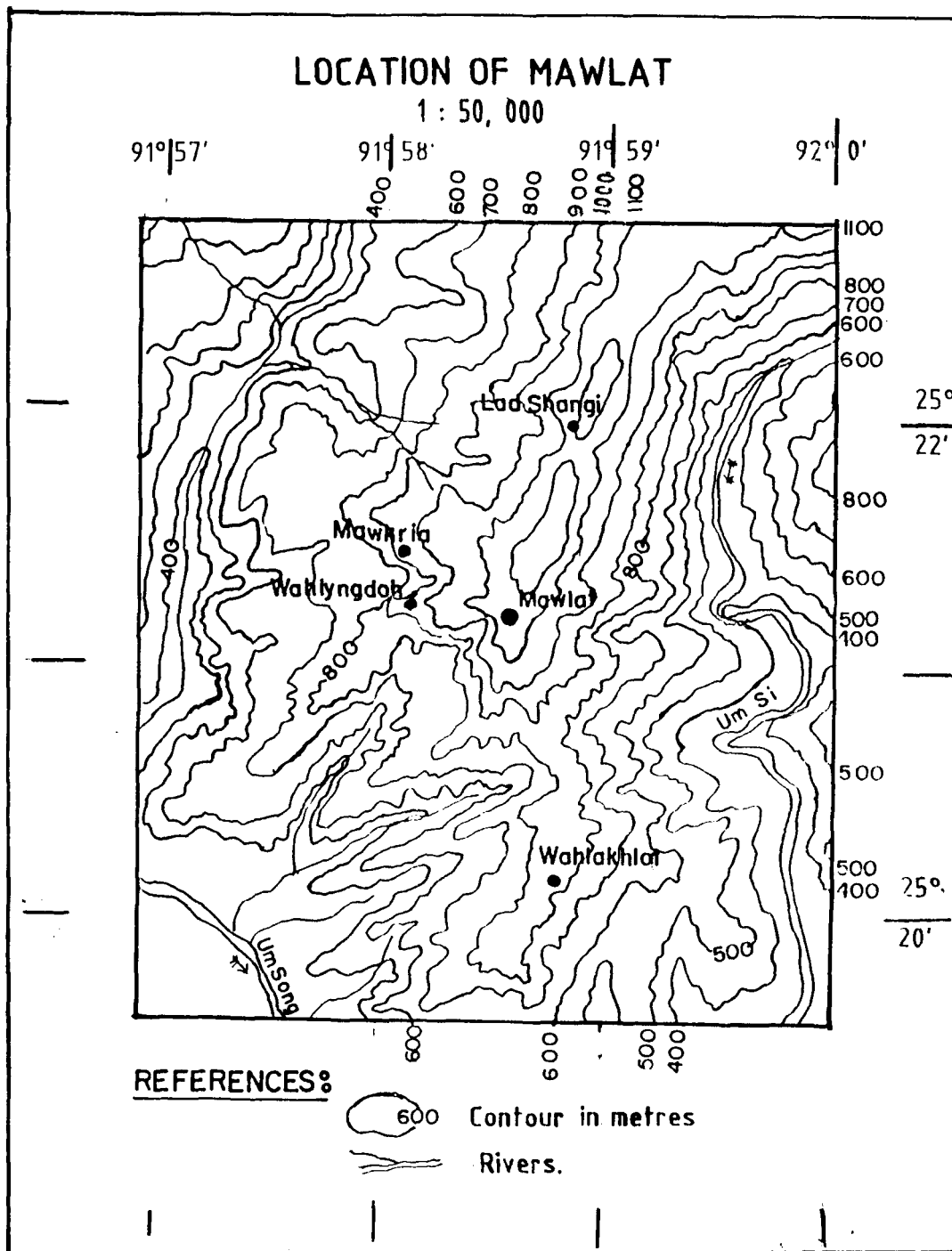


Fig. 3. 10

from A to B and tend to increase, thereafter (Fig. 3.9). No marked change in organic carbon was noted along the slope profile both from A to B; however, its value increases appreciably at C. Both WHC and LL show variations in the whole slope profile as in (silt + clay)/sand ratio.

3.4: MAWLAT :

Mawlat, 55 km. from Shillong, is located between 25° 30' to 25° 35' N and 91° 40' to 91° 45' E longitude at an altitude of 1140 m from msl (Fig. 3.10). It falls within the physiographic division number one, Fig 2.1. The topography is hilly with steep slopes running from E to W. In general, the gradient is more than 50 per cent, even at the length of 0 to 50 m. Erosion is very severe with rapid runoff. The betel leaf is widely cultivated, but it is learnt that the cultivation is severely effected due to scarcity of water during the growth period and damages are caused by regular landslides, specially during the rainy season.

Geology is similar to the Sohiong area, where main rock types are shale, sandstone and granite gneiss.

3.4.1: Soil Profile Analysis :

Four distinct sites were identified in Mawlat area (Fig. 3.11). The A is a convex slope ranging from 36.4 to 58.9 per cent. There are scattered boulders accumulated extensively at the lower point. At the base of boulders,

FORM OF HILLSLOPE
MAWLAT

Metres 5 0 5 10 Metres

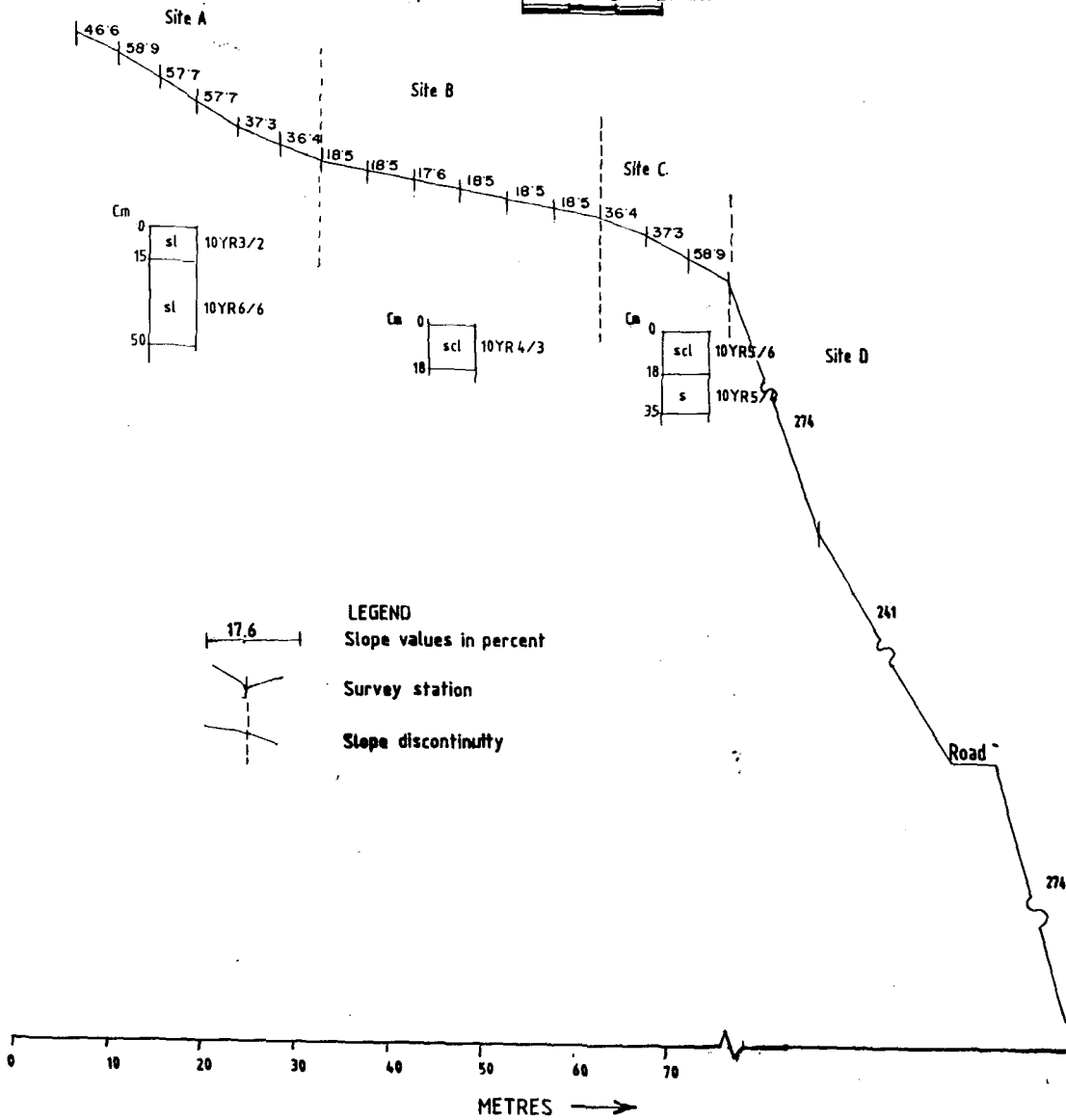


FIG. 3.11

there are large accumulations of flakes and chips which show the evidence of sheetwash. Apart from sheetwash, A is affected by talus creep and rockslide mass movement, also. The B, a mild rectilinear slope of 30 m length ranges from 17.6 to 18.5 per cent gradient. It is affected by soil creep. The C, 15m long, a free face ranges from 36.4 to 58.9 per cent. There are cracks, on the exposed rocks and slab slide, rockfalls and topples occur. The slope, then drops to about 200 m with a gradient 65 to 70 to form inaccessibility at the site D; the zone of intense rapid mass movements where translational landslide and topple, slab and wedge failure take place. There is a break of slope at 120 m length with an angle of 60° . At the base of 60° slope, detritus of blocks, boulders, cobbles and chunks are accumulated. There is a bund of boulders on the road at this point and this types of bunds are found in almost all the turns and sharp bends on the road.

3.4.2: Soil Analysis :

Soil samples were examined at each site and their morphological characteristics are shown in Table 3.7.

Soils of A are shallow, excessively drained, very dark grayish brown, sandy loam, fine, weak, granular in structure, underlain by brownish yellow, sandy loam, very fine, single grained soils resting on the bed rock. Soils of B are dark brown to brown sandy clay loam, with fine, weak, subangular

TREND OF SOIL CHARACTERISTICS AT

MAWLAT

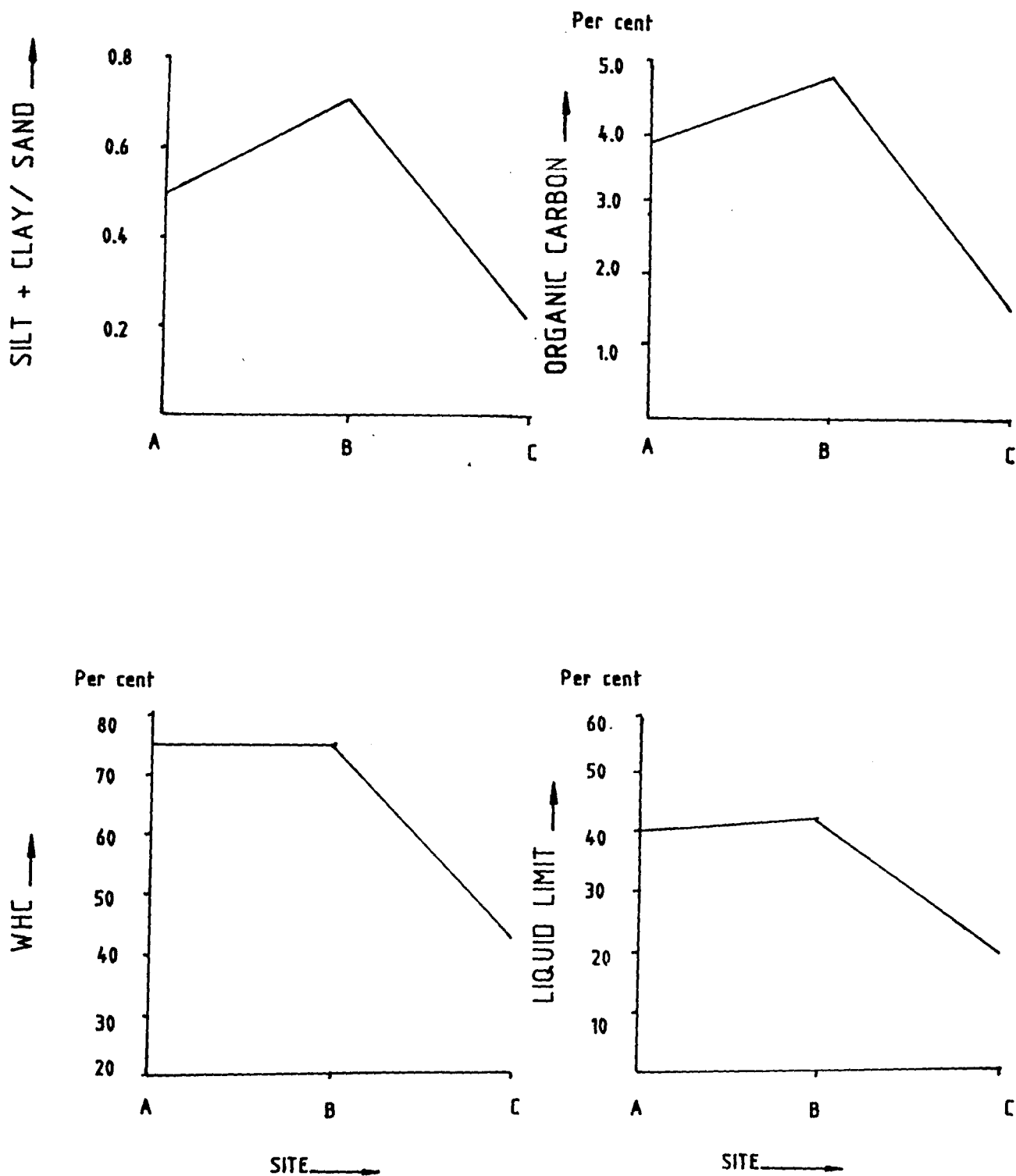


FIG. 3.12

blocky structure. Soils of C have similar character of B, except the yellowish brown colour with sand in the second layer.

Soil particle analysis and organic carbon content of slope profile show higher presence of finer soil fractions and organic carbon at B, which sharply decreases at C (Fig. 3.12). Both WHC and LL show no appreciable variation from A to B, thereafter, they decrease sharply with parallel decrease in finer soil fractions and organic carbon.

Table - 3.7

Characteristics of the Soils of Mawlat

Site	Average Depth Gradient (%)	Depth (cm)	Moist Colour	Sand %	Silt + Clay Sand	Org.C %	W.H.C. %	Liquid limit %	pH
1	2	3	4	5	6	7	8	9	10
A	49.1	0-15	10YR 3/2	67.0	0.49	3.89	75.45	40.0	4.4
		15-50	10YR 6/6	72.1	0.38	2.11	54.45	28.0	4.4
B	18.3	0-20	10YR 4/3	57.5	0.73	4.69	74.66	42.0	4.3
C	44.2	0-18	10YR 5/6	82.5	0.21	1.51	43.47	20.5	4.4
		18-35	10YR 5/4	90.3	0.10	0.50	32.56	17.0	4.6

Source: Estimated by the author.

3.5: SMITH :

Smith, 12 km. away from Shillong, is located between $25^{\circ} 30'$ and $25^{\circ} 31'$ N latitude and $91^{\circ} 54'$ to $91^{\circ} 55'$ E longitude (Fig. 3.13). It falls within the physiographic

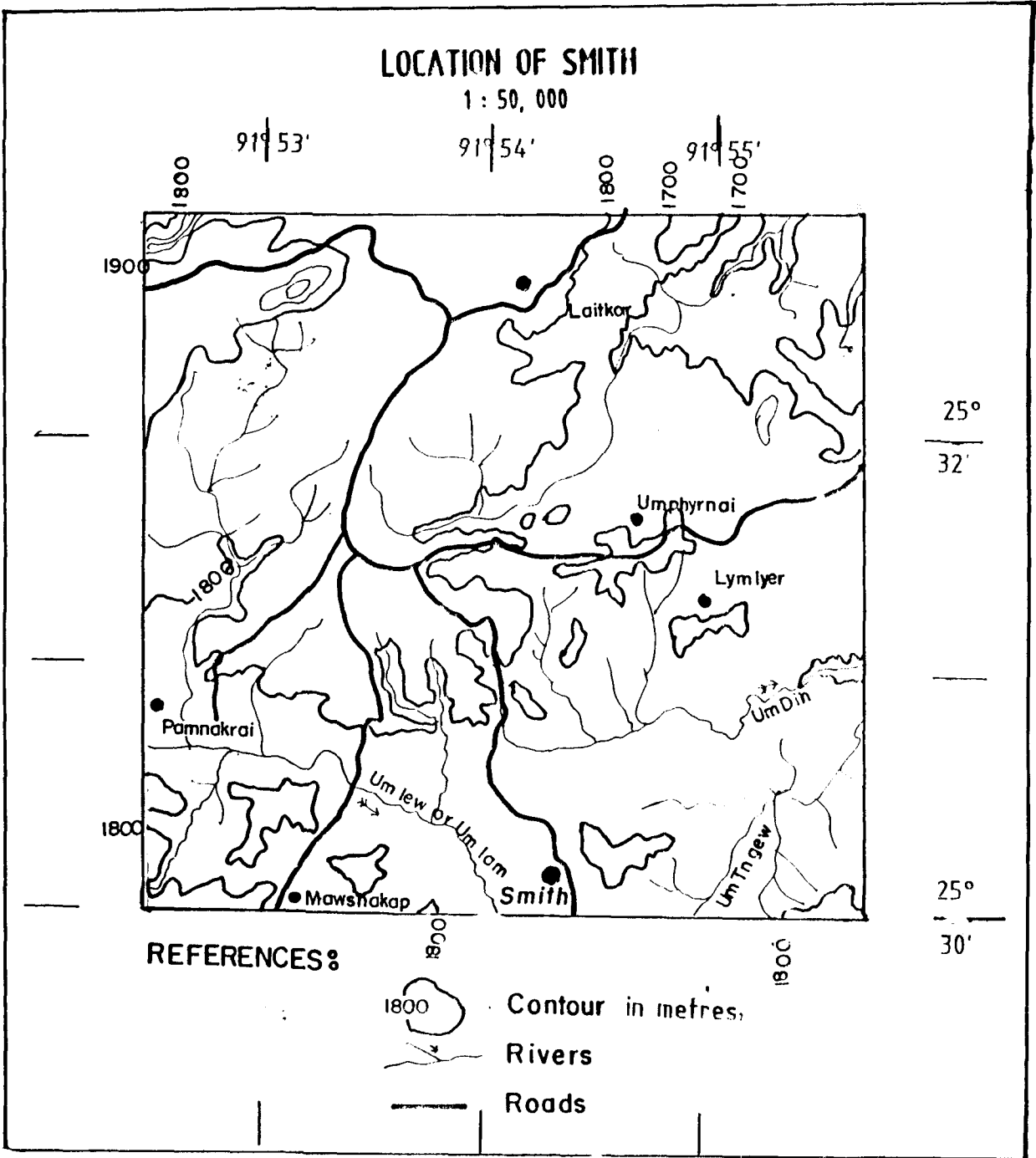


Fig. 3.13

unit number four, Fig. 2.1. The general topography consists of moderate high hills with wide valleys. The area mainly consists of Archean gneissic complex of the Meghalaya plateau. Biotite gneisses represent the country rock of the area which is traversed by basic and acidic intrusions. The biotite gneiss material is overlain by the quartz-sillimanite. Quartzites are seen exposed in most part of the area. The rocks are hard but closely jointed (GSI, Report No. 489).

3.5.1: Slope Profile Analysis :

A slope profile analysis was carried out in this area along the maximum gradient (Fig. 3.14). Site A is 90 m long with a gradient 3.2 to 24.1 per cent. It is covered with dried grass. There is rill formation of 1 to 2 cm along the slope. Previously, potato was cultivated but they are left fallow because of soil creep. Gullies are also formed in the lower part of the site with 30 cm width and 15 cm depth. Moss and algae are spread over the barren parts. B is comparatively near-planar with a length of 80 m with the maximum gradient being 10.5 per cent. Features similar to A is observed here, too. Thereafter, C of 46 m length with 14.1 per cent gradient with an exception of 55.4 per cent slope with 8 m length is identified. Immediate to this site, gully formations start. Soil creep was observed in a limited area. Potato cultivation is still practised here and seed beds are prepared with massive cowdung application. At the bottom, a

'nullah' of 12.3 per cent gradient is flowing down, where exposed granite rocks are found. After this, a concave site D with 42 m length having slopes ranging from 1.7 to 7.0 per cent gradient is identified. This site is, in fact, a valley floor of the 'nullah'. There is further upward convexity of 15 m width with 3.5 to 8.7 per cent gradient (Site E) and another 15 m with 17.6 to 30.6 per cent gradient (site F). Beyond this, a convex slope starts with 1.7 to 5.2 per cent slope. Ten per cent of surface is covered with boulders and cobbles.

3.5.2: Soil Analysis :

Soil samples are collected from each site and their characteristics are cited in Table 3.8. Soils found on the convex slope of site A are shallow, well drained, dark yellowish brown, silt loam, fine, weak, crumb, very strongly acidic (pH 4.5), underlain by dark brown to brown silty clay loam to silty clay, medium, moderate and angular blocky. Soils of B is very dark grayish brown, silt loam, medium, moderate, subangular blocky, strongly acidic (pH 4.5). Soils of C are dark brown to brown silt loam, fine, weak, subangular blocky, strongly acidic (pH 4.5). Soils of D and E are dark brown, loam, fine, weak, subangular blocky in structure and highly acidic (pH 4.9). Soils of F are dark reddish brown to dark brown, clay loam, fine, moderate, subangular blocky and are highly acidic (pH 4.9); while soils of G are dark brown, loam, weak, subangular blocky and highly

TREND OF SOIL CHARACTERISTICS AT

SMITH

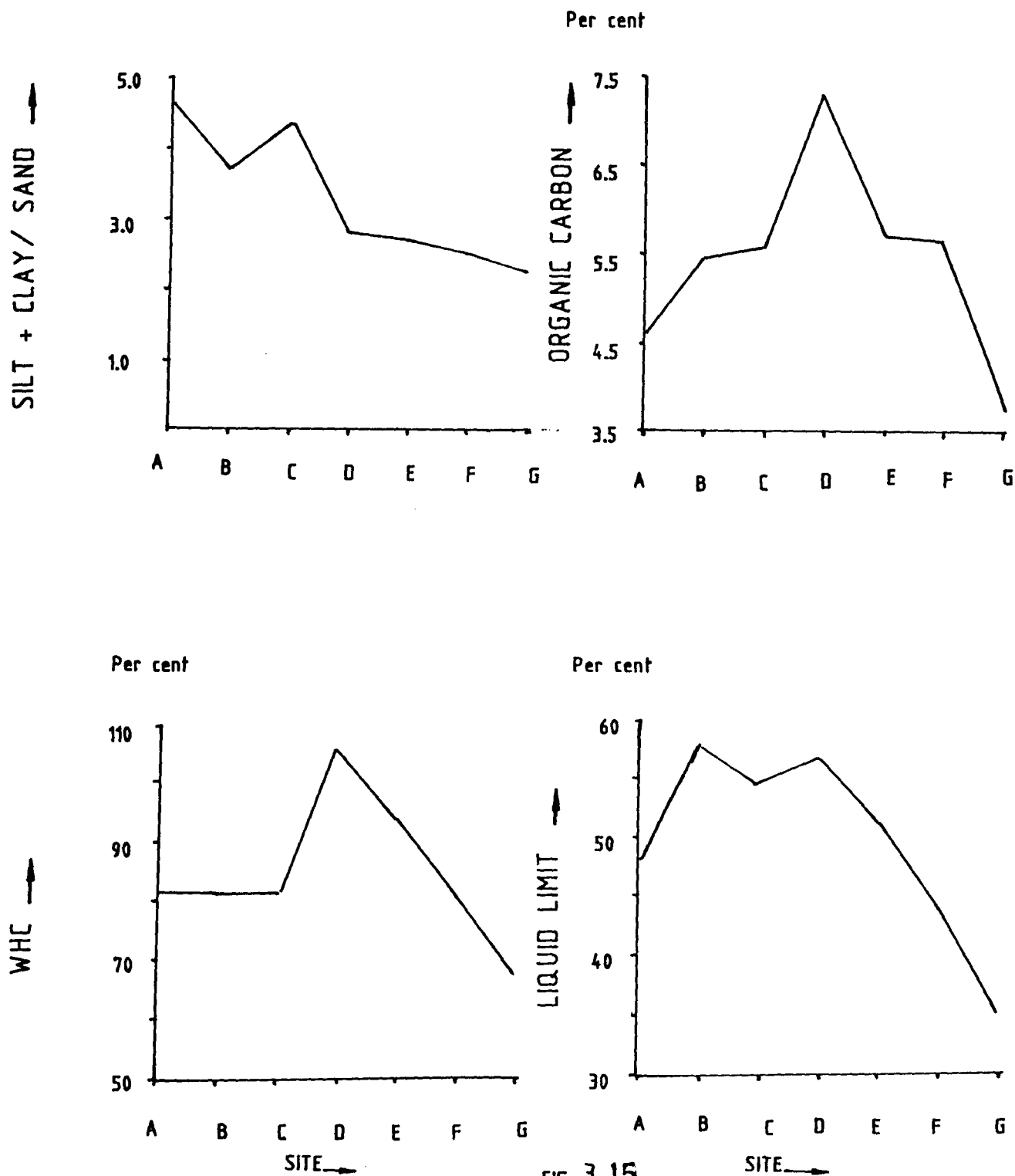


FIG. 3.15

acidic (pH 4.5).

Data in Table 3.8 shows no change in total sand content from A to C beyond which its gradual increment was observed upto F with peak value at G.

Table - 3.8

Soil Characteristics of Smith

Site	Average Gradient %	Depth (cm)	Moist Colour	Sand %	Silt+Clay Sand %	Org.C %	W.H.C. %	Liquid limit %	pH
1	2	3	4	5	6	7	8	9	10
A	16.9	0-16	10YR 4/4	17.8	4.61	4.66	81.1	48.5	4.5
		16-40	7.5YR4/4	13.9	6.19	1.26	64.5	42.5	4.5
		40+	7.5YR3/4	5.8	16.2	0.87	60.9	41.0	4.5
B	7.3	0-20	10YR 3/2	21.1	3.73	5.23	80.9	58.0	4.4
C	13.5	0-22	10YR 4/3	18.6	4.37	5.78	80.8	54.5	4.5
D	4.7	0-19	7.5YR3/4	26.5	2.77	7.3	106.1	57.0	4.9
E	6.4	0-16	7.5YR3/4	27.3	2.66	5.72	93.8	51.5	4.9
F	25.0	0-20	5YR3/4	28.8	2.47	5.67	80.7	44.0	4.9
G	4.2	0-22	10YR 4/3	30.6	2.26	3.7	68.1	35.0	4.5

Source: Estimated by the author.

It is interesting to note that organic carbon content increase gradually from A to C reaching its peak value (7.3%) at D; thereafter the value decreases maintaining a constant level (5.7%) at E and F and an abrupt fall (3.7%) at G (Fig. 3.15).

There is no conspicuous change in WHC from A to C. Abrupt increase in WHC at D and gradual fall thereafter, may be related to organic matter content of soils.

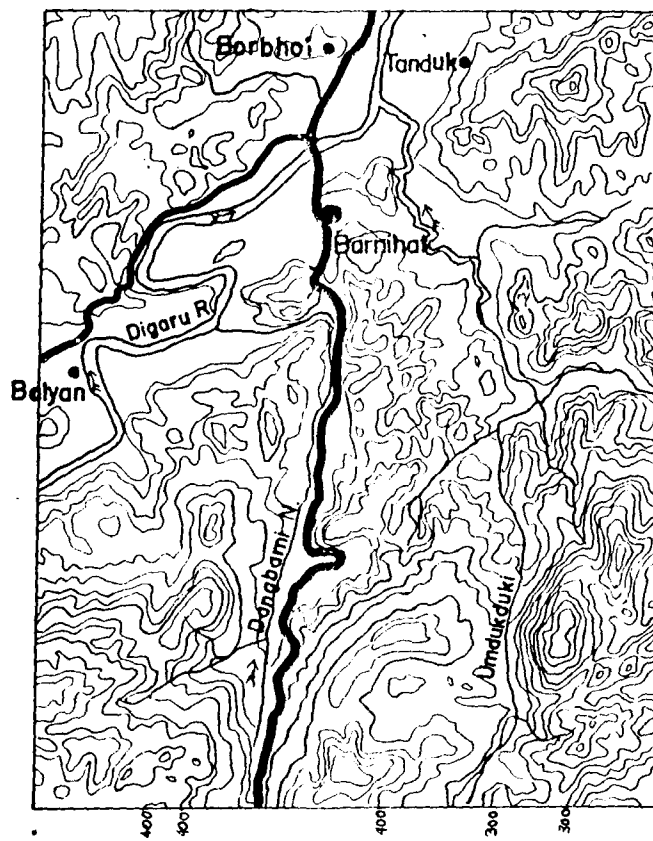
A scrutiny of data in Table 3.8 shows that rise or fall in liquid limit at slope site A to D is quite opposite to

LOCATION OF BARNIHAT

1 : 50, 000.

91° 52'

91° 53'



REFERENCES 8

400 Contour in metres

Rivers

Roads

FIG. 3.16

that observed for (silt+clay)/sand ratio. The liquid limit values, however, show gradual fall from D to G, although the rate of fall may not be at par, as observed in (silt+clay)/sand ratio.

3.6: BARNIHAT :

The study areas near Barnihat, G. S. Road, on the Assam Meghalaya border is located between $26^{\circ} 2'$ to $26^{\circ} 3'$ N and $91^{\circ} 52'$ to $91^{\circ} 53'$ E longitude (Fig. 3.16). It falls within the physiographic unit number three, Fig. 2.1. The 'jhum' cultivation is highly localised and practised in a small area.

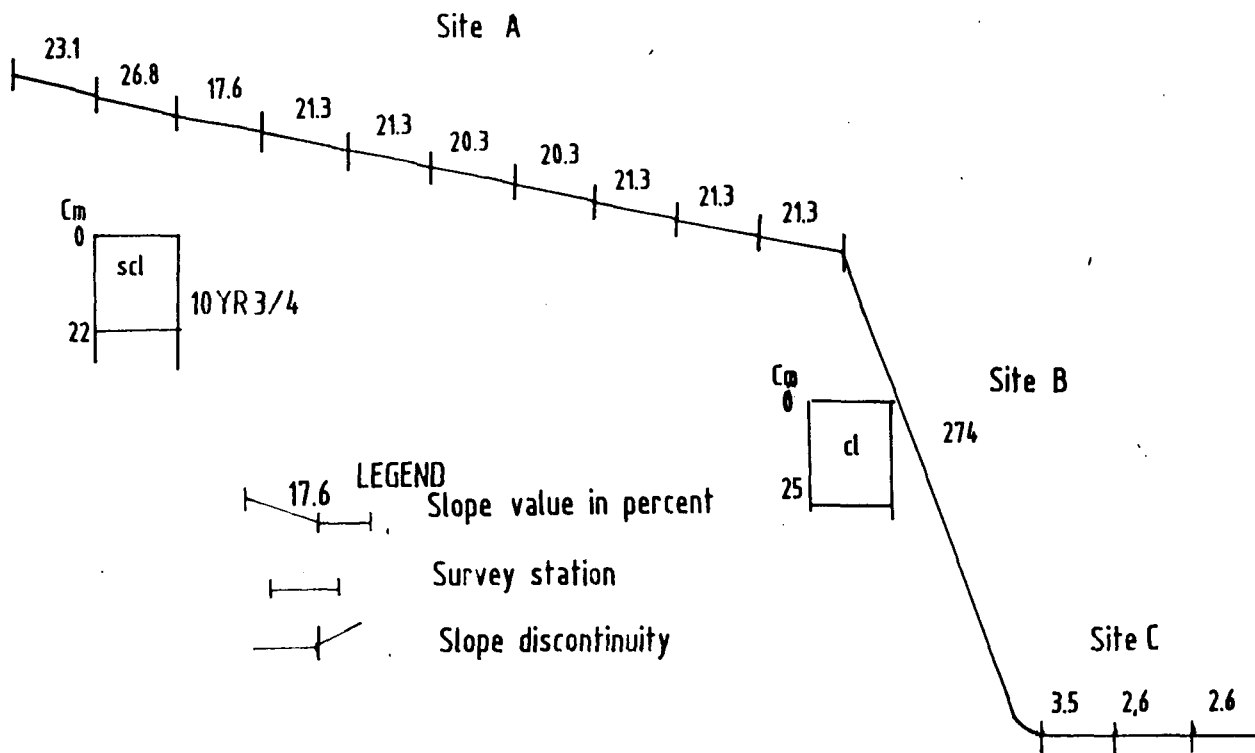
The area is made up of granites and gneisses which, however, is concealed by layers of alluvium. It is widely accepted that indiscriminate destruction of forests as a result of shifting cultivation, coupled with high rainfall in this region, has led to slope instability including mass movements and soil erosion, with consequent siltation of rivers causing floods in the lower sectors of the main river system. This increases enormous losses of cultivated land every year. The associated soil losses resulting from jhuming have been established by ICAR'S studies (ICAR, 1978).

3.6.1: Slope Profile Analysis :

A slope profile analysis was carried out in this area (Fig. 3.17). A convexo-rectilinear site was identified as a typical recurring type of the area. The measured site A is 80

FORM OF HILL SLOPE BARNIHAT

Metres 10 0 10 20 Metres



LEGEND

- 17.6 — Slope value in percent
- Survey station
- Slope discontinuity

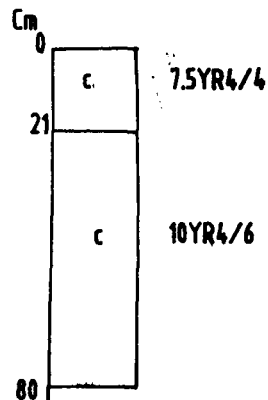


Fig. 3.17

m length with a gradient of average 21.4 per cent. Soil creep is identified as the main mass movement at this site. It is followed by a free face of 50 m length with 274 per cent gradient (site B). It is characterised by wedge slide and topples. The base of this slope is terminated by a narrow (15 m) stream valley (site C). The accumulation of soils at the base of some relatively permanent trees give an approximate indication of rate of soil creep. Other sites of this type can be more extensive.

3.6.2: Soil Analysis :

Three soil samples one each at A, B and C were collected and their characteristics are described in Table 3.9. Soils of A are dark yellowish brown, sandy loam, medium, moderate, sub-angular blocky. Soils of B are clay loam, dark brown, coarse, strong, sub-angular blocky, while soils of C are moderately deep, dark brown to brown, clayey, moderate, medium, subangular blocky underlain by dark yellowish brown, clayey, medium, strong, angular blocky soils. They are strongly to very strongly acidic in nature.

Loss of finer soil particles due to 'jhuming' at A and severe mass movement at B result their accumulation at valley (C) and thus, resulting in a higher (silt + clay)/Sand ratio (Fig. 3.18). There is a gradual fall in organic carbon content from A to C. No regular pattern in variations of WHC in the whole slope profile were noted. The variation in LL could be related to, either finer soil accumulations or

TREND OF SOIL CHARACTERISTICS AT BARNIHAT

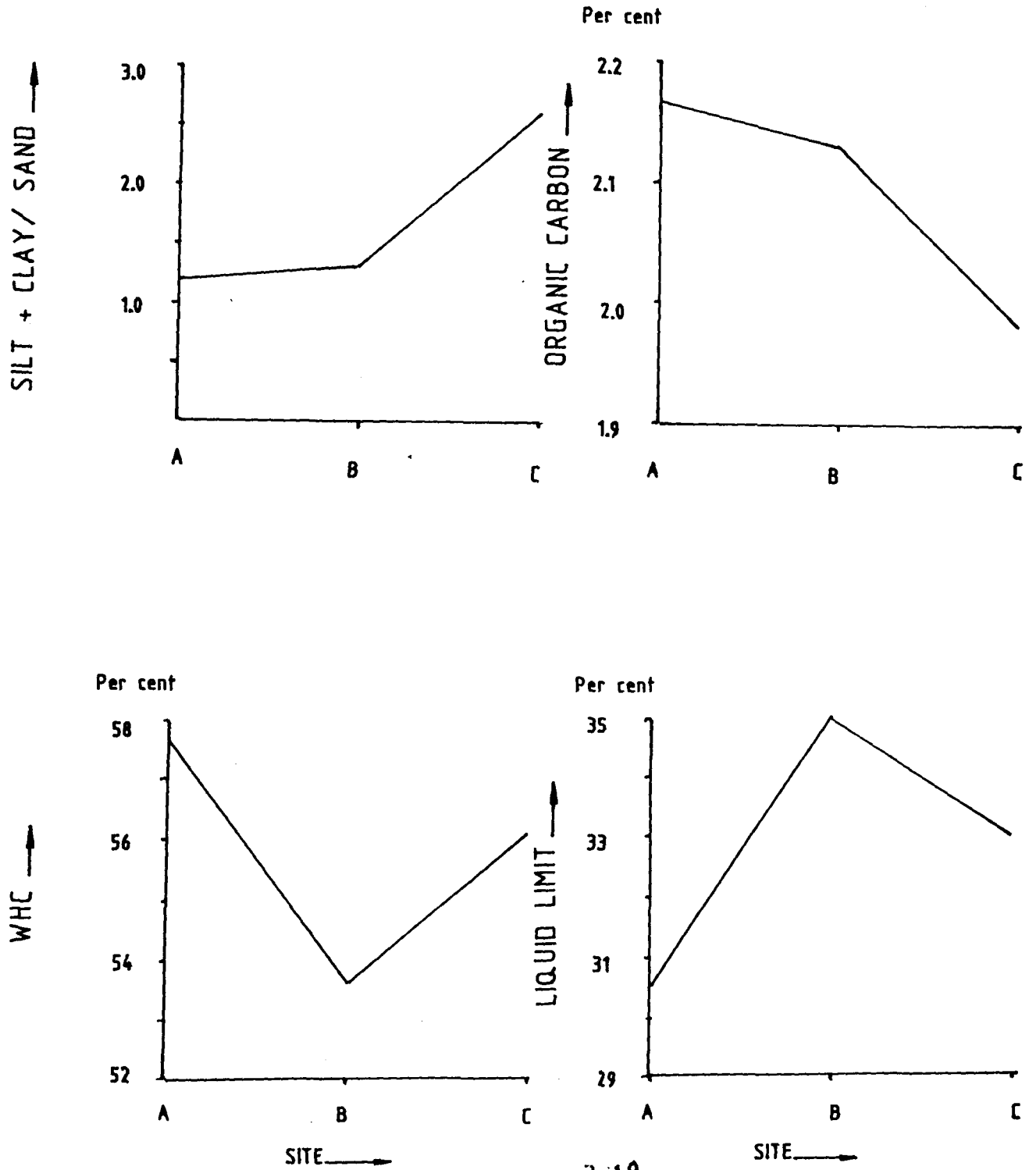


FIG. 3.18

organic carbon distribution.

Table - 3.9

Soil Characteristics of Barnihat

Site	Average Gradient %	Depth (cm)	Moist Colour	Total Sand %	Silt+clay Sand	Org.C %	W.H.C. %	Liquid limit %	pH
A	21.45	0-22	10YR 3/4	45.7	1.18	2.17	57.8	30.5	5.5
B	274	0-20	7.5YR3/4	43.2	1.31	2.13	53.6	35.0	5.5
C	2.9	0-21	7.5YR4/4	27.6	2.62	1.98	56.1	33.0	5.1
		21-81	10YR 4/6	21.6	3.65	1.01	53.2	36.0	4.6

Source: Estimated by the author.

3.7: JARAIN :

Jarain, a coal mining zone, extends from 25° 17' to 25° 20' N and 92° 7' to 92° 10' E longitudes with an altitude ranging from 600 to 1000 m from msl (Fig. 3.19). It falls within the physiographic unit number five, Fig. 2.1. Drainage types are both perennial and seasonal. Humid tropical vegetation with cultivable patches are common. In general, hills are moderately steep, irregular, having hillside drainage lines. The rapid runoff thereon, induces a slope wash on some concentrated line, commonly rills and gullies.

The geology in this area is the Cherra Sandstone of the Thuria Stage (Paleocene) of Jaintia Series. It overlies the rocks of Shillong series (Proterozoic). Coal seams are found interbedded with shales and sandstones of Cherra Sandstone. Thin layers of coal are found all around Jarain, thickness of which varies from 15 cm to 40 cm. The Cherra Sandstone is

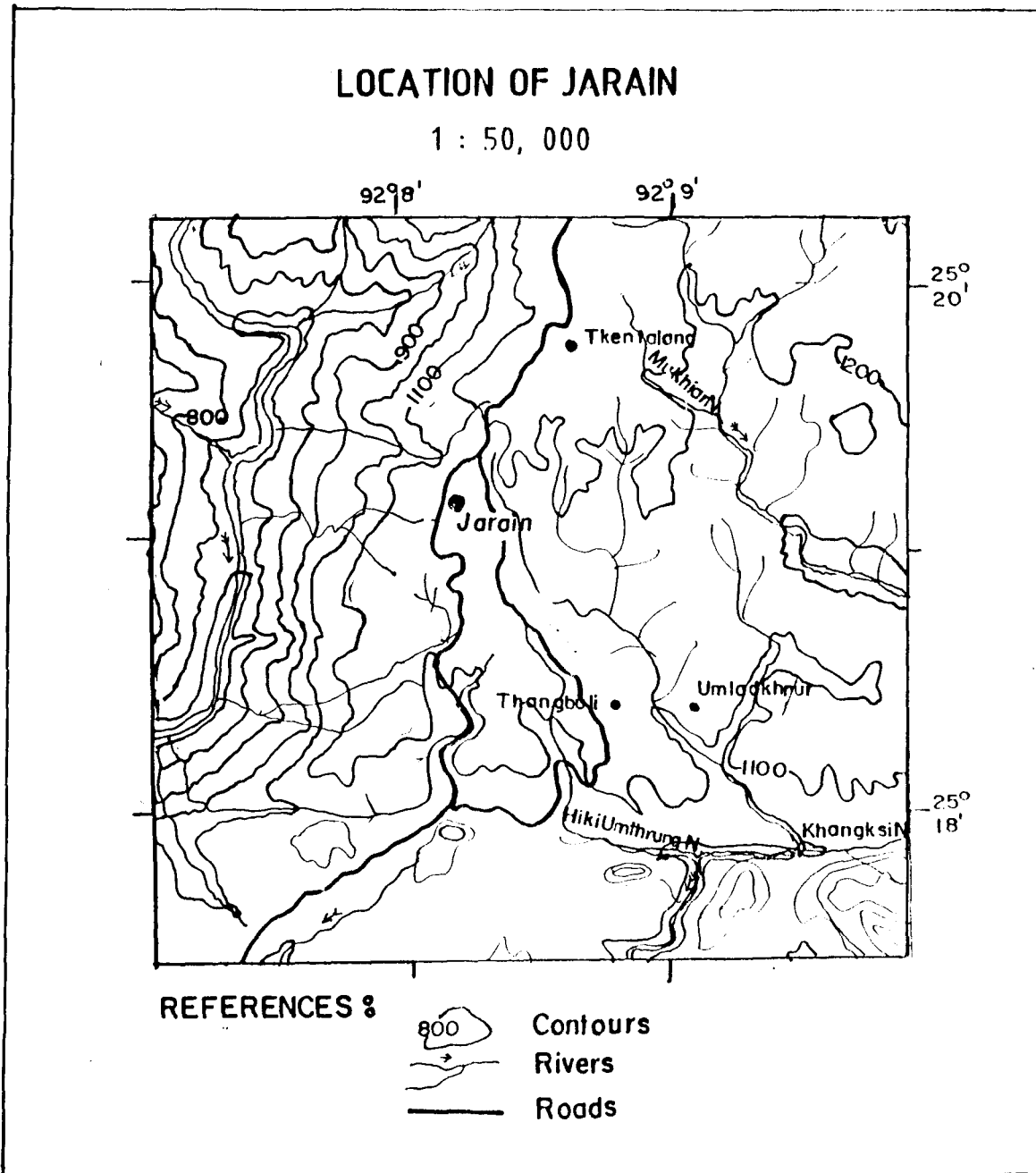


Fig. 3. 19

composed of block alum shale, ferrigenous sandstone, black shale and friable sandstone (Changkakoty 1964).

3.7.1: Slope Profile Analysis :

A profile facing E-W was selected for site analysis (Fig. 3.20) and five distinct sites were identified. From the crest, site A extends upto 25m which has sumital convexity. Surficial materials comprises of coarse sand, gravels with grits, flanks and chunks. There are many exposed rocks of size $30 \times 60 \times 30$ cm³. The presence of algae and mosses are the indices of sheetwash and soil creep mass movement. Below this (B), a convex slope, varying from 17.6 to 46.6 per cent slope gradient is identified. It is essentially a denudational form, underlain by solid rock and bearing only a veneer of detritus, either at rest or moving very slowly downwards owing to high rainfall action. In this site, the weak rocks of shales are removed and step and rise like structure $15\text{cm} \times 30\text{cm}$ are observed which shows the weak materials are moved due to rock slides and talus creep. In this site, the exposed rocks are covered by moss and algae. Quite a number of pitcher plants are available. Similar types at steep erosional sites tend to occur on the lower parts of valley sides associated with channel under cutting at the base.

Slope leads down to valley floor (site C). It is bunded for paddy cultivation. The gradient ranges from 0.8 to 4.3 per cent. The site is however, presently kept fallow and is

FORM OF HILLSLOPE JARAIN

Metres 5 0 5 10 Metres

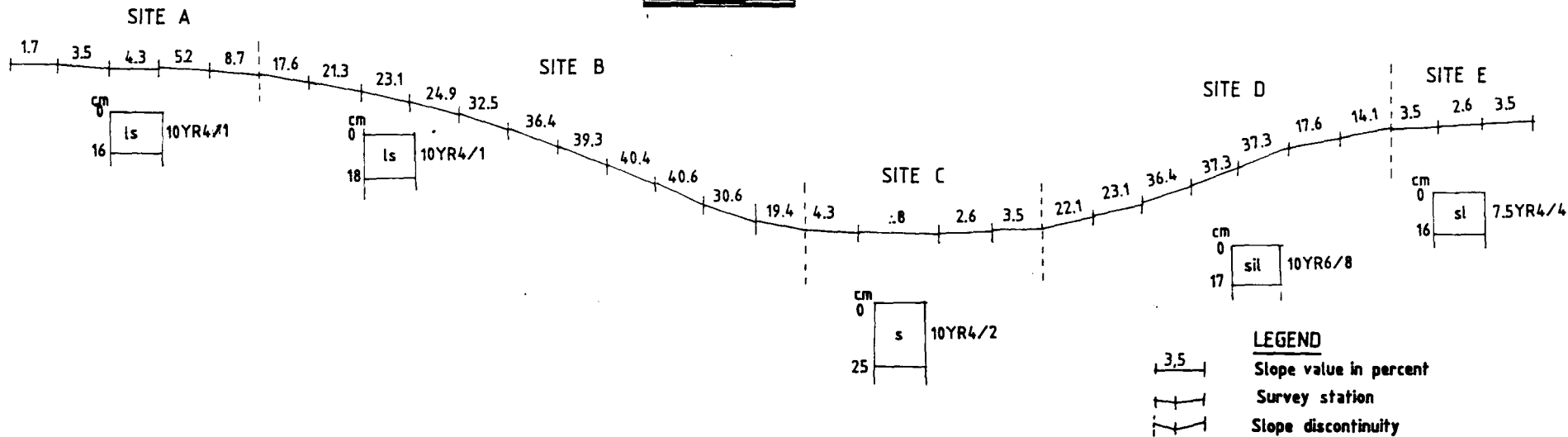


Fig. 3.20

full of weeds. Crossing this towards west, D is identified which is convex with an inflexion of 14.1 to 37.3 per cent gradient. It extends upto 35 m with soil and talus creep mass movement. Beyond this, a summital convex slope E ranging from 2.6 to 3.5 per cent gradient prevails, where soil creep is prominent.

This is a typical convexo-concave slope comprising an upper convexity and lower concavity. Such slope forms are typical of weak rocks like shale, sandstone in the Jaintia Hills area, where the actual variety of landscape from place to place is a reflection of differences in the lengths and heights of the slopes.

3.7.2: Soil Analysis :

The morphometric and physico-chemical properties of soils collected at different sites are shown in Table 3. 10. Soils of A and B are dark gray, loamy sand, fine, weak, single grained, while soils of C are dark grayish brown, sandy, fine, weak, single grained. The west facing soils of D&E are more brownish. Soils of D are brownish yellow, sandy clay loam, medium, moderate, sub-angular blocky and soils at E are dark brown to brown, sandy loam, with medium sub-angular blocky structure. Soils are very strongly acidic (pH 4.6 to 4.9).

TREND OF SOIL CHARACTERISTICS AT

JARAIN

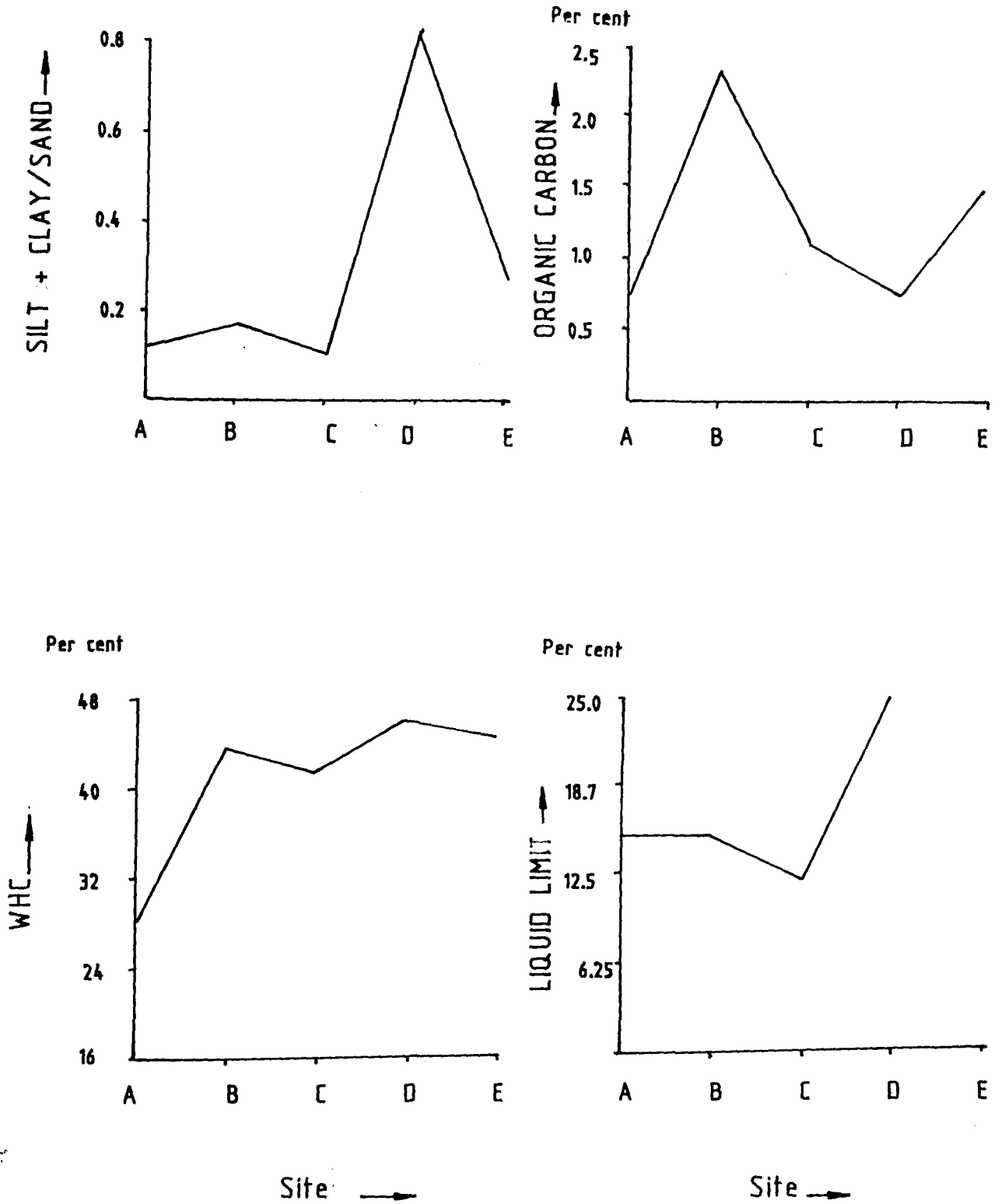


FIG. 3.21

Table - 3.10

Soil Characters of Jarain

Site	Average Gradient (%)	Depth (cm)	Moist Colour	T.S. (%)	Si+C Sand	Org.C (%)	W.H.C. (%)	Liquid limit (%)	pH
A	4.7	0-16	10YR 4/1	87.9	.13	0.69	28.01	15.0	4.0
B	30.2	0-18	10YR 4/1	84.8	.17	2.35	42.04	15.0	4.8
C	2.8	0-25	10YR 4/2	90.5	.10	1.08	38.33	12.0	4.8
D	26.8	0-17	10YR 6/8	54.9	.82	0.73	46.09	25.0	4.6
E	3.2	0-16	7.5YR4/4	77.7	.28	1.51	43.37	-	4.8

Source: Estimated by the author.

Soil analytical data shows that finer soil particles relative to coarse fractions remain more or less constant from A to B; thereafter, it decreases (Fig. 3.21). Rapid rise in (silt + clay)/sand ratio at D may be due to the depositional effect of finer soil particles transported from the west facing slope at site E.

There is an increase in organic carbon content at B but its value gradually declined to D with an abrupt increase at E. Variation in WHC and LL in the whole slope profile could be related to both the finer soil fractions and the organic matter content.

3.8: Bapung :

This site is similar to that of Jarain and is under coal producing zone of Meghalaya. The area is located between 25° 24' to 25° 26' N and 92° 18' to 92° 20' E longitude (Fig. 3.22). It falls within the physiographic unit number four,

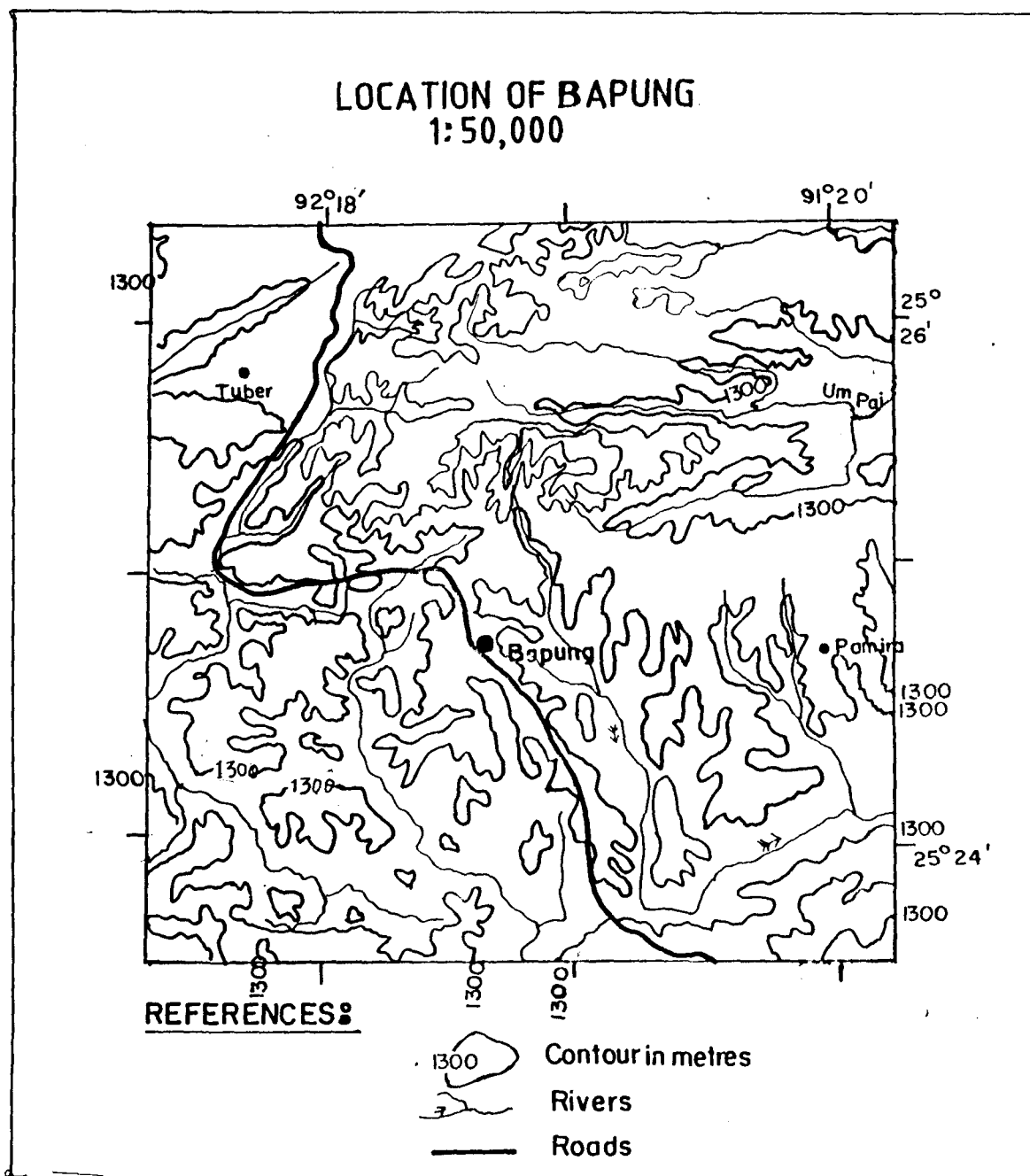


FIG. 3.22

FORM OF HILLSLOPE
BAPUNG

Metres 5 0 5 10 Metres

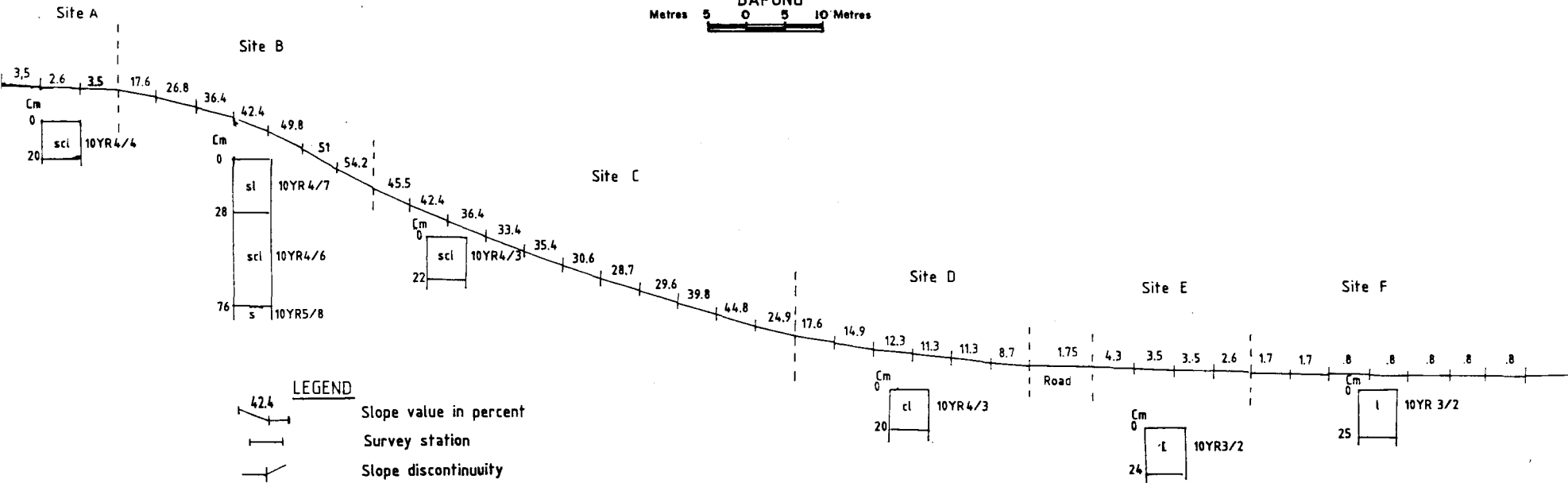


FIG. 3.23

Fig. 2.1. In general, the area is of low amplitude and moderate slopes, covered with Theria sandstones of Lower Paleocene age. These are more or less friable, soft to medium hard, medium to coarse grained, reddish brown to brownish white colour with bands of shales, carbonaceous shales and coal. Theria Sandstone is unconformably underlain by granites and gneisses and met in the valley portion (Barkakoty, 1972).

3.8.1: Slope Profile Analysis :

A slope profile analysis was applied over a typical valley side (Fig. 3.23). Site A consists of 2.6 to 3.5 per cent gradient, showing a uniform summital convexity measuring 15 m length. There is quite a luxuriant growth of pine vegetation. The surficial materials are gravels covering 20 per cent of the surface area. Sheetwash mass movement is observed at this site. Below this, is B, extending 35 m, a convex slope with 17.6 to 54.2 per cent gradient. Trees are cut here for a proposed orchard where dried leaves are spread over it. Soil creep mass movement is prominent at this site. Beyond this, site C forms upto 55m where some small rills of 3 to 4 cm. width and 15 to 20 cm. depth are observed exhibiting soil and talus creep. Large numbers of boulders (30 x 30 x 20 cm³) are scattered over the slope covering 40 per cent of the area. D is identified with the same characteristics of surficial materials below C, but the gradient is 8.7 to 17.9 per cent. A road runs across this slope just after D and below this, are E and F, where paddy

is cultivated. The gradient of E is 2.6 to 4.3 per cent, while that of F is 0.8 to 1.7 per cent. In E, bunds are more frequent than F for stagnating water. There is evidence of prominent cracks developed on the surface. Mass movement process is practically nil at these sites.

Table - 3.11

Soil Characteristics of Bapung

Site	Average Gradient %	Depth (cm)	Moist Colour	Sand %	Silt+Clay Sand %	Org.C %	W.H.C. %	Liquid limit %	pH
1	2	3	4	5	6	7	8	9	10
A	3.2	0-20	10YR4/4	53.2	0.3	3.45	64.51	34.5	4.8
B	39.7	0-28	10YR4/6	76.9	0.69	1.01	34.83	16.0	4.9
		28-75	10YR5/8	58.9	0.11	0.83	41.66	21.5	5.0
		75-90	10YR5/8	89.7	0.87	0.07	23.60	9.5	5.4
C	33.1	0-22	10YR4/3	45.4	1.20	5.01	63.50	40.0	4.5
D	12.7	0-20	10YR4/3	22.2	3.50	3.38	82.06	54.0	4.7
E	3.5	0-24	10YR3/2	28.8	2.47	4.04	94.99	55.0	4.5
F	1.1	0-25	10YR3/2	34.0	1.94	4.69	87.73	51.5	4.7

Source: Estimated by the author.

3.8.2: Soil Analysis :

A perusal of data in Table 3.11, shows that soils of A are dark yellowish brown, sandy clay loam with fine, weak and sub-angular blocky. Soils of B are moderately deep, excessively drained, dark yellowish brown, sandy loam, fine, weak and sub-angular blocky, underlain by yellowish brown, sandy clay loam to sandy, medium and moderate sub-angular blocky soils. Soils of C are dark brown to brown, sandy clay loam, medium, moderate, sub-angular blocky and are

TREND OF SOIL CHARACTERISTICS AT BAPUNG

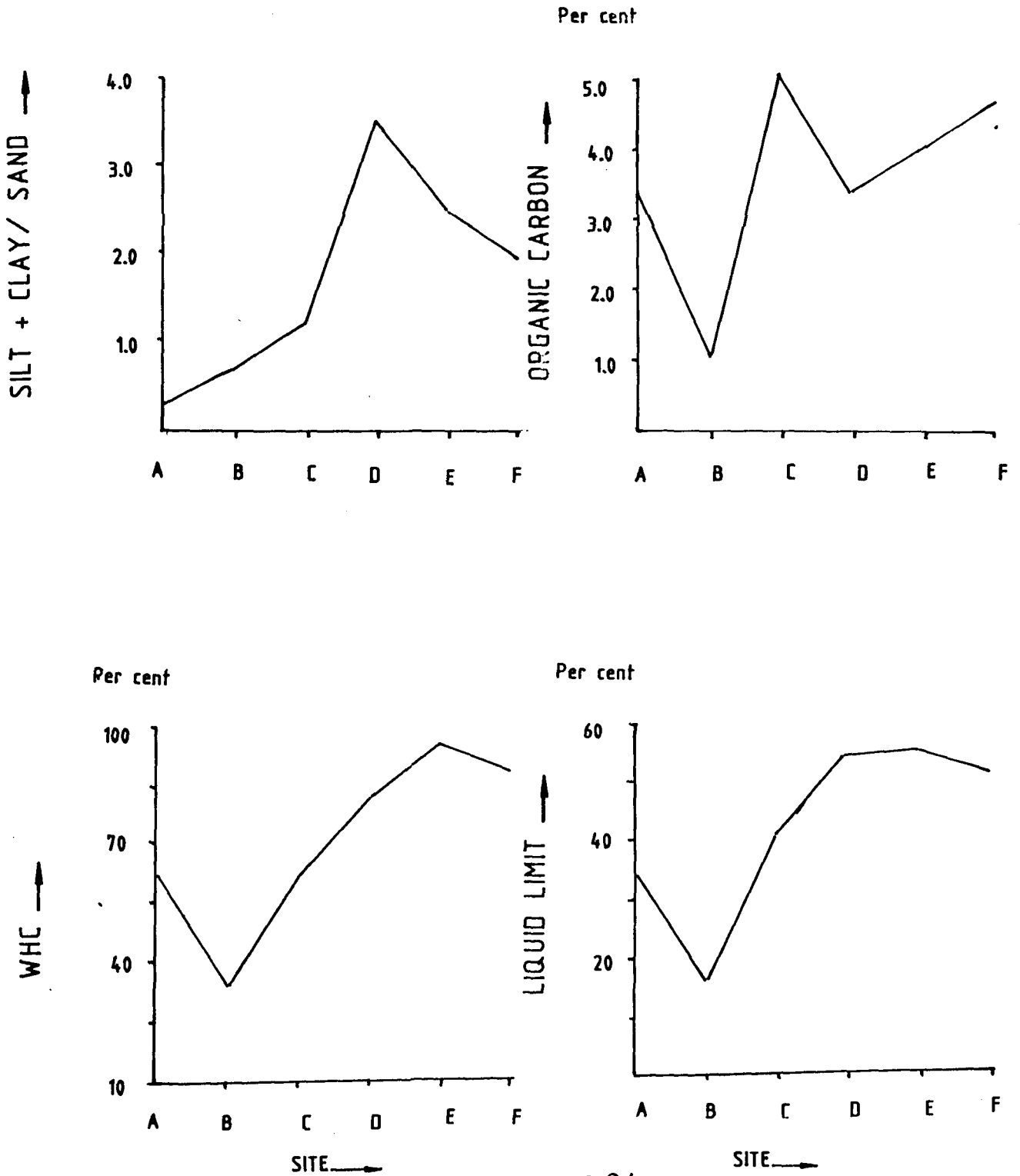


FIG. 3.24

excessively drained. Texture of D, E and F soils gradually decrease to finer size and colour change from dark brown to very dark grayish brown. Structures are fine, moderate and sub-angular blocky. Soils are strongly acidic (pH 4.5).

There is a gradual increase in (silt + clay)/sand ratio from A to B, there after the ratio falls at E and F (Fig. 3.24). There is no regular pattern in the variations in the organic carbon content in the whole profile. Its value sharply decreases from A to B and thereafter, increases abruptly at C. The second fall in organic carbon content was observed at D, wherefrom, values gradually increase upto F. Like organic carbon both W.H.C. and L.L. decline at B, beyond which the latter sharply increases upto D, and tends either to remain constant or decrease at F.

3.9: Komrrah :

It lies between $25^{\circ} 10'$ to $25^{\circ} 15'$ N latitude and $91^{\circ} 40'$ to $91^{\circ} 45'$ E longitude (Fig. 3.25). It lies within the physiographic division number one, Fig. 2.1. The area comprises of E-W trending rugged hills, dissected by small tributaries of the Umsohryangkew river. The southern part of Shillong plateau is dissected by a sharp escarpment. Beyond these hill ranges, there are the flat plains towards south bordering Bangladesh. The altitude of the summit is 150 m above msl.

The area is a limestone quarry and is being carried out by KLMC (Komrrah Limestone Mining Co.Ltd.), where both India and Bangladesh governments are participating.

3.9.1: Slope Profile Analysis :

Slope profile analysis was carried out along the measured slope of about 330 m long consisting of steep to very steep forested hills underlain by limestone interbedded with sandstone and shales (Fig. 3.26). It is a south facing profile. The higher parts of the profile consists of site A with 3.5 to 8.1 per cent gradient extending upto 30 m. The area is covered with arecanut palms, betelvine and turmeric cultivation . The underlain bed rock is composed of sandstone. This slope is affected by soil creep mass movement. There is a convex-linear slope B, ranging from 19.4 to 35.4 per cent where rills and gullies of B of 10 cm width and 15 cm depth have developed. The geology of this 40 m long slope is composed of limestones tending towards E-W and interbedded with shales that are mostly exposed. The surficial materials found in this site are boulders, mostly $30 \times 60 \times 30$ cm³ covering 50 per cent of surface area. In this site, soil and talus creep of mass movements are identified. A rectilinear slope C is identified with 40 m length having 35.4 to 38.4 per cent gradient. It is covered with big boulders with almost 90 per cent coverage. Rapid mass movement e.g. slides and topples occur in this area due to

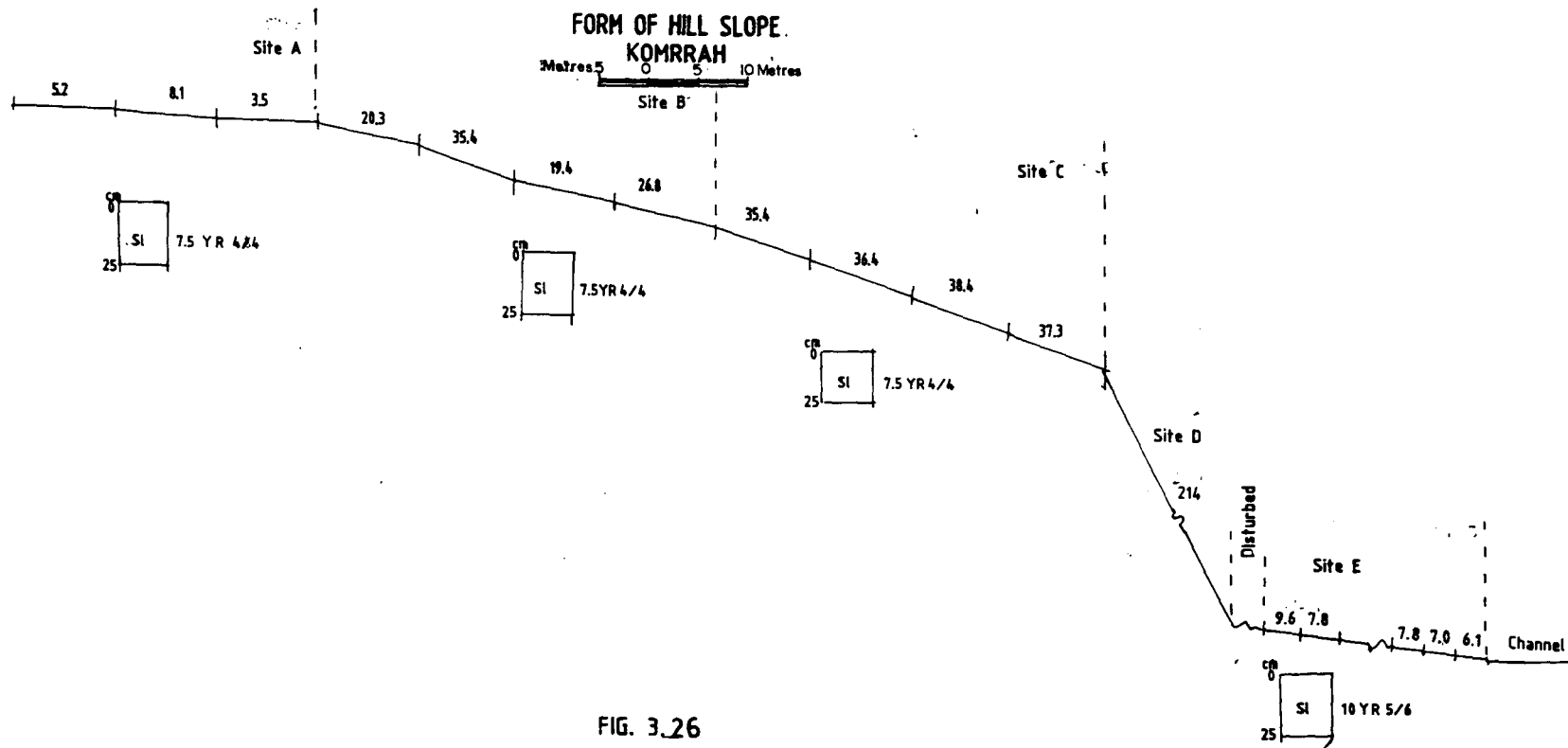


FIG. 3.26

quarring and blasting. The size of the gullies extend upto 30 to 45 cm width and 20 to 25 cm depth. There are prominent cavities and sink holes exhibiting typical rugged limestone zone. A free face slope D of 150 m length with 214 per cent slope was also observed where topples and landslides are vigorous due to quarring and blasting. It consists of gravel deposits, boulders, pebbles and cobbles with 90 per cent surface cover.

Downwards this of site, there is a disturbed site, 15 m length with an angular inflexion of 30° where debris materials get accumulated from above. Beyond this, a near planner, E with an average gradient 7.8 per cent is identified. Beyond that, a channel flows, whose bed is 6 to 7 m deep and full of boulders, cobbles and blocks.

3.9.2: Soil Analysis :

The morphology and physico-chemical characteristics of soils are presented Table 3.12.

Soils of A and B are dark brown to brown, sandy loam, fine, weak, sub-angular blocky and strongly acidic (pH 5.2). Soils of C are also similar to the above, exception being that the soils are neutral (pH 7.1). Soils of E are yellowish brown, sandy loam, single grained and slightly acidic (pH 6.3).

Particle size analysis shows gradual loss of finer soil

TREND OF SOIL CHARACTERISTICS AT KOMRRAH

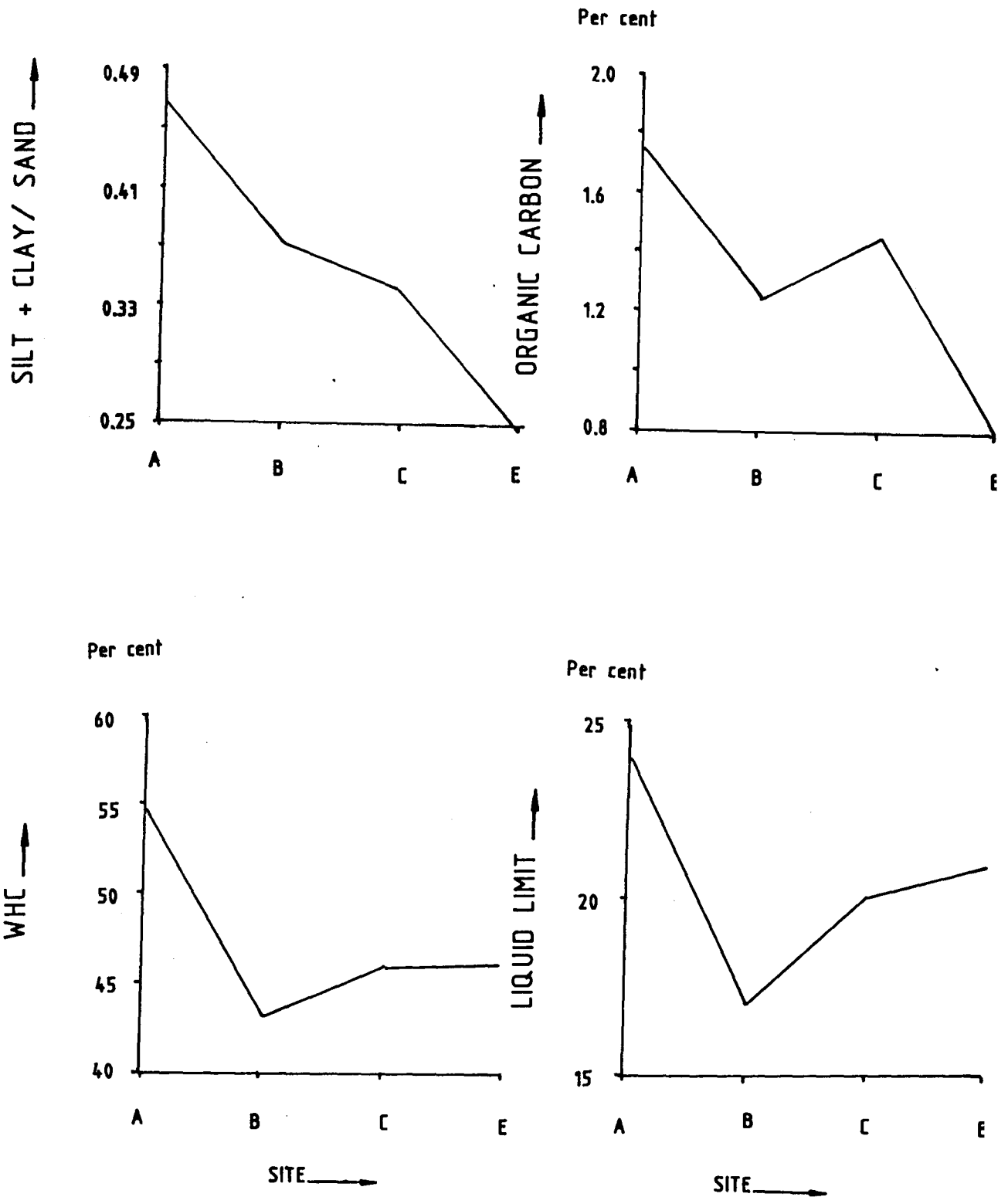


FIG. 3.27

fractions along the slope profile (A to E) (Fig. 3.27). Similar results are also observed in organic carbon content with its slight increase at C. Both W.H.C. and LL behave similarly as organic carbon upto B, thereafter, the former increase at C maintaining constant level upto E, while the latter linearly increases upto the end point of the slope profile.

Table - 3.12

The Morphology and Physico Chemical Characteristics of Soils

Site	Average Gradient %	Depth (cm)	Moist Colour	Total Sand %	Silt+Clay Sand	Org.C %	W.H.C. %	Liquid limit %	pH
A	5.8	0-25	7.5YR4/4	67.5	0.48	1.75	55.1	24.0	5.2
B	25.5	0-15	7.5YR4/4	72.0	0.38	1.24	43.6	17.0	5.3
C	36.9	0-11	7.5YR4/4	74.6	0.34	1.44	45.7	20.0	7.1
D*	-	-	-	-	-	-	-	-	-
E	7.8	0-25	10YR 5/6	79.6	0.25	0.81	46.1	21.0	6.3

* - Soils not available

Source: Estimated by the author.

3.10: SONAPUR :

Sonapur is located in the southern part of the Shillong plateau and extends from 25° 0' to 25° 10' N and 92° 15' to 92° 25' E longitude. It falls under the physiographic divisions number one, Fig. 2.1. It comprises a flat topped hill area, where altitude ranges from 250 to 300 m above msl. The hills are dissected by deep gorges and canyons. A river drains the surface water into the Surma valley in Bangladesh. (Fig. 3.28).

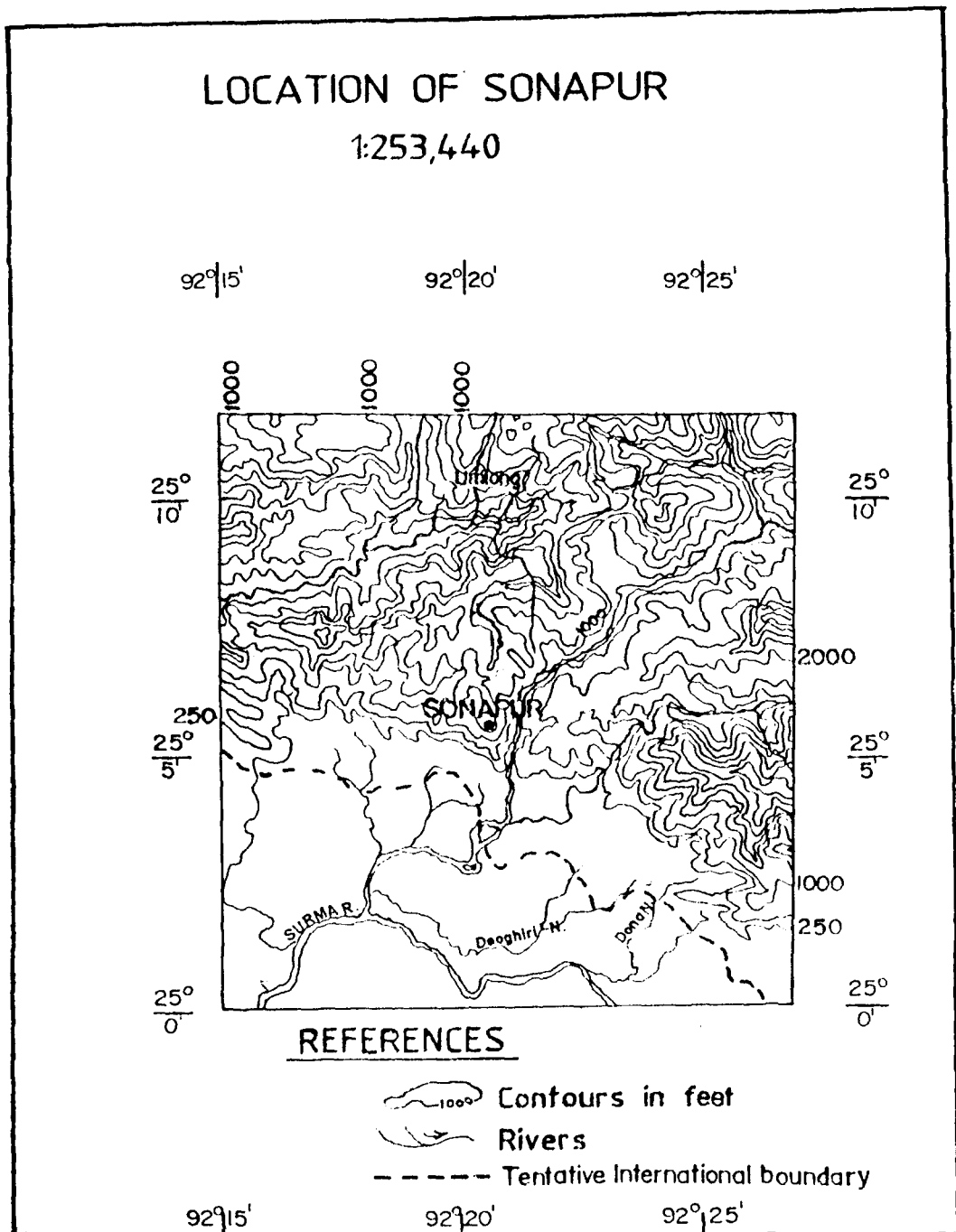


FIG. 3. 28

Rock types of the area consists mostly of sandstones and limestones of Upper Cretaceous to Eocene age. The sandstones are massive, ferruginous and intermixed with siltstone and shales. These are highly brecciated and fractured towards the bottom. The interbedded Umlatdoh Limestone (Lower Eocene) is also massive to thinly bedded limestones with thin marly and sandy limestone bonds occurring towards the middle and rich calcareous sandstone zones at the base (Chakravarty and Bhattacharya, 1972).

The site is well known for natural landslide and is responsible for several incidents of calamities especially during the rainy season.

3.10.1: Slope Profile Analysis :

Slope profile analysis shows that the site A is a convex slope (Fig. 3.29). It is full of evergreen vegetation. The surrounding parts consist of rocks with distinct cracks and joints. The rocks are of irregular shape controlled by local joint system. The free face, B stands with an angle of 75° over about 200 m length. It is bare, usually consists of joints over fault surfaces. Mass movements of topples and landslides are common with boulders of Size $210 \times 240 \times 240$ cm³. After this, C of talus (scree) slope developes, which is an accumulation of rocks that fall as topples, slab slide and wedge slide. The slope gradient drops to 0.6 per cent towards the end of this site. After this, a mild convexity developes

FORM OF HILLSLOPE
SONAPUR

Metres 5 0 5 10 Metres

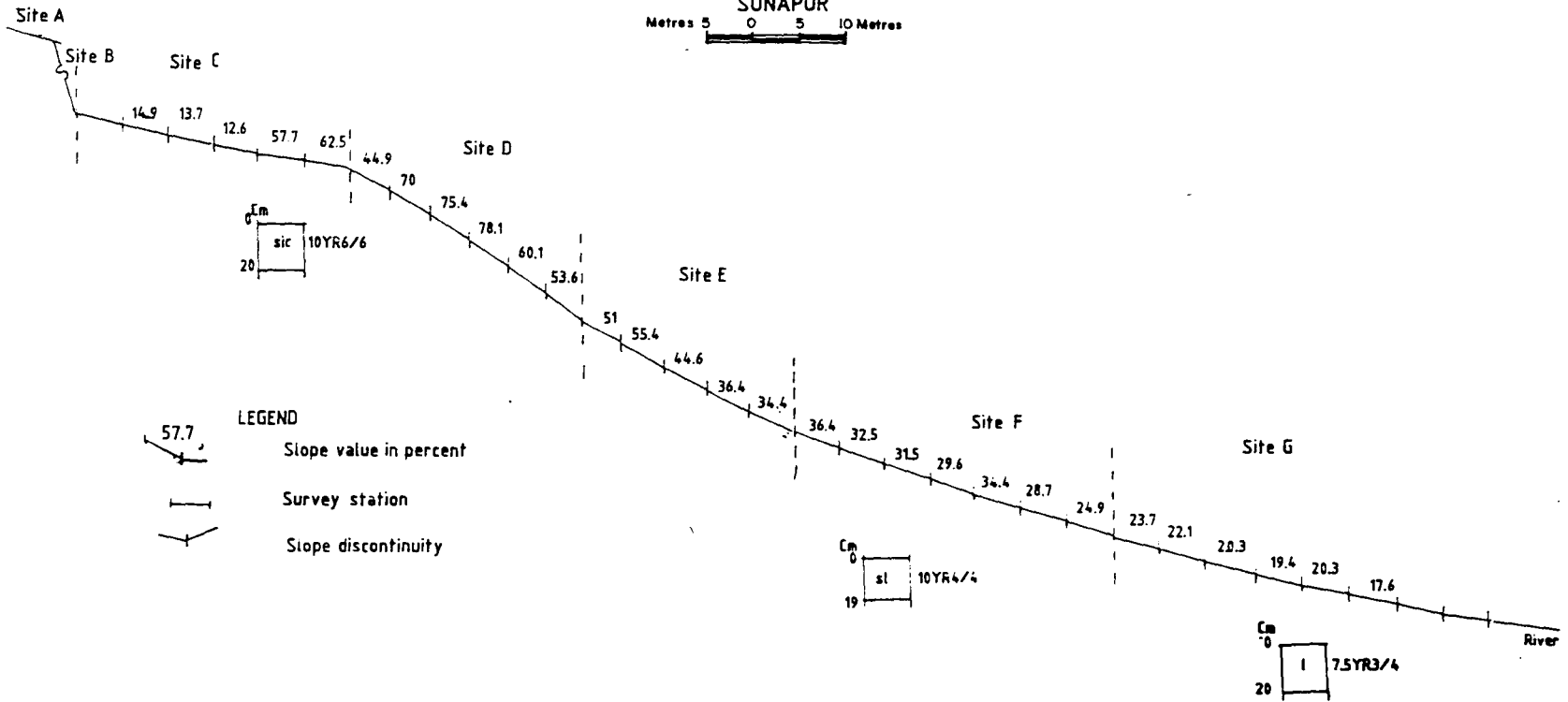


Fig. 3.29

having a plain bed rock with boulders (site D) consisting of sandstones. The boulders, blocks and cobbles and chunks are, however, of different kinds including limestones. The soil conservation department is taking measures by wrapping big boulders together with hard perforated nets, which prevent them from quick falling. A concave site E with slope ranging from 46.6 to 60.1 per cent is identified which is full of boulders, cobbles, pebbles and angular to sub-angular blocks, chunks and flakes. The bed rock is sandstone, interbedded with shales and distinct lineaments are formed. In this zone, water still flows (i.e. during the month of January) as seepage (between marl and sandstone junction). After this, a convexo-linear slope is identified ranging from 29.6 to 36.4 per cent gradient which is the main transportational slope (site F). Transportation of material by sheetwash is most prominent as larger stones tend to have accumulations of smaller rock fragments and finer soil particles washed downwards of the slopes, leaving little terracettes behind them. Moreover, soil and talus creep and rockslide type of mass movements are taken place this site. There are formation of tunnels in the sub-surface, which shows lowering of cohesion and shearing stress. In this zone also, the boulders are wrapped with perforated plastic net. Pebbles, flakes are common alongwith boulders and blocks. Gullies of size 30 cm wide and 30 to 60 cm length are common. There are numerous rills and incipient gullies. Rise and step like structures are common. A few broom plants are also found in the

TREND OF SOIL CHARACTERISTICS AT SONAPUR

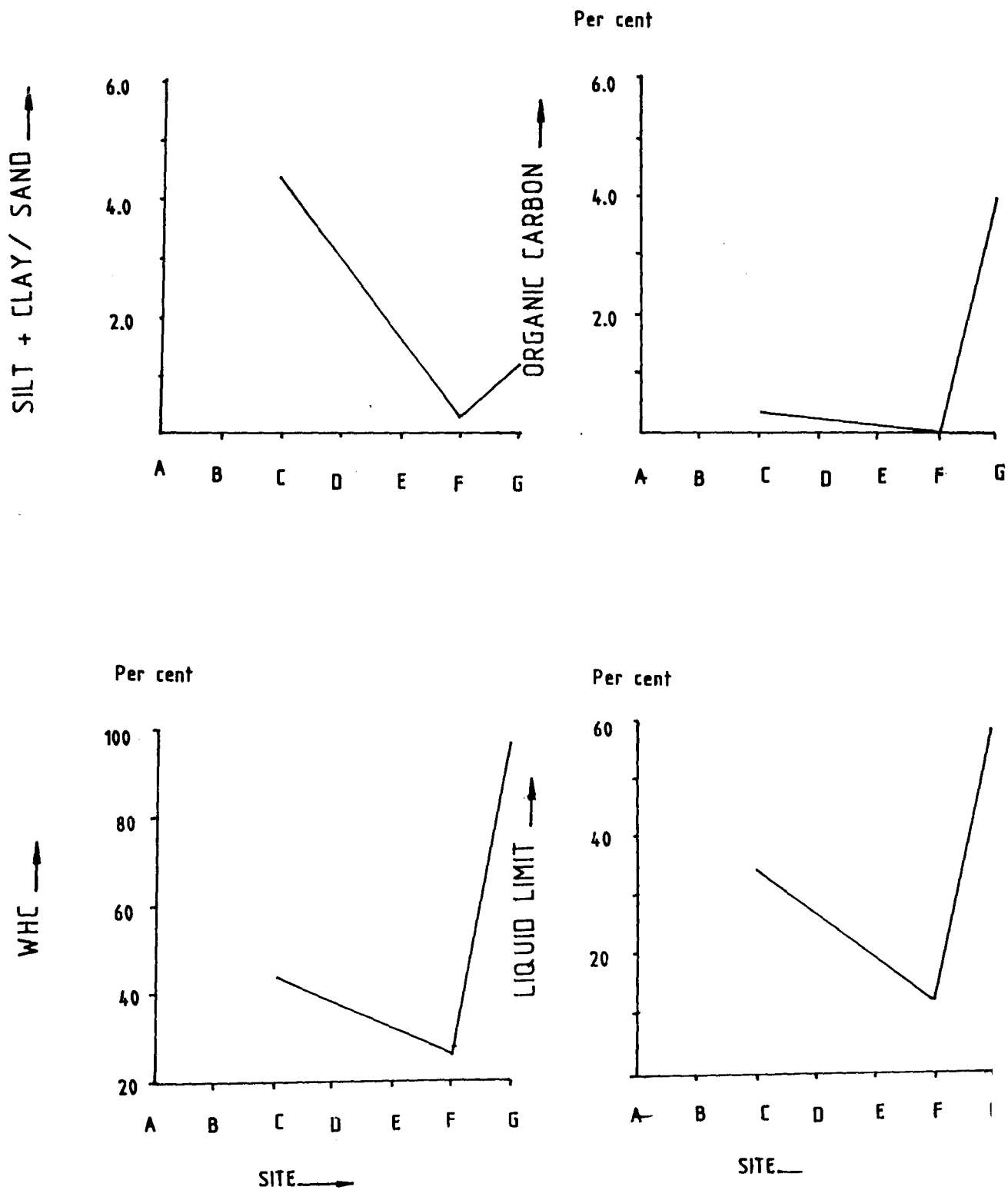


FIG. 3.30

cleavages. Columnar structure of bed rocks and capping on small rocks are frequent. Few logs are lying around there. Logs are slippery and are full of mosses which show continuous fluvial actions on it. The last site G, including the edge of the road has the similar character as the above but its magnitude of actions are slightly less. The slope ranges from 17.6 to 28.7 per cent. Soil and talus creep of low magnitude occur at this site. After this, there is a 7 m wide road and it is the place where blockage due to landslide always occurs, especially during the rainy season.

3.10.2: Soil Analysis :

Three soil samples were collected in site C, F and G and their characteristics are shown in Table 3.13.

The soils of C are brownish yellow, silty clay, medium and moderate sub-angular. Soils of F are dark yellowish brown, sandy clay, medium, weak, sub-angular and both soils are extremely acidic (pH 4.1). Soils of G change to dark brown, loam fine, weak, sub-angular and slightly acidic (pH 6.3) in nature.

Soil analysis shows the (silt+clay)/sand ratio decreases sharply from C to F and thereafter, increases at G. Other parameters as organic carbon, WHC, LL follow the similar pattern in variations corresponding with the (silt+clay)/sand ratio (Fig. 3.30).

Table - 3.13

Soil Characteristics of Sonapur

Site	Average Gradient %	Depth (cm)	Moist Colour	Sand %	Silt+Clay Sand	Org.C %	WHC %	Liquid limit %	pH
A*	-	-	-	-	-	-	-	-	-
B*	-	-	-	-	-	-	-	-	-
C	13.7	0-20	10YR 6/6	18.8	4.31	0.35	44.47	35.0	4.3
D*	-	-	-	-	-	-	-	-	-
E*	-	-	-	-	-	-	-	-	-
F	33.6	0-19	10YR 4/4	73.6	0.35	0.08	27.17	12.0	4.1
G	22.1	0-20	7.5YR2/4	44.7	1.23	4.07	94.96	58.5	6.3

* - Soils not available

Source: Estimated by the author.

The intra and interrelationship amongst the slope and mass movement and soil properties with their statistical interpretations are given in the Chapter IV.

CHAPTER - IV

DISCUSSION

4.1: Slope Mass Movement :

An abstract of data showing gradient, length, shape, mass movement, rocktype and thickness of 'A' horizon are presented in Table 4.14.

Table - 4.14

Sites Showing Gradient, Length, Shape, Mass Movement, Rock Types, and Thickness of 'A' Horizon

Site	Average Gradient (Degrees)	Slope Length (m)	Slope Shape	Mass Movement Type	Mass Movement Scores	Rock Type	Thickness of A horizon (cm)
1	2	3	4	5	6	7	8
Barnihat B	69.9	50	Recti- linear	Wedge- slide	5	Granite & gneiss	20
Ryngngain C	46.6	135	-do-	Topples Slabslide Rockslide	6	Sandstone granite	20
Mylliem C	38.0	90	Convex Recti- linear	Rockfall, soil and talus creep	4.5	Granite quartzite	16
Sohiong C	33.1	15	Recti- linear	Rockslide Wedgeslide	4.5	Sandstone shales & granitic gneiss	16

Table 4.14 contd.

1	2	3	4	5	6	7	8
Mawlat A	26.1	30	Convexo concave	Talus creep & rockslide	3.5	Sandstone shales & granite	15
Sohiong B	24.9	15	Convex	Soil & Talus creep	2.5	Sandstone shale granite & gneiss	25
Mawlat C	23.8	15	- do -	Slabslide rockside & Topple	5	Shales, sand stone granite.	18
Bapung B	21.6	35	- do -	Soilcreep	2	Sandstone	28
Komarrh C	20.2	40	Convex- Recti- linear	Rockslide	5	Limestone	11
Ryngngain B	20.2	35	Rectili- near	Soilcreep	2	Sandstone granite	20
Sonapur F	18.5	35	Concavo Convex	Soil & talus creep	2.5	Limestone Sandstone	19
Bapung C	18.3	55	- do -	-do-	2.5	Sandstone	22
Jarain B	16.8	55	Convex	Rockslide & Talus creep	3.5	Convex	18
Mylliem B	15.6	35	Convexo- Concave	Soil & talus creep	2.5	Granite quartzite	18
Jarain D	15.0	35	Convex	- do -	2.5	Sandstone	17
Komrrah B	14.3	40	- do -	- do -	2.5	Limestone	15

Table 4.14 contd.

1	2	3	4	5	6	7	8
Smith F	14.0	15	- do -	Sheetwash	0	Gneiss	20
Ryngngain A	13.5	80	Convex Recti- linear	Soilcreep Sheetwash	2	Sandstone granite	21
Sonapur G	12.4	40	Convex	Soil & talus creep	2	Limestone	20
Sohiong A	12.2	40	* Concavo Convex	Sheetwash Soil creep	1.5	Sandstone, Shale, gra- nite gneiss	13
Barnihat A	12.1	80	Convex Rectilinear	Soilcreep	2	Granite & Gneiss	22
Mawlat B	10.3	40	Recti- linear Concave	- do -	2	Shales, sand stone granite	20
Smith A	9.5	90	Convex	- do -	2	Gneiss	16
Sonapur C	7.8	15	- do -	Talus Creep	3	Limestone Sandstone	20
Smith C	7.8	45	Convex Rectilinear	Soilcreep	2	Gneiss	22
Bapung D	7.2	30	Convex	Talus & Soil creep	2.5	Sandstone	20
Mylliem A	6.8	25	Concave Convex	Soilcreep	2	Granite quartzite	17
Smith B	4.1	80	- do -	- do -	2	Gneiss	20
Komrrah A	3.3	30	Convex	- do -	2	Limestone	25

Table 4.14 contd.

1	2	3	4	5	6	7	8
Jarain A	2.6	25	- do -	Sheetwash Soil creep	1.5	Sandstone	16
Smith G	2.4	30	Concavo Convex	Nil	0	Gneiss	22
Jarain E	1.8	15	Convex	Soilcreep	2	Sandstone	16
Bapung A	1.8	15	Convex Rectilinear	Sheetwash	1	- do -	20
Komrrah E	4.4	50	Concave	Trace mass movement	0	Limestone	25
Smith E	3.6	15	Concavo Convex	- do -	0	Gneiss	16
Smith D	2.6	42	Concave	- do -	0	- do -	19
Bapung E	2.0	20	- do -	- do -	0	Sandstone	24
Barnihat C	1.7	15	- do -	- do -	0	Granite & gneiss	21
Jarain C	1.6	23	- do -	- do -	0	Sandstone	25
Bapung F	0.63	35	- do -	- do -	0	- do -	25

Based on severity the types of mass movement observed in the present investigation of East Khasi and Jaintia Hills of Meghalaya are arranged as topple > wedge slide > rock slide > talus creep > soil creep > sheetwash and scoring with numerals 1,2,3,4,5 and 6 were allowed to indicate progressive

increase in severity, respectively.

4.1.1 : The highly significant and positive relationship ($r=0.77$, $p=1$ per cent) observed between gradient and severity of mass movement in the present study suggest that with increase in the gradient, severity of mass movement increases. Several workers (Carson and Kirkby, 1972; Goudie, 1990; Strahlar, 1950) reported dependence of mass movement on the gradient.

However, severity of mass movement does not depend solely on the steepness of the slopes, rather length and shape of the slope also come into play in the process of mass movement (King, 1957; Wischmeier and Smith, 1958, Clark & Small 1982). In the present investigation the highly positive and significant ($p = 1\%$) relationship between slope length and severity of mass movement suggests the increase in severity of mass movement along with parallel increase in slope length. This is in conformity with the findings of King (1957).

The above explanation lends support to observed slow mass movement, eg., talus creep, soil creep and sheetwash decrease with slope gradient from 60-3%, where slope length different sites varies from 15 m to 90 m. Increase of slope length with parallel decrease of slope gradient reduces velocity of falling of soil and rock masses producing slow mass movement. This suggests that in rapid and moderate type

of mass movement, gradient as explained earlier seems to play a major role in determining mass movement irrespective of slope length (Goudie, 1990).

4.1.2 : In addition to above, the shape of the slope also plays a vital role in occurrence of different types of mass movements. Crozier (1986) reported that concave and steeper hillslope sides are more vulnerable to rapid landslide. In the present study, types of slopes identified can be arranged in order of severity of mass movement as rectilinear > convex > concave. Clark and Small (1982) reported that convexity has most often been responsible for soil creep, rain splash and slope wash and argued that such processes require increasingly steep slope angles down the profile in order to transport the increasing amount of material that must pass progressively to lower points in a given time. He further reported that concavity is usually associated with either erosion or deposition by running water, whether as wash or as channel flow. In the present investigation, it is found that slow mass movement like sheetwash, soil creep occur in convex slope. Topples, wedge slide, rockfall etc. occur in the rectilinear slope, while there is trace mass movement in the concave slope. Contrary to it, Grant (1974) and Subramanyam and Rao (1986) based on aerial photo interpretations reported that mass movement is generally abundant in concave slopes and rare in convex slopes. The deviation may be due to methodology adopted for identification of shape of slopes

Based on the foregoing discussion and



presented, there is a strong evidence to suggest that severity of mass movements is the resultant product of interaction of steepness, length and shape of the slope. In the present investigation the rectilinear shape alongwith greater slope length and with increase in steepness of slope give rise to rapid mass movement, viz. topple, wedge slide and rockfall. In the convex slope, where both length and steepness of slopes in the majority of the observed sides decreases, slow mass movement seems to be a regular phenomenon, viz. sheetwash, soil creep, talus creep and rapid mass movement are not important features. The concave shape as observed in different sites of the present study are generally associated with both shorter length and low gradient for which no or little mass movement was observed.

4.1.3 : However, geology of the existing rocks might have also played a role in the severity of mass movements. Durgin (1977) attributed differences in mass movement because of the nature of weathering and rock character. Varnes (1978) has also included physical disintegration of rocks from frost action and thermal action etc. acting on different types of rocks. In the present investigation, it is observed that mass movement e.g. topples, wedge slide, rockfall confined to areas (Mylliem, Ryngngain, Sohiong, Mawlat, Barnihat) developed from hard rock types like granitic and gneissic complex. Slow mass movements like soil creep, talus creep occur on soft rock zones (Bapung, Jarain, Sonapur, Komrrah) comprising of sandstones, shales etc. The reason may be

attributed to variations in heat absorption between types of rocks. Larger variations in temperature action between the surface and inner layers of rocks in the hard rock masses caused rapid exfoliation than those of the soft types. Varnes (1978) has also listed disintegration of rocks as one of the causes of mass movements, but in case of Smith, the above observation does not hold good. Smith, which occurs in the hard rock zone, experiences only slow mass movement viz. sheetwash and soil creep, which can be attributed to low gradient.

4.2: Soil Development :

4.2.1 : The thickness of A horizon is found to increase with decrease of gradient. In the present investigation a weak negative correlation ($r = -0.16$) between gradient and thickness of A horizons suggest that with an increase of the gradient there is a parallel decrease in thickness of A horizons. It is evident that with increase of slope, soils become shallower. This is attributable to erosion hazard (Fitzpatrick, 1988) resulting in thinner A horizons. Several workers (Ruhe and Walker, 1968; Pennock et al, 1987, and Beckett, 1968) also report similar results.

4.2.2 : The colour of the soil varies from 10 YR to 5 YR in hue with values from 6 to 3 and chroma from 6 to 1 depending on their position on the slope profile and mostly, on the organic matter content of the soil. This is also reported by

AIS & LUS (1971). In addition, local drainage conditions of the soil influence the colour of the soil (Birkeland, 1984). Well oxidised soils with high organic carbon content on steeper hillslopes as in Ryngngain C gives rise to very dark grayishbrown (10 YR 3/2) colour. In contrast, soils with the similar drainage condition but with low organic carbon content tended to give rise to dark brown colour (7.5 YR 3/2) as found in Barnihat B. With increase in the wetness of soils, with interaction of organic carbon, its colour changes from yellowish brown (10 YR 5/6) to very dark grayish brown (10 YR 3/2). In the present investigation, imperfectly drained soils with high organic carbon content (Smith D) exhibit dark brown colour (7.5 YR 3/4). Conversely, similar sites (Komrrah E) with low organic carbon content tend to give rise to yellowish brown colour (10 YR 5/6).

4.3: Characteristics of Soils :

4.3.1 : The distribution of mechanical composition of soils, in terms of sand, silt and clay is found to vary greatly in different sites.

The silt and clay/sand ratio increases from site A to B at Mawlat and Ryngngain, slightly at Jarain B and gradually, from A to C and then, abruptly at D at Bapung. The increase of the ratio is due to accumulation by sheetwash over 30 m slope length at Mawlat A and over 80 m slope length at Ryngngain A. Sharp increase in the ratio at Ryngngain B could be attributed to the slope length (Wischmeier and Smith,

1958). Accumulative effect of finer soil particles due to slower and seasonal mass movements is observed in the case of A to C of Bapung where gradient also increases gradually. Sharp increase of the ratio at D in Bapung could be due to an exceptional increase of gradient (55.4 per cent for 8 m at C) from where, the finer materials might have been washed away and get deposited at D. In Jarain, however, finer particles relative to coarser, remain more or less constant from A to B because of mild convexity of site A. The increase of finer materials from the higher to lower sites could be due to the process of particle sorting. The similar results were also reported by Malo et al, (1974). In contrast to this, there is a decrease of finer particles in Sohiong from A to B, in Sonapur from C to F and in Komrrah from A to C and a slight decrease in Myllem from A to B. The gradient is 45 to 48 per cent in Sohiong B, 214% at B of Sonapur and 35.4 to 38.4 per cent at C of Komrrah where rapid mass movement is operative is the main cause for such an abrupt decrease. In case of Komrrah, the ratio falls abruptly from C to E. Site D of Komrrah, 150 m in length with 214 per cent gradient is a zone of rapid mass movement, where topples and landslides affect a decline of particle size ratio at E. The slight decrease of the ratio at Myllem B could be attributed to the convexo-concave shape, though steepness varies from 19.4 to 28.7 per cent but falls abruptly at C due to steeper gradient (57.5 to 78 per cent) accentuated by rapid mass movement. Similar variations in textural distribution in soils were also

reported by Zinde and Jain (1982). Decrease of the ratio in case of sites C of Mawlat and Myllem can also be explained by higher gradient of 36.4 to 58.9 per cent and 58 to 78 per cent respectively. An abrupt increase at D of Jarain could be due to the depositional effect of finer soil particles from the west facing slope site E. Finer soils particles from both east facing sites A and B and west facing sites D and E are accumulated at valley floor C, but the same is drained away by water action over C. Both erosional and depositional effects are responsible for increase of finer particles at sites C of Sonapur and C of Ryngngain. Similar examples are also cited by Huggett (1976).

The decrease of finer soil particles at E, F and G in case of Smith is due to puddling action for rice cultivation (Lal, 1982). This leads to deposition of sand during the rainy season. Works of Pofali and Hirekurur (1983) also suggest similar type of results.

4.3.2. : There is a similar trend of variations in organic carbon content in both Jarain and Mawlat. It increases at B due to the accumulative process and a sharp decrease at C due to the rapid mass movement. Malo et al (1974) postulate that hillslope sedimentary process affects the quantity of organic matter that has accumulated in the soil at various positions. He observes logarithmic increase in organic carbon in the surface soil from shoulder to the toe slope. This also holds good in the present investigation upto site B of

Jarain, Mawlat, Ryngngain and upto D of Smith. But sharp decline at C in case of Jarain, Mawlat and Smith is due to erosion and rapid mass movements. Exceptionally high organic carbon at D is attributable to poor drainage conditions. (Brady, 1984). The higher organic carbon at E of Jarain is possibly due to less decomposition in the west facing slope position (Subramaniam and Rao, 1986). The increase of organic carbon content in case of C at Ryngngain could be due to the same reason as explained by Malo et al (1974).

The trend is the opposite in cases of Sohiong, Komrrah and Sonapur. The decrease at B of above locations is generally due to the mass movement. Abrupt decrease at B in Bapung is due to the clearing of natural vegetation. Sudden rise in organic carbon at C could be explained by the deposition of organic debris washed out from the upper slope. Human distrubances (since a road runs across the slope site) might have resulted in the loss of organic carbon at E and F. Higher organic carbon at C of Sohiong is attributable to microbial growth. In Sonapur, the sharp increase of organic matter at G follows the trend of particle size distrubition. The slight decrease of organic carbon at B may be due to same reason as put forward by Malo et al (1974), who reports minimum organic matter content on shoulder of landscape. In the present study, though the slopes are not identified as per Malo's criteria, the shoulder part is in fact, a part of the convex portion of the profiles of the present study

(sites B).

There is a decrease of organic carbon as slope increases in case of Myllem and upto B of Barnihat. Similar results are reported by Beckett (1968) and Perring (1959). In Byrnihat, the fall of organic carbon at B is due to the steeper slope, but low at C though it is a concave slope, may be due to the removal of organic carbon by runoff action on the valley floor.

4.3.3 : With the increase in organic matter and finer soil particles, WHC increases and light textured soils possess lower WHC (Brady, 1984). This is true in all sites of the present study. In case of Mawlat, WHC show no appreciable variation from A to B, thereafter, they decrease sharply with parallel decrease in finer soil fractions and organic carbon. Similar pattern is also observed in Myllem, Sonapur, Ryngngain and Komrrah.

4.3.4 : Majority of samples show similar pattern in liquid limit to those observed for WHC. The variations of liquid limit could be explained due to reasons furnished in respect of water holding capacity.

4.4 : A correlation matrix amongst the variables is attempted in Table 4.15. It shows relationship between the variables. Significant correlation (at 5% level) between gradient and (silt + clay)/sand ratio indicates that the relative proportion of coarser fractions decreases with the increase

Table - 4.15

Correlation Matrix between Soil Variables and Average Gradient

Average Gradient	(Si+C)/ Sand	Organic Carbon	WHC	LL	pH
1.00	0.30 *	- .13	-.18	- .13	.04
	1.00	.55**	.61**	.74**	-.22
		1.00	.90**	.84**	-.19
			1.00	.95**	-.086
				1.00	-.12
					1.00

* - Significant at 5% level.

** - Significant at 1% level.

of slope and this is more prominent with respect to the lower gradient than the counter part. Values at lower slopes have a greater relationship than those at the higher gradients. Decrease of coarser fragments with increase of slope was also reported by Furley (1968) and Steen (1957).

Although the correlation value does not reach the level of significance, organic carbon content tends to decrease with increase of slope and this is in agreement with the findings of Roger (1941) and Furley (1968).

pH has virtually no relationship to the gradient. It is weakly positive. In contrast, Perring (1959) working on chalk grasslands reports that pH distribution shows a direct increase with gradient, both for the total slope and for the upper slope, taken separately; the values rise over the lower slope and are less clearly related to the gradient. Because of the variations in the environmental conditions the pH in

the present samples might have deviated from the former.

Both water holding capacity and liquid limit show a negative correlation with gradient, but both the variables bear strong correlation with the particle size distribution (r being 0.61 and 0.74 with WHC and liquid limit, respectively) and organic carbon (r being 0.90 and 0.84 with WHC and liquid limit, respectively) suggesting a change in the former with parallel change in the latter.

CHAPTER - V

SUMMARY AND CONCLUSION.

5.1 :

The discussion in the preceding chapters have revolved round the theme of 'slope mass movement and associated soils' in the context of East Khasi and Jaintia Hills of Meghalaya, with the objective to identify slope forms and type of mass movement acting on, to relate slope forms and type of mass movement and finally, to investigate relationship between the occurrence of unstable mass movement slopes and their associated soils, and between the occurrence of relatively stable slopes and their associated soils.

It has been emphasized in many ways that studies slope mass movements are placed as a prominent branch of geomorphology. However, studies on its relationship with soils are meagre. The study on East Khasi & Jaintia Hills has been appropriately selected to not only understand the slope mass movement processes, but also to highlight its relationships with soils. Consequently, the peculiar physical setting with its distinct geology in East Khasi and Jaintia Hills made it possible to take up such a study with several important results.

5.2 :

In this study, process form approach has been adopted throughout. Effective explanations in the study have again proved the assumption that there is a direct relationship between mass movement processes and various slope forms with its composition of soil.

5.2.1 : This work provides evidence of the morphological basis of the site, despite boundary difficulties in some areas. Slight differences in surface forms are found to be commonly reflected. The present work varifies the differentiation quantitatively in terms of the gradient. Thus, site analysis helps clearly to distinguish slope forms. The slope forms with shape and length are found to be the most effective method in explaining mass movement processes and their associated soils. Further, scorings of mass movement allowed on the basis of its severity has come out to be a normative classification of mass movement.

5.3 :

It is found that there is a highly significant and positive correlation between the gradient and the severity of mass movement. Further, it is found that the increase of the slope length with parallel decrease of the gradient reduces velocity of falling of rocks and soil masses, producing slow mass movement. In addition, shape of the slope plays an important role in different type of mass movement. According

to severity, a mass movement is found to vary from rectilinear, convex to concave. It was also found that severity of mass movement is the resultant product of interaction of steepness, length and the shape of the slope. Moreover, geology seems to play a vital role in evaluating severity of mass movements. It is observed that rapid mass movements e.g. topples, wedge slides, rockfalls are confined to areas developed from hard rocks while slow mass movements like soil creep, talus creep developed on softer rocks. The study reveals the following important soil properties as regulated by slope.

(i) The thickness of A horizon shows an inverse relationship with the gradient.

(ii) Soil colour depends upon their position on the slope profile interacting with organic carbon content and local drainage conditions.

(iii) Proportion of finer soil particles to coarser size distribution shows significant negative correlation with slope gradient. Variations in the ratio amongst the soil are explained by accumulation due to the mass movement, particle sorting, shape of the slope, aspects, land clearing and management practices.

(iv) Organic carbon tends to decrease with increase in the slope. Variations in the above is explained by erosion and mass movement, drainage conditions, aspects, clearing of

natural vegetation, human interferences and microbial activities.

(v) Both water holding capacity and liquid limit behave significantly with the trend of either finer soil particles or organic matter content.

(vi) pH distribution does not show any relationship with the gradient.

5.4 :

Though the study shows a clear cut relationship between slope mass movement and soil, it would have been an ideal attempt to study a larger number of samples embracing wide range of variations in the given environmental conditions.

5.5 :

It is relatively easy to show that there is a significant relationship between human interventions and slopes. Many processes of the mass movement and slope formation processes have direct impact on land use. In the present study, both natural and artificial hazards have been focussed.

5.6 :

The relationship between geomorphology and engineering in the context of slope study is important. During the past decades geomorphologists and engineers have started to work rather, closer both in common interest and in professional

co-operation. But studies embracing mass movements, slope forms and pedogenic properties are found to rather more interesting and possess a great significance for the study of both the cultural as well as natural landscapes. Therefore, detailed study in respect to the hazard management and prediction, slope management and control, land use and resource potential aspect are to be emphasized and studied in future.

APPENDIX-I

Monthly Rainfall and Mean Maximum and Minimum Temperature

Months	Shillong			Cherrapunji		
	Rainfall (mm)	Temperature max	Temperature min. °C	Rainfall (mm)	Temperature max.	Temperature min. °C
Jan.	15.2	15.5	3.6	19.8	15.8	7.6
Feb.	28.5	17.1	6.4	37.3	16.9	10.5
Mar.	59.4	21.5	10.5	178.9	20.5	12.9
Apr.	136.4	23.8	14.1	605.2	22.0	15.1
May	325.4	23.7	15.5	1705.1	22.1	16.3
Jun	544.6	23.7	17.4	2921.5	22.9	17.3
Jul.	394.9	24.1	18.1	2456.7	22.2	18.4
Aug.	334.6	24.1	17.8	1827.5	22.5	18.4
Sep.	314.9	23.6	16.6	1167.7	22.9	18.1
Oct.	220.2	21.8	12.9	447.4	22.4	15.9
Nov.	34.9	18.9	7.7	46.7	19.7	11.9
Dec.	6.3	16.4	4.5	4.9	17.0	8.8
	2415.3			11418.7		

Source: Climatological Tables of Observatories in India (1931-1960), Indian Meteorological Department, Govt. of India, Pune.

APPENDIX - II

Slope Angle Conversion Table

Degrees	Percent
1	1.75
2	3.5
3	5.2
4	7.0
5	8.7
6	10.5
7	12.3
8	14.1
9	15.8
10	17.6
11	19.4
12	21.3
13	23.1
14	24.9
15	26.8
16	28.7
17	30.6
18	32.5
19	34.4
20	36.4
21	38.4
22	40.4
23	42.4
24	44.5
25	46.6
26	48.8
27	51.0
28	53.2
29	55.4
30	57.7
31	60.1
32	62.5
33	64.9
34	67.4
35	70.0
36	72.7
37	75.4
38	78.1
39	81.0
40	83.9
41	86.9
42	90.0
43	93.3
44	96.6
45	100.0

BIBLIOGRAPHY

1. All India Soil and Land Use Survey, (1971) : Soil Survey Manual, IARI, New Delhi.
2. Barkakoty, B., (1972) : Report on the Detailed Investigation for Coal around Bapung, Jaintia Hills, Meghalaya, 1971-72, G.S.I., Directorate of Mineral Resources, Shillong.
3. Ball, B. C. & O'Sullivan, M. F., (1982) : "Soil Strength and crop emergence in direct drilled and ploughed cereal seedbeds in seven field experiments, Journal of Soil Science, 33, 609-622, Edinburgh.
4. Baver, L., Gardner, W.H. and Gardner, W.R., (1972): Soil Physics, New York, Wiley.
5. Beckett, P.H.T., (1968) : "Soil formation and Slope development. I. A new look at Walter Penck's Anfbereitung Concept," Z. Geomorph (N.F.) 12, pp. 1-24.
6. Birkeland, P.W., (1984): Soils and Geomorphology, Oxford University Press, Oxford.
7. Black, C.S., (1965) : Methods of Soil Analysis, Part II. Am. Soc. Agrn. Inc. Madison, Wisconsin, U.S.A.
8. Brady, N.C., (1984): The Nature and Properties of Soils, 9th Edition Macmillan Publishing Co., New York.
9. Brunsdon, D. and Jones, K. K. C., (1974) : "Evolution of landslipped slopes in Dorset", Phil. Trans. Roy. Soc., A, 283, pp 605-31.
10. Campbell, I.A. and Evans, D.J.A., (1990) : "Glaciotectonism and landsliding in Little Sandhill Creek, Alberta". Geomorphology 4, pp 19-36.
11. Carson, M.A., (1971) : "An application of the concept of threshold slopes to the Laramie Mountains, Wyoming", Inst. Brit. Geogs. Spec. Publ. 3, pp 31-47.
12. Carson, M.A. & Kirkby, M.J., (1972) : Hillslope form and processes, Cambridge University Press.
13. Chakravarty, S.K. and Das, M.K., (1982) : Petrology and Geochemistry of Myllem Granite, Khasi Hills District, Meghalaya, Report No. 548, Geological Survey of India, Shillong.

14. Chakravarty, S.N. and Bhattacharya, U., (1972) : Report on the Geology and Coal resources, G.S.I., Shillong.
15. Changkakoti, U.N., (1964) : Report of one Preliminary Investigation of Coal around Jarain, Umlatodoh and Sutnga areas of Jowai Subdivision, UK & J. Hills, Assam, G.S.I, Shillong.
16. Chorley, R.J., Schumm, S.A. and Sugden, D.E., (1985) : Geomorphology, Muthuen & Co., New York.
17. Clark, M. and Small, J., (1982) : Slopes and Weathering Cambridge University Press, Cambridge.
18. Crozier, M. J., (1969) : "Earth Flows and related Environmental factors of Eastern Otago", J. Hydrol, N. 2., 7, pp 4-12.
19. Crozier, M.J., (1986) : Landslides: Causes, Consequences and Environment, Croom Helm., London.
20. Curry, B.B. and Melhorn, W.N., (1990) : "Summit Lake Landslide and Geomorphic History of Summit Lake Basin, North Western Nevada", Geomorphology 4, pp 1-17.
21. Durgin, P.B., (1977) : "Landslides and the Weathering of Granitic Rocks" Geological Society of America, Reviews in Engineering Geology, Vol 3, pp 127-32.
22. Feller, C., (1979) : Cah. ORSTOM Ser. Pedologic 15(3), p 291, in Lal, R. and Kang, B.T., 1982, Management of Organic matter in soils of the Tropics and sub-tropics in Non-Symbiotic Nitrogen Fixation and Organic matter in the Tropics, Symposia Paper I, 12th International Congress of Soil Science, New Delhi.
23. Fitzpatrick, E. A., (1988) : An Introduction to Soil Science, 2nd Edition, New York.
24. Furley, P.A., (1968) : "Soil formation and Slope Development 2. The relationship between Soil formation and gradient angle in the Oxford area", Z. Geomorph (N.F.), 12, pp 25-42.
25. ----- (1971) : "Relationship between Slope form and Soil properties developed over chalk parent materials", in D. Brusden (ed.), Slopes Form and Process., IBG., Spec. Publ., 3, pp 141-63

26. Gardiner, V. and Dackombe, R., (1983) : Geomorphological Field Manual, George Allen and Unwin, London. pp. 21-28.
27. GSI, (1969-70) : Report on the Geology & Coal Resources of the central part of the Mawlong-Shellia coalfield of UK & J. Hills, Meghalaya.
28. --- : Report No. 489, Shillong.
29. ----- (1974) : Miscellaneous Publication No. 30., Shillong.
30. Gerrand, A.J., (1990): "Soil Variations on Hillslopes in humid temperate climate", Geomorphology, 1990, 3(3/4) pp 225-244, Birmingham, UK.
31. Goudie, A., (1990): "Geomorphological Techniques", Unwin Hyman, London.
32. Grant, K., (1974) : "Terrain Classification for Engineering purpose of Sale area, Victoria", CSIRO, Tech Paper No. 18.
33. Hall, G.F., (1983) : "Pedology and Geomorphology", in L.P. Wilding, N.E. Smeck and G.F. Hall (Ed), Pedogenesis and Soil Taxonomy, I. Concepts and Interactions, Elsevier, Amsterdam, pp. 117-140.
34. Hoore, J.D., (1961) : "Tropical Soils Vegetation", Proc. Abidjan Symp. 1959, pp. 49-55 in Lal, R and Kang, B.T. 1982, Management of Organic matter in Soils of the Tropics and Sub-tropics in Non-Symbiotic Nitrogen Fixation and organic matter in the Tropics, Symposia Paper I, 12th International Congress of Soil Science, New Delhi.
35. Hugget, R.J., (1976) : "Lateral Translocation of Soil plasm through a small valley basin in the Northern Great Wood, Hertforshire", Earth Surface Processes 1: pp 99-109.
36. Hutchinson, J.N., (1968): "Mass Movement" in Fairbredge, R.W. The Encyclopnedia of Geomorphology, pp 688-95
37. ----- (1970) : "A Coastal mudflow on the London Clay Cliffs at Beltinge, North Kent", Geotechnique, 20, pp 412-38.

38. Hutchinson, J.N. and Bhandari, R.K., (1971): "Loading a fundamental mechanism of mudflows and other mass movements", Geotechnique, 21, pp 353-8.
39. ICAR Research Complex for NEH Region, (1978) : Shifting Cultivation in North East India, Shillong.
40. Jenny, H., (1941): Factors of Soil Formation a System of Quantitative Pedology, McGraw-Hill, London.
41. King, L., (1957) : "The Uniformitarian Nature of Hill-slopes" in Slope Morphology, edited by Schumn, S.A & Mosley, M.P., Pennsylvania, 1973.
42. Kirkby, M.J., (1967) : "Measurement and Theory of Soil Creep", J. Geol, 75, pp 359-78.
43. ----- (1971) : "Hillslope Process Response models based on the continuity equation", in Brunnsden, D. (ed.) Slopes form and process, I.B.G. Special Pub. 3, pp 15-30.
44. Kuntze, Von H., (1967) : "Wasserhaushalts and Grunland-forschung bei Grundwasser boden ins humiden Klima" in Patrica Davis, 1985, "Influence of organic matter content, moisture status and time after reworking on Soil Sheer Strength", J. of S.S., 36, pp. 299-306, Edinburgh.
45. Lanyon, L. E. and Hall, G.F., (1983) : "Land-surface Morphology, 2. Predicting landscape instability in Eastern Ohio.", Soil Sci., 136, pp. 382-386.
46. Lal, R., and Kang, B.T., (1982) : "Management of Organic Matter in Soils of the Tropics and Subtropics in Non-Symbiotic Nitrogen Fixation and Organic Matter in the Tropics", Symposia Papr I 12th Intetnational Congress of Soil Science, New Delhi.
47. Malo, D.D., Worcester, B.K. Cassel, D.K. and Matzdorf, K.D., (1974) : "Soil Landscape Relationship in a closed Drainage System.", Soil. Sc. Soc. Amr. Proc., Vol. 38.
48. O'Loughlin, C.L., (1972) : "A preliminary study of landslides in the Coast Mauntains of South Western British Columbia", in O. Slaymaker and H.J. MacPherson (eds.), Mountain Geomorphology, Vanconver, BC, British Columbia Geographical Series 14, pp 101-12.

49. Pandey, S., Ghose, B., Roy, B.B. and Abichandani, C.T., (1967) : "Geomorphic Influence on Soil Genesis in Semi-Arid and Arid Environments" in Journal of the Indian Society of Soil Science, Vol. 15, No.3, New Delhi.
50. Patto, P. M., Clement, C.R. & Forbes, T.J., (1978) : "Grassland poaching in England and Wales. Permanent Grassland Studies" in Patricia Davies, 1985, Influence of Organic matter content, moisture status and time after reworking on Soil strength, J. of I.S., Vol. 36, British Society of Soil Science, Edinburgh.
51. Pennock, D.J., Zebarth, B.J, and Jong, D. E., (1987) : "Landform Classification and Soil Distribution in Hummocky Terrain, Saskatchewan, Canada" Geoderma, 40, p. 297-315, Amsterdam.
52. Perring, F., (1959) : "Topographical Gradients of Chalk Grassland", J. Ecol., 47, p. 447.
53. Piper, C.S., (1950) : Soil and plant Analysis, Hans. Publishers, Bombay.
54. Pofali, R.M and Hirekerur, L.R., (1983) : "Significance of Geomorphological Analysis for Soil Mapping" in Geographical Review of India., Vol.45, No.2, Calcutta, pp. 24-34.
55. Prior, D. B., Stephens, N. and Archer, D. B., (1968) : "Composite mudflows on the Antrim Coast", Geogr. Annaler, 50 A, pp. 65-78.
56. Rib, H.T. and Liang, T., (1978): "Recognition and Identification", Chapter 3 in Schuster, R.G. and Krizek, R.J. (ed.) Landslide analysis and control, Transportation Researcher Board Special Report, 176, pp. 34-80.
57. Rice, R. M., Corbett, E.S. and Bailey, R.G., (1969) : "Soil Slips related to vegetation, topography and soil in Southern California", Water Resources Research, Vol.5, pp. 647-59.
58. Roy, B.B, Ghosh, B. and Pandey, S., (1967) : "Landscape-Soil Relationship in Chohtan Block in Barmar District in Western Rajasthan" in Journal of the Indian Society of Soil Science., Vol. 15, No. 1., New Delhi.

59. Rube, R.V. and Walker, P.H., (1968) : "Hillslope models and Soil formation, I. Open System", Trans. 9th Int. Congress Soil Sci., Adelaide, pp. 551-560.
60. Schumm, S. A., (1956) : "The role of creep and rainwash on the retreat of badland slopes", Am. J. Sci. 254, pp. 693-706.
61. Schumm, S. A., (1956) : "Evolution of drainage systems and slopes in badlands at Perth", Amiky, New Jersey. Bull Geol. Soc. Am., 67, pp. 597-646.
62. Sharpe, C.F.S.,(1938): Landslides and Related Phenomena, Columbia University Press, New York.
63. Sidle, R. C, Pearce, A. J. & O'Loughlin, C. L., (1985) : "Hillslope Stability Landuse", American Geophysical Union Water Resources Monograph II, American Geophysical Union, Washington DC.
64. Singh, B. and Prakash, S., (1966) : A Text Book of Soil Mechanics, Roorkee.
65. Skempton, A.W., (1953) : "Soil Mechanics in respect to geology", Proc. York. Geol. Soc., 29, pp. 33-62.
66. Small, R.S., (1985) : The Study of Landforms A Text book of Geomorphology, Press Syndicate of the University of Cambridge.
67. Snedecor, G. and Cochran, W.S., (1967) : Statistical Methods, Oxford & IBH Publishing Co. Calcutta.
68. Subramaniam, S.K. and Rao, D.P., (1986) : "Mass Movement Studies in Kosi Catchment, Nepal - A Semi Quantitative Approach using Aerial Photographs", Photonirvachak, Vol. 14. No.1, Dehradun. pp. 61-65
69. Steen, E., (1957) : "The effect of aspect and slope on Vegetation and soil in a natural pasture", (trans) Fordbr Forsk, pp. 86-9 quoted in Furley, P.A., 1971, Relationships between slope form and soil properties developed chalk materials, In D. Brunsdon (ed) Slopes Form and Process IBG, Spec. Publ. 3, pp. 141-163.
70. Strahler, A.N., (1950): "Equilibrium theory of Erosional Slopes approached by frequency distribution Analysis", American Journal of Science, Vol. 248, pp. 673-96.

71. Statham, I., (1976) : "A Scree slope rockfall model", Earth Surface Process, 1, pp. 43-62.
72. Terwilliger, V. J., (1990) : "Effects of vegetation on soil slippage by pore pressure modification", Earth Surface Processes and Landforms., 15, pp. 553-70.
73. Terzaghi, K., (1950) : "Mechanism of landslide - An Application of Geology to Engineering Practice", Berkey Volume, Geological Society of America.
74. Twindale, C. R., (1959) : "Some Problems of Slope Development", Geol. Soc. Australia, Jour., 6, pp. 131-147.
75. Varnes, D.J., (1978): "Slope movement types and process" in R.G. Schuster and R. J. Krizek (eds.) Landslides, Analysis and Control, Washington DC, National Academy of Sciences, Special Report 76.
76. Ward, W.H., (1945) : "The Stability of Natural Slope", Geogr. J., 105, pp. 170-191.
77. Wischmeier, W. H. and Smith, D.D., (1958) : "Rainfall Energy and its Relationship to soil loss", Trans. Am. Geo phys. Union, 39, p. 289.
78. Wooldridge, S. W., (1949) : "Geomorphology and Soil Science, J. Soil Science, 1, pp. 31-34.
79. Wright, R.L., (1972): "Some Perspectives in Environmental Research in Developing Countries", Geoforum., 10, pp. 15-33.
80. ----- (1973) : "An Examination of the Value of Site Analysis in Tropical Australia", Z. Geomorph., 17(2), pp. 156-184.
81. ----- (1984) : "Applied Geomorphology" in C.W. Finki (ed.) The Encyclopedia of Applied Geology, New York, Van Nostrand Reinhold.
82. Young, A., (1972) : "Slopes" Oliver and Boyd, Edinburgh, pp. 288.
83. Zende, N.A., and Jain, S.P., (1982) : "Soil Mapping and Land Use Plan in Tehri-Garhwal District, U.P., Using Aerial Photo-interpretation Technique, Highlighting Soil-landscape Relationship and Land Utilization" in Photonirvachak, Vol. 10, No. 3, pp. 41-47, Dehradun.

1240 Library
 Rec. No. 102495
 Rec. by HSTG
 Date
 Class by
 Substituting by
 Date