GEOMORPHOLOGY OF TRIPURA

By

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DOCTOR OF PHILOSOPHY

To

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NORTH-EASTERN HILL UNIVERSITY

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This is to certify that the thesis titled "*The Geomorphology of Tripura*" submitted by Shri S.C. Mazumder to the Department of Geography, North Eastern Hill University, Shillong, for the fulfilment of the degree of Doctor of Philosophy is a bonafide study of the author to the best of my knowledge. All quotations, extracts and ideas of other studies have been duly referred to.

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The views expressed in the study entirely of the author and the views and opinions of other authors and scholars are duly quoted and cited in the text. The omissions in the study are either of ignorance or of negligence and the mistakes, the sole responsibility of the author.

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Mazumder
SURESH CHANDRA MAZUMDER

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GLOSSARY

AtharaMura,	Athara Mura Hill Range (Hill-range with eighteen peaks).
Bara Mura,	Bara Mura Hill Range (hill-range with twelve peaks).
Bari	A group of huts or Cottages or buildings.
Bill,	Shallow Water body.
Boka Bill,	Boka Bill connotes a particular geological formation after the name of the place.
Charras,	Streams.
Chaima,	Sorma (one major tributary of the Gumti River).
Dupi Tilla,	Geological formation named after the hill Dupi Tilla.
Gang or Nadi,	River
Jampui Tlang,	Jampui Hill Range (Jampui).
Longtarai,	Longtarai Hill Range
Lunga (Loonga),	Broken mounds and low sub-ranges (Low lying dissected lands).
Mura,	Peak.
Sagar or Dighi,	Big Pond
Sakhan Tlang,	Sakhan Hill range (Sakhan).
Tilla,	Hill.
Unokuti hill,	Unokuti means never less than one crore,(refers to the number of God and Goddess).

C H A P T E R - I

INTRODUCTION

Geomorphology is the science of landscapes. It describes the landforms and attempts to explain their origin in terms of geology, climate and earth's surface processes.

Traditionally, the study was essentially concerned with interpretation of the origin and evolution of landforms in a qualitative way. The Davisian school of thought aimed at explaining landscapes in terms of the concept of cycle of erosion in relation to "Structure, Process and Stages" (Davis, 1904).[1]

In recent years, increasing attention has been paid to quantitative aspects. Morphometric techniques have been evolved for utilizing various cartographic information about the earth's surface configuration to arrive at numerical indices. Both quantitative and qualitative information provided in published topographical maps, aerial photographs and landsat imagery, or data directly collected by field investigation are utilised for this purpose. Thus geomorphology has

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[1]W.M. Davis, The Explanatory Description of Landforms, Vol. 3, Belgrade (1924), p.24.

become more rigorous.

"Geomorphology, which is concerned with landforms, materials and their related processes, is pertinent to all aspects of environmental management (Cooke and Doornkamp, 1974).[2] The scope of the subject as a science is, therefore, much wider than that of physiography which is mainly descriptive.

Earth's surface is covered with flora and fauna adapted to different climatic and terrain conditions. In addition to the physical factors, the biota imparts a specific character to the evolving landscapes. As a consequence of interaction of multiple variables, heterogeneity on micro level is an inescapable characteristic of any broad geomorphic region. But inspite of diversity, a thread of unity runs through the landscape of a specific region giving a characteristic regional signature.

STATEMENT OF THE PROBLEM

So far, no empirical study has been done in respect to the Geomorphology either for the State of Tripura or for any river basin or any part thereof. Even physiographic regional analysis of the North Eastern

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[2] R.U. Cooke and J.C. Doornkamp, Geomorphology in Environment Management, Oxford (1974), p.7.

Region of India has not been undertaken, while a number of studies on regional geomorphology of different parts of India have been done by geographers as well as geologists during the last few decades.

The State of Tripura has not yet been fully mapped by the Geological Survey of India. Geological mapping has been done by GSI only in some parts of the west Tripura District and Khowai Sub-division of North Tripura District. Landsat imageries are helping in better mapping of geological and neo-tectonic features of the State and its adjoining areas. Socio-economic and statistical bulletins, published by the State Government give very little physiographical and geomorphological information. Considerable time has been devoted in the collection and compilation of rainfall, humidity and temperature data for a period of 29 years (1950-1978).

At the initial stage of research work, the researcher had to visit Agartala, the Capital of the State for several times. Field investigation was tedius and difficult mainly due to poor communication system difficult terrain in the eastern part of Tripura, and hostile activities of the insurgents in the hilly terrain of the region. Due to paucity of sufficient published geological, geomorphological and meteorological data base, this research work is mainly based on field investigation, conducted by the author in different field seasons.

OBJECTIVES

In the present study an attempt has been made to investigate and interpret the geomorphic elements, processes, and forms and their spatial distribution. One of the objectives is to find out the main characteristics of the geomorphic elements and their resultant effect on the regional geomorphological processes which had operated in the past geological periods and continuing even today also. The State of Tripura forms a geomorphic region with alternate north-south trending hill ranges and river valleys. One can easily demarcate its boundary with deltaic Bangladesh.

In an agricultural state like Tripura for scientific developments of agriculture terrain evaluation assumes special significance. As such, evaluation of the impact of the geomorphic processes in shaping the different landforms both in space and time, and interpretation of their characteristic manifestations form the core of this research. An attempt has been made in the same direction, from both academic and applied points of view.

The main objectives of the study are categorically stated below:

(i) The basic objective is to investigate, examine and interpret geomorphic characteristics of the State of Tripura in relation to lithology and structural characteristics of rocks and the geomorphic processes working in the region in shaping and developing the different landforms.

(ii) To investigate the evolution of drainage systems, patterns and their characteristic features.

(iii) To investigate, describe and interpret the erosional activity, mainly under the impact of weathering processes and fluvial action of streams and rivers.

(iv) To examine the nature of differences both in structure, processes and stages in the western and in the eastern part of the Bara Mura Hill range.

(v) To examine the nature of slopes, slope elements, slope profiles and evolution of slopes in relation to rock structure, geomorphic elements and processes.

(vi) To identify the erosion surfaces with the help of morphometric tools and techniques.

(vii) To regionalise the study area in respect of both physiographic and geomorphic facies as noticed in various parts of the State.

JUSTIFICATION

The State of Tripura within its small geo-political territory represents varied topography, lithology, lineaments and neo-tectonics, complex geological formations with numerous geomorphic elements which provide ample scope for intensive study, investigation and analysis in terms of fluvial geomorphic processes and their resultant impact in shaping the landform developments.

Tripura is one of the remote States of the North Eastern Region of India, where no systematic geomorphological study has so far been undertaken.

Some of the geographers have termed the State as a part of Surma Valley, where as the Gumti river basin is in no way a part of the Surma valley. The west flowing Gumti with its own distinct characteristics constitute a separate basin, which is directly connected to the Meghna river and occupies about one-fourth area of Tripura.

Applied geomorphology mainly deals with the problems of practical planning for the optimum utilization of the land and water resources of a region. The State of Tripura which has complex geomorphic features, the utility of the subject is immense, specially in the field of perspective agro-economic planning. The application and utility of detailed geomorphological maps are often required. The geomorphological maps may be used as base maps for preparation and compilation of other maps, to have information about landforms suitable or unsuitable for the purpose aimed at. Specially for the purpose of land use planning, plantation, forest development, transportation, settlement to check soil erosion, construction of roads selection of dam sites, various projects for agro-economic and socio-economic developments, such geomorphological studies become more essential.

Thus, there is a need to investigate, study and analyse the geomorphic elements, specially the processes which are actively operating in the region. Morphometric analysis is essentially needed to reveal the geomorphic elements and the processes involved in the evolution of different components of the landscapes of the region as a whole.

This research is an attempt to consider the fluvial system and its components in such a way that the inherent instability of the system can be comprehended, and suitable data provided to the geologists, geomorphologists, stratigraphers, sedimentologists, landmanagers, conservationists and civil engineers. Thus, the study is important not only from the point of view of academic

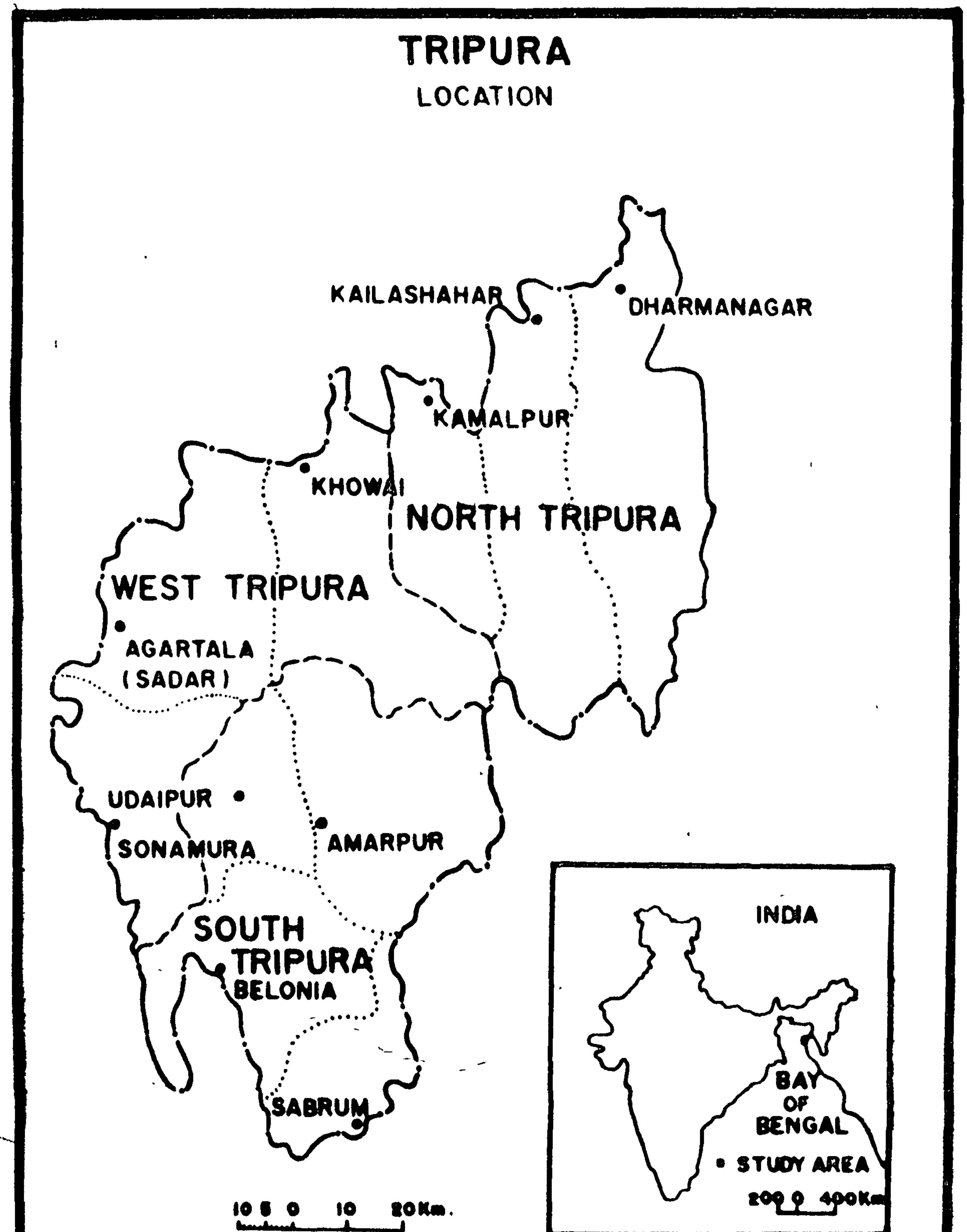
TRIPURA
LOCATION
KAILASHAHAR
DHARMANAGAR
KAMALPUR
KHOWAI
NORTH TRIPURA
WEST TRIPURA
AGARTALA
(SADAR)
UDAIPUR
SONAMURA
AMARPUR
SOUTH
TRIPURA
BELONIA
SABRUM
10 5 0 10 20Km.
INDIA
BAY
OF
BENGAL
STUDY AREA

FIG. 1

interest, but it has also practical utility.

STUDY AREA

Tripura is one of the States of the North Eastern Region of India. Geographically, this State is located in the South-Western part of aforesaid region and is surrounded by Bangladesh in the north, south and west, in the East by Cachar District of Assam and Aizawl district of Mizoram. This study area is located in between $20^{o}56'$ - $24^{o}32'$ N latitudes and $91^{o}09'$ - $92^{o}20'$ E longitudes. It occupies a geographical territory of about 10,477 sq. Kms., with maximum extent of about 183.5 Km. in East-West and about 112.7 Km. in the North-South direction. The State supports a total population of 20,47,351.[3] It is very near to the Bay of Bengal and is under the direct impact of monsoon. Tropic of Cancer passes through the southern part of the State.

Administratively, there are 3 Districts and 10 Sub-divisions as indicated in the location map. Administrative boundaries of the districts and even that of most of the Sub-divisions are delimited by the geomorphic features viz: (i) hill ranges (Muras), (ii) hills (Tillas),

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[3]Provisional Census Report of 1981, Series (21), Tripura, p.25.

(iii) rivers (Nadis or Gang) and (iv) streams (charras).

SOURCES AND DATA BASE

The materials necessary for the study as far as possible have been collected from the publications of memoirs, records and reports of Geological Survey of India; National Atlas Organisation, National Remote Sensing Agency, topographic sheets as available on various scales published by the Survey of India, Land Sat imageries, latest publications of geomorphological literature, Journals, meteorological data as published by the Meteorology Department.

Geomorphological data have been collected through extensive field studies in various parts of the study region. Recent studies and reports of the Directorate of Quaternery Geology and Geomorphology, Geological Survey of India, Shillong have yielded useful data. Many parts of the eastern Tripura have not been mapped by the Geological Survey of India. Some shallow ridges are located in the northern and southern parts, outside the study region for which data base could not be extended fully. Adjoining regions have been studied only by the landsat imageries. Meteorological data as available from the observatories located mostly in the sub-divisional headquarters are not giving the actual rainfall that is taking place in the hilly region. Some of the observatories are installed after 1960, as such data for a very long period is not available.

Instrumental observations viz. theodolite traverse were made in some parts of dissected hills of west Tripura to prepare the slope profiles, to see the nature of slopes. Pictorial views are given at the end of some of the chapters as a supplementary evidence. Maps, figures, graphs and photographs given in the thesis attempts to give a clear picture of the natural configuration of the region, illustrating different aspects of geomorphic elements and giving birds-eye-view of the study area. All the maps and figures have been prepared by the author. To illustrate exact landform types, numerous field photographs have been given.

METHODOLOGY

Geomorphic research methodology depends mainly on the location of the study area, its litho-stratigraphic formations and the processes involved in shaping the landforms. The State of Tripura is located in the humid tropical climatic zone with heavy rainfall under the impact of South-west Monsoon. Physically and chemically weathered materials are being transported from the hills and uplands to the lower reaches of the river valleys, under the action of streams and rivers. The nature of landform developments could be mostly readily and directly observed when the process is very intense viz. mass-wasting, landslides, a dust storm and hail storm or a flash flood due to cloud burst etc.

The State of Tripura is located near the Bay of Bengal, and experiences tropical humid climatic conditions. Its young topographic features are being actively shaped by fluvial processes. Available morphometric techniques, methods and tools have been utilised to analyse the linear, areal, quantitative and qualitative aspects of the subject.

If we know or establish the process which had formed the soil and litho-stratigraphic units, we can also more readily appreciate the nature of the surface features associated with them. During rainy season, debris insitu and weathered materials are being transported to the lowlying alluvial plains surrounding the hill ranges. For clear understanding of the major changes of landforms and processes involved in such changes, the knowledge of minor landform facies and nature of their changes is a must to have an integrated picture.

Geomorphometric methods, tools and techniques of the late 19th century have become the basis of the present day approach with some modifications. Though both exogenic or endogenic forces were responsible for the initial development of Tripura and its adjoining region, yet later modifications were done by the exogenic forces. Changes of land forms are taking place under the fluvial processes which forms the main part of this study.

Generally relevant methods, principles, formulae and general aspects of the chapter concerned are given at the beginning of all the chapters. Chapter on quantitative analysis of 12 small selected basins forms the basis for derivation of some of the conclusions, out of the established correlation of the morphometric variables. While last chapter gives the conclusions and statements of the subject as a whole.

As climate changes, so do the fluvial processes by which material is relocated. Thus, division, subdivision and grouping of the land surface is quite different from the classification of surface features which is precisely concerned with their spatial associations. For the purpose of spatial analysis of important geomorphic elements, features, processes and for proper regionalisation, landsat imageries have been consulted.

Figures and tables are given chapterwise; maps, graphs, profiles and statistical tables constitute the main part of the chapter along with relevant descriptive and analytical literature. Again each chapter has been sub-divided into several parts according to the contents of the chapter concerned.

PLAN OF WORK

In the introductory chapter, general aspects statement of the problem, objectives, justification of research, study area and its location, data base and its sources, methodology and plan of work have been focussed.

In the second chapter, an attempt has been made to discuss the geology. In fact geology plays an important role in shaping the geomorphic features of Tripura. It is also attempted to investigate why within a small region geological formations are different

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at various areas, specially the geological contrast between west Tripura and east Tripura is explored to explain the variations in geomorphological expressions.

In the third chapter, the development of landscapes under the impact of internal and external processes is highlighted. The present day topography is the outcome of interaction of tectonic and fluvial processes. The nature of important geomorphic features of the State viz. river valleys, streams, flats, slopes, remnant hills and hill ranges is examined in detail. The distribution pattern of these elements is analysed and explained. For better understanding of the fluvial geomorphic processes, the following aspects have been considered :

(i) a study of watershed zones;

(ii) an assessment of climatic factors;

(iii) an examination of the geomorphic elements;

(iv) an assessment of the nature of fluvial erosion, and

(v) a study of the denudation history and evolutionary course of drainage development etc.

In the fourth chapter quantitative analysis of 12 small selected basins have been presented to reveal both linear and areal aspects, particularly of the basins and generally of the region as a whole. The method of R.E. Horton (1945)[4] as modified by A.N. Strahler (1952)[5] has been applied for quantitative analysis of drainage network.

Numbering, ordering, measurement of stream lengths are done for computation of the sinuosity indices of all the selected basins. Stream frequency, drainage density and average slope have been worked out for mapping etc. In this chapter it is also attempted to correlate twenty two morphometric variables with the help of computer (Spectrum/7), to analyse, their qualitative inter-relationships.

In the fifth chapter, the slope form, nature of profiles, linearity and areal extent of slopes and their characteristic properties have been documented and analysed. In Tripura due to varied topography, lithology and structures, the landforms have very rare similar slopes; as a matter of fact, no particular law can be applied with certainity.

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[4]R.E. Horton, Erosional Development of Streams and their Drainage Basins : Hydrological Approach to Quantitative Morphology, Bull. Geol. Soc. Amer; Vol. 56 (1945), pp.275-370.

[5]A.N. Strahler, Dynamic Basins of Geomorphology, Bull., Geol. Soc. Amer, Vol. 63 (1952), pp.923-938.

The concept of horizonation is central to all field studies of the physical sciences and landforms may be categorised by the degree of development of its vertical cross-section. In this chapter it has also been tried to study and interpret the imprints that had been left by the tectonic and fluvial processes, both on the development of slopes. An attempt has also been made to analyse the scientific and mathematical data to explain the origin and evolution of slopes.

Chapter six deals with morphometric analysis of landforms with the aid of various morphometric tools and techniques to have a clear documentation of the geomorphic characteristics of the region.

In the seventh chapter, an attempt has been made to delimit the study area into micro geomorphic regions, to get the spatial distribution pattern of both physical and morphological units. Linear and areal extent of slopes, stream frequency, drainage pattern, relief, altitude and climatic aspects have been considered in combination with geology, rock structure, lineaments and tectonics for the purpose of regionalisation. To characterise the different morphological units, qualitative and quantitative analysis have been done in combination with the geological literature and the conclusions have been verified in the field.

In the last chapter, Summary and Conclusions of the study have been presented, vis-a-vis the objectives.

CHAPTER - II

GEOLOGY

Geologically, Tripura is a part of the Assam-Burma geological province. The Tertiary deposits reach a great thickness, here probably thicker than that of any other part of India. In the Tertiary succession, there are several gaps, of which the most important one is the absence of the record of upper part of the Oligocene. P. Evan's (1932)[1] Survey of Assam, laid the foundation of stratigraphic classification of the Tertiaries. He classified the tertiary succession in various series from recent to Eocene as follows :

(i) Alluvium
(ii) Dihing Series
(iii) Dupi Tila series
(iv) Tipam series
(v) Surma series
(vi) Barail series, and
(vii) Disang series.

The coal-measures of the region belonging to the Barail Series, are unconformably overlain by the Surma Series. The Barails and the Disangs are not exposed in Tripura. The Surma Series has a wide extent in the State of Tripura and its adjoining regions.

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[1] P. Evans, Explanatory Notes to Accompany a Table showing the Tertiary Succession in Assam, (1932), p.169.

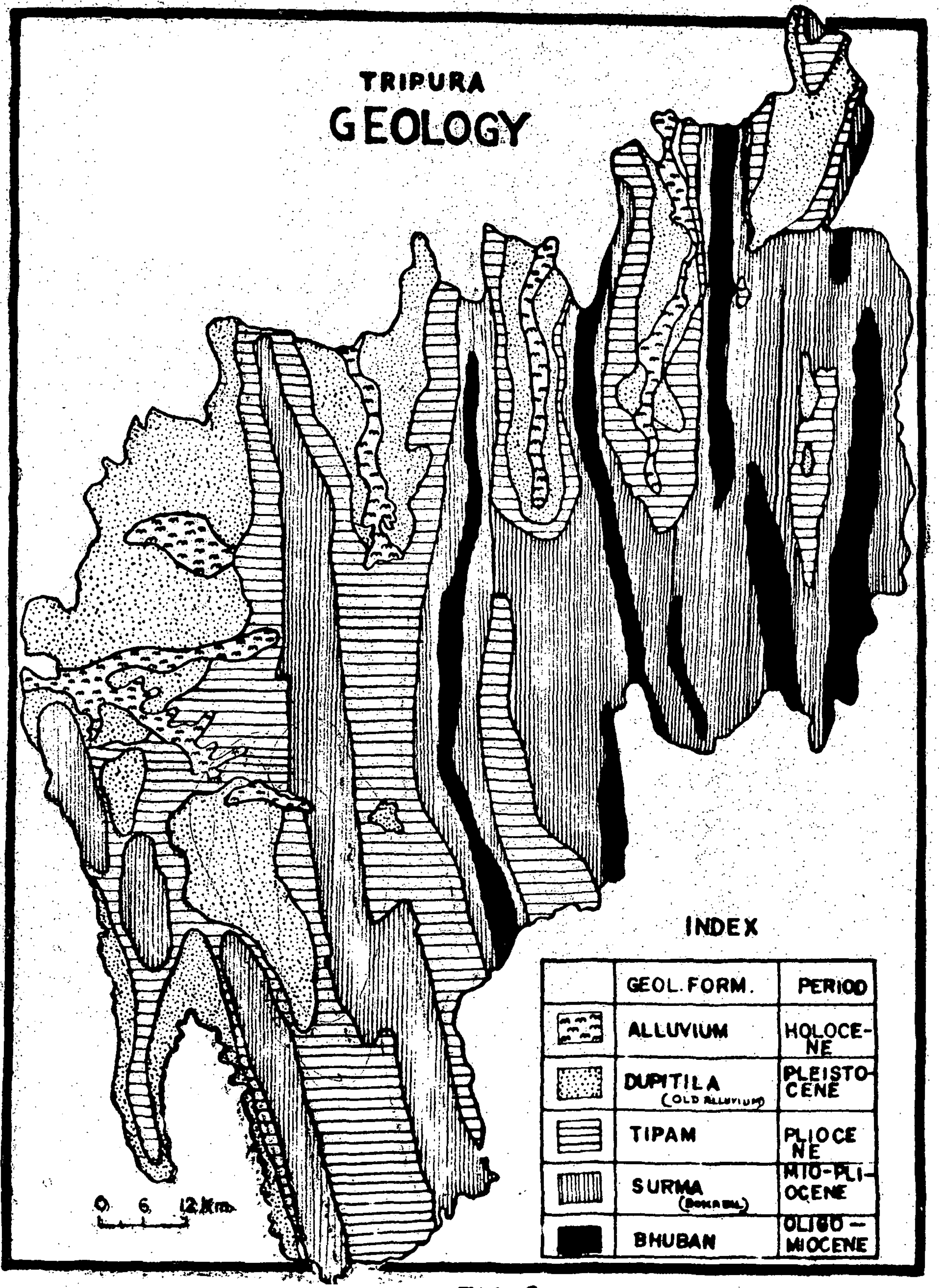
TRIPURA
GEOLOGY
INDEX
GEOL. FORM.
PERIOD
ALLUVIUM
HOLOCENE
DUPITILA (OLD ALLUVIUM)
PLEISTOCENE
TIPAM
PLIOCENE
SURMA
MIO-PLIOCENE
BHUBAN
OLIGO-MIOCENE
0 6 12 Km.

FIG. 2

It is composed of sandstones, sandy shales, mudstones and thin conglomerates, generally free from carbonaceous content. Indications of petroleum deposits are found in the Surma Series in several places. The Surma Series is marine but remarkably unfossiliferous.

The Tertiary beds are folded into sharp anticlines and narrow synclines. Both anticlines and synclines of the State are narrower in comparison to the Surma valley. In the north-east Tripura and its adjoining areas like north Cachar hills the anticlines open out against a belt of thrust-fault which could be followed to an extent of about 500 kilometer upto the north-east of Assam.

The delineation of the following geological and geomorphic features have been done on the basis of photo-interpretation. (Fig. II):

(i) Lineaments
(ii) Trend lines
(iii) Regional Structures, and
(iv) Broad lithological units.

Interpretation of geological features has been done on the basis of the study of tone, texture, drainage, landforms, erosion pattern and landuse in conjunction with field checks. It has been observed that in the western part of Tripura some north-south trending subdued hill ranges exist viz. (i) Sona Mura, (ii) Chikania and (iii) Gojalia etc. Anticlinal axes of all these hills trend North-west - South-East direction.

A transverse regional cross-fold trending ENE - WSW acts as the watershed in between north and south flowing rivers. The common features of all the longitudinal hills and hill-ranges are that their trend lines vary from NNW to NNE with mean around North-South forming an arcuate range with convexity towards west. Alluvium formations along Haora, Manu, Buri Gang, Khowai and Dholai rivers are circumscribed by either Dupi Tila or Tipam formation. Whereas, in case of Deo river in between Sakhan and Jampui hill ranges Alluvium formation is being circumscribed by Boka Bill Formation of Surma Group and Tipam formation. Rock sequence is reepresented entirely by sedimentary rocks viz. sandstone, shale, clay and range in age generally from Miocene to Recent.

GEOLOGICAL SUCCESSION

Generalised geological succession in Tripura is represented in tabular form which also gives the geological age of the respective formations (Table-1). The hard sedimentary rocks of lower Bhuban formation are exposed in the higher ridges of the easternmost part. The recent geological formations are the outcome of fluvial sedimentation. The successive formations had been deposited in various periods. Deposition was discontinuous. There are unconformities and gradational to transitional contacts in between the formations.

TABLE - 1

Generalised Geological Succession in Tripura

Period	Group	Formation	Lithology
1	2	3	4
Recent	Recent	Alluvium	Alluvium represented by unconsolidated pale to dirty grey silt, sand, clay, silty clay,,sandy clay etc. Sometimes with decomposed vegetable matters and yellowish brown coarse river Sand, gravels and concretions i.e. Alluvium Valley fill.

Contd.....

Source: Geological Survey of India, Miscellaneous publication No.30, Geology and Mineral Resources of North-Eastern States of India, Part-IV (Tripura) (1974) National Remote and Sensing Agency's Report on Tripura, Vol. I, Generalised Geological Successions, G.1 (1979), Photo interpretation and field observations.

1	2	3	4
Pleisto-cene	Dupi Tila	Plesto-cene(Old Alluvium)	Earthy brown to buff sandy clays with grayish brown to reddish brown sand loam, mottled sandy clays, clayey sand-stone, coarse to gritty ferruginous sandstone including lenticular bands, and pockets of bluish to gray pla-stic clays, silicasand and laterites.
Unconformity			
Plio-cene	Tipam Sand stone	Champa-nagar	Massive medium to coarse, fria-ble, sub-arkosic sandstone, with occasional laminae of sandy-shale and abundant lumps of sillicified fossilwood.
			Contact gradational
		Manu-bazar	Fairly bedded, fine to medium subarkosic sandstone, including laminated layers and thick lenti-cular bands of sandy-shale, silt stone and sandy mudstone.
Contact transitional			
Mio-plio-cene	Surma	Boka Bil	Thinly laminated and thinly bed-ded repetition of sandstone, siltstone, shale alterations, shales mudstones and ferrugi-nous sandstone with irregular partings of fine to coarse sand and inter-stratified thick occa-sionally lenticular horizon of medium to coarse micaceous sandstone with mudstone.
			Contact Gradational to transitional
Oligo-Mio-cene	Surma	Upper Bhuban	Grey silt stone and soft sand-stone often micaceous
			Contact transitional
		Lower Bhuban	Indurated, hard, compact, both massive and well-bedded sand-stone, dark to olive shale, sandy shale and siltstone repe-atedly occurring in space
Oligo-			Disangs and Barails are not

ROCK FORMATIONS

Surma Group

Surma group consists of two main sub-groups of rocks which are (a) Bhuban and (b) Boka Bil. Bhuban Sub-group is sub-divided into three formations which are as follows:

(i) Upper Bhuban Formation,
(ii) Middle Bhuban Formation, and
(iii) Lower Bhuban Formation.

Bhuban Sub-group consists of indurated sandstone and shales. The variations in colour range at some places from yellow to cream. These rocks are less feldspathic and finer grained in comparison to the Tipams. In the State of Tripura, the part of the Middle Bhuban sandy shales and sandstones and the Upper Bhuban fine grained, compact, well-bedded sandstone are exposed only in the eastern and central part. In this sequence these are current bedded sand lenses, indicating turbulence in current during sedimentation. Apart from that ripple-drift-cross laminations, load casts and other turbidite structures are prevalent.

Though some of the geological literature reflects three types of Bhuban Formations as mentioned above, it is difficult to differentiate between the Lower and Middle Bhuban Formations.

Lower Bhuban Formation and
Middle Bhuban Formation

Lower Bhuban Formation is mainly a well bedded, grey sand stone unit alternating at places with fine silt-stone and is found in the easternmost part of Tripura bordering Mizoram. This rock type is exposed in the anticlinal core of the Jampui and Sakhan hill ranges e.g. Phuldengee is the highest point (939 m.) on the Jampui hill where rock exposure is clearly visible. The sandstone is medium to fine grained, sometimes micaceous and at places calcareous with association of bands of limestones. Limestone is exposed on the western face of the Jampui anticline on Kanchanpur-Manpui road. Strike of this unit varies between North-South and NNW-SSW with a set of prominent lineaments trending NE-SW.

On landsat imagery Lower Bhuban sandstone shows light to medium grey tone, resistant strike ridges, broad dissection, joint controlled short parallel drainage and few trend lines.

Upper Bhuban Formation

This rock formation is mainly exposed in the anticlinal core of Athara Mura and Longtarai hill ranges.

It is thinly bedded, grey siltstone, often associated with soft sandstone and some shale bands; at place, it is micaceous and contains glauconite. Strike of the unit changes between NNW-SSE, N-S and NNE-SSW with moderate dip. Out of three sets of lineaments i.e. NE-SW, ENE-WSE and NW-SE, NE-SW lineament is very conspicuous. In most of the cases, lineaments traverse from one formation to another. This formation is present in the Sakhan and Jampui anticlines in association with lower Bhuban sandstone. It shows medium grey tone, less resistant strike ridges, moderately well dissect, less joints and many trend lines with medium drainage density.

BOKA BIL FORMATION

This formation is conformable with and gradational to both underlying Bhubans and the overlying Tipams. In Tripura, it is exclusively argillaceous in character and is represented mostly a thick piles of shale, clay-stone and mudstone beds. Boka Bil shales is occasionally inter-bedded with sandstone bands. At places, it comprises thinly laminated siltstone and shale alternations. The shale is generally dark grey and thinly laminated. This type of rock is widely exposed in the whole Tripura State and has maximum areal extent. In Sona Mura, Chikania, Gojalia and Bara Mura anticlines - these are exposed in the core. Sometimes the shale is calcareous. The beds are generally low to moderate dipping but adjacent to the faults. These become very steep even near vertical. Strike varies between N-S, NNW-SSE and NNE-SSW. Beds are sub-horizontal along the crest of folds. They are deeply dissected. These also form low lying dissected strike parallel ridges. There are NE-SW, NW-SE and ENE-WSW sets of lineaments. Faults are mostly in N-S direction.

On satellite imagery, the Boka Bil shale formation shows dark grey tone, fine to medium texture, high dissection, dendritic drainage with high density and many parallel trend lines often taking a curve.

TIPAM GROUP

Tipam group rests conformably on the Surma group and is unconformably overlain by the Dupi Tila group. This is mainly a sandstone formation with minor shale and siltstone interlayers. At many places, Tipam sands are oxidised and become light brick colour. Strike of formation is mostly N-S with low dip (10^o-20^o) dip becomes steeper near faults. It is traversed mostly by N-S faults and is exposed at the foot hills and in the synclinal valley areas and is not traversed by many lineaments. Few of the lineaments traversing Bhuban and Boka Bil Formation are continuous in this Unit.

From the satellite imagery it is difficult to differentatiate upper and Lower Tipam Formations. On imagery Tipam Formation shows mottled tone, medium to coarse texture, dendtiric drainage with moderate density, moderate dissection with few zones of gully erosion.

Tipam comprises medium yellow to light buff and brownish yellow sand rock with rate laminations of biotite and altered grains of limonite or hematite. Except for the ferruginous bands and scarce greyshale silt laminations, the rocks of this formations are massive, cross-bedded and contain about twenty five per cent decomposed feldspar fragments and about five per cent mica.

In Tripura, the Tipam Sandstone sub-group of Tipam group is again sub-divided lithologically into two distinct formations viz. (1) the Lower Tipam (Manu bazar) Formation and (ii) the Upper Tipam

(Champa Nagar) formation.

Lower Tipam Formation

In the lower part of this formation shale bands are mostly seen in contact with the Boka Bil shale. It consists of bedded, fine to medium grained, sub-arkosic sand stone including thinly laminated layers, and thick lenticular bands of sandy shale, siltstone and sandy mudstone of blackish to fresh water shallow marine facies.

Upper Tipam Formation

This formation consists of medium to coarse, massive, friable, sub-arkosic sandstone with minor sandy shale, and abundant lumps of silicified wood. The primary sedimentary structures like trough cross-bedding indicates a continental to deltaic environment of deposition. In the upper horizon fossil woods and current beddings are highly concentrated and in the lower horizon it is well bedded sandstone.

DUPITILA FORMATION

It is primarily a formation topped by sandy mottled clay at the upper horizon and is exposed in the synclinal valley area. This formation is mostly bordered by Tipam Formation. Sediments vary from earthy brown to buff sandy clay with greyish brown and reddish sandy loam followed down by mottled sandy clay, clayey sandstone and coarse to ferruginous sandstone including lenticular bands. There are pockets of greyish to bluish plastic clays. The main areas are :

(i) Northern part of Dharmanagar,
(ii) Northern side of Bisramaganj,
(iii) Eastern side of Agartala

Glass sand is seen at places on the eastern side of Agartala. This formation is mostly unconsolidated to semi-consolidated. The upper part is loamy and clayey due to pedogenesis. At many places, the upper part is lateritised mottled clay with ferruginous modules. It is mostly horizontally bedded locally with vary low dip. Low lying rounded flat topped mounds (Tillas) are formed by the Dupi Tilla Formation and the Tipam Formation.

Lenticular conglomerate with pebbles of claystone and siltstone is embedded in a matrix of sand and clay towards the basal parts. The maximum thickness of these deposits to the north of Agartala is about 15 m. In the landsat imagery, this formation shows medium to darker grey tone, medium texture, many small valley fills, and zones of gully erosion. The drainage system developed in this formation is predominantly dendritic.

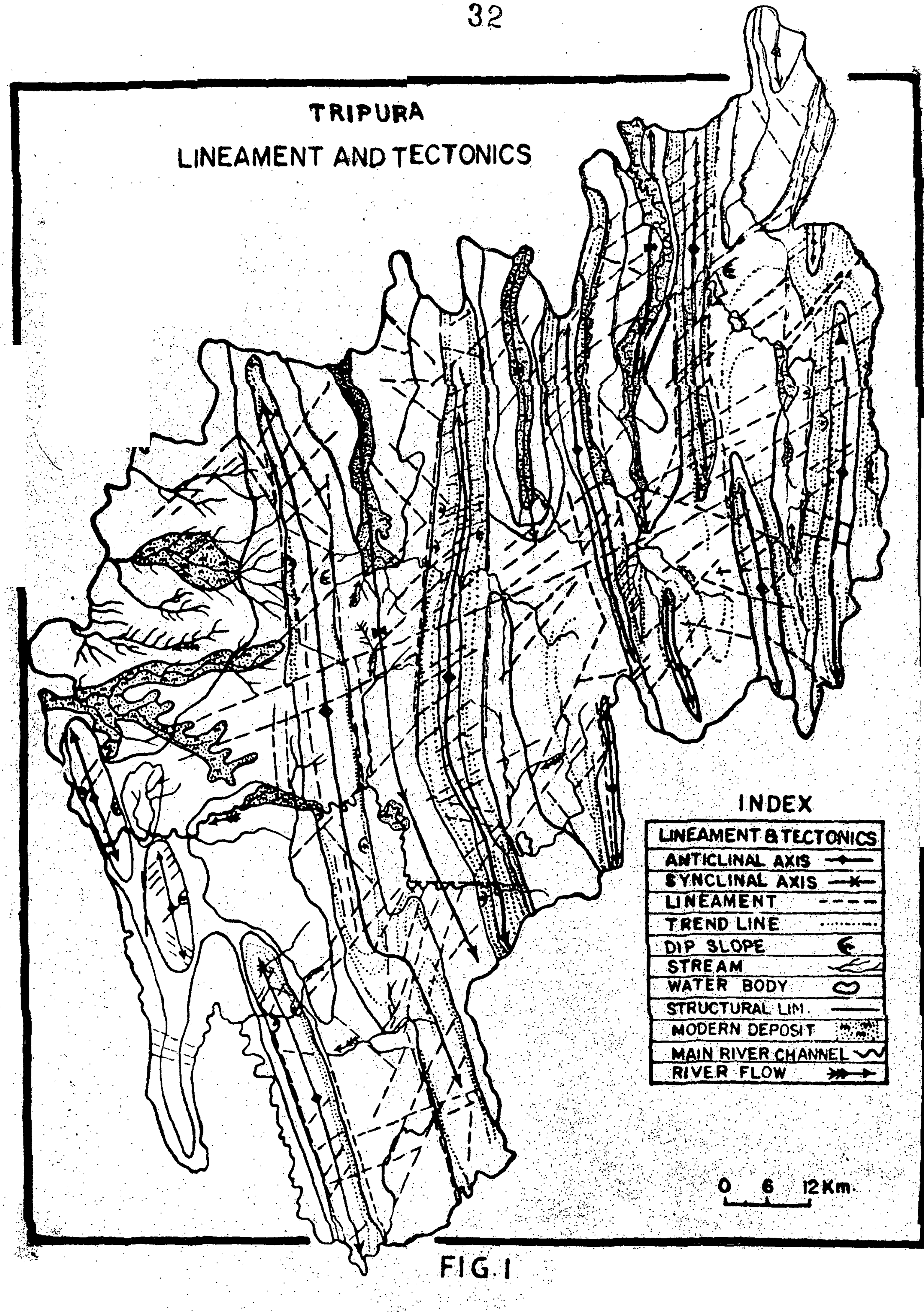
TRIPURA
LINEAMENT AND TECTONICS
INDEX
LINEAMENT & TECTONICS
ANTICLINAL AXIS
SYNCLINAL AXIS
LINEAMENT
TREND LINE
DIP SLOPE
STREAM
WATER BODY
STRUCTURAL LIM.
MODERN DEPOSIT
MAIN RIVER CHANNEL
RIVER FLOW
0 6 12 Km.

FIG. I

RECENT ALLUVIUM FORMATION

This constitutes the youngest formation in the State, formed during the Holocene period. This formation differs conspicuously from the Dupi Tilla. It comprises unoxidised alluvium deposited in flood plains of rivers. The Dupi Tillas include highly oxidised fluviatile deposits of pleistocene period. This formation occurs along the important rivers of the State viz. Gumti, Khowai, Manu, Deo and Haora etc. This includes alluvial plains of the different rivers and valley fill deposits. Sediment deposition is taking place along all the rivers, mainly during the flood seasons, at various rates, depending on the nature of lithology of catchment area and the volume of water it discharges and the river energy. These sediments are mostly unconsolidated sands, silts and clays. The alluvial plains show typical landforms like natural levee, point bar, channel bar, abandoned channel, back swamp etc. Nature of sediments vary with the type of landform elements. In landsat imagery, these are of light grey to mottled tone and of fine to medium texture. Fluvial landforms are well reflected in the imagery.

LINEAMENTS AND TECTONICS

Structural geology is the principal determinant of the first order landform of Tripura. The anticlines form the hills and the synclines form the valleys attesting to youthful topography. The details of the scenario are the result of deep sculpturing by rivers and gullies in a sub-tropical environment of high rain fall. Geomorphic activity of rivers is conspicuous both in its destructive and constructive form. The entire study region is of irregular shape and can suitably be called undulating land locked strip of land surrounded by alluviul plains of Bangladesh to the north west and south.

Geologically, the State seems to have risen from the sea bed to its present altitude during the late Cainozoic period. The western part is very closely connected with the plains of Bangladesh, whereas, the eastern part has intimate relationship with the Mizo hills and Chittagong hill tracts. Thus, the land surface in the eastern Tripura is mountainous and rugged terrain in contrast to the Alluvium plains of the Western part. The whole terrain abounds in rivers and streams, hill ranges, small hills, low lands, flood plains. The control of tectonic elements on development of rugged topography is very clear.

The north-south trending hill ranges are higher in the central parts and gradually merges with the plains of Bangladesh to the north and south. The general elevation of each successive hill range and base of the intervening synclinal river basins increases systematically from the west to east.

An ENE-WSW trending subdued cross fold forms the major watershed between the north and south flowing rivers. This transverse hill range descend in elevation towards the west and ultimately merge with the high altitudinal parts of Bara Mura and Athara Mura ridges. The prominent structural features are shown in the lineament and tectonic map (Fig. II). Tectonically, the whole State of Tripura is characterised by a series of continuous to discontinuous north-south trending anticlines and synclines developed on Neogene sedimentary strata.

The anticlines are traversed by long N-S trending regional sub-vertical faults, adjacent to the crestal zone of the anticlines. These faults are indicated by the presence of parallel to sub-parallel lineaments and trend lines. The important features recognised from landsat imagery analysis are:

(i) Lineaments,
(ii) Trend lines,
(iii) Regional structures, and
(iv) Broad litho-stratigraphic units.

Southern part of Sakhan and Jampui hill ranges are of lower Bhuban Formation. The strike of these parts varies between N-S and NNW-SSW with very steep slope. A very prominant set of NE-SW trending lineament is present in this part. In the west of this part along Athara Mura and Longtarai hill ranges, three important sets of lineaments are present viz. NE-SW, ENE-WSW and NW-SE of which NE-SW is prominent. These lineaments are accompanied by many trend lines which traverse from one formation to another. In the southern parts of Bara Mura range there are NE-SW, NW-SE, ENE-WSW lineaments. These lineaments are indicators of very prominent dissection, responsible for the development of badland topography. In most of the cases faults are in the N-S direction.

The intensity of the fold movement is higher in the eastern part, the amplitude of these folds increase towards the east where these are characterised by compressed anticlines. Parallelism of the regional strike of the beds, axial planes of the folds and faults are very much distinct. Few shallow, flat, elongated dome shaped folds exist in the western part. Later generation of folding movement might have taken place, as is indicated by the splits and curves of many fold. Later fold system might have developed due to adjustment in the basement blocks on which Tertiary deposits rest.

Anticlinal hill ranges rest dominant control on the direction of flowage of almost all the rivers of the State. The State's major structural trend is almost in the N-S direction. The plunge of the fold is shallow and the axial plane is curvilinear. Most of the anticlinal ridge-crest flanks are traversed by sub-vertical faults, parallel to the axial planes. The intensity of fold movement is higher in the eastern part of the State. There are few disconnected open and shallow anticlinal ridges in the south-western part viz. Gozalia Mamun Bhagna and Sona Murá etc. Some other disconnected shallow hill ranges are also observed in the aerial photographs, aligned in the north or south of the main hill ranges, which are mostly outside the study area.

The river valleys of variable width are aligned along the synclines. Bhuban Formation form the core of the ridges, which is surrounded by Boka Bil, Tipam, Dupi Tila and Alluvium formations respectively. The exposed geological formations vary in age from Miocene to Holocene period. The Barails of oligocene age which presumably form the basement are not exposed in Tripura. The tectonic history of the area is lucidly recorded in the system of folds, faults and fractures.

CHAPTER-III

THE FLUVIAL GEOMORPHIC PROCESSES

> "We may consider the level of the sea to be a grand base level, below which dry lands can not be eroded, but we may also have, for local and temporary purposes, other base levels of erosion, which are the levels of the beds of the Principal Streams which carry away the products of erosion."
>
> – J. W. POWELL (1875)

The genesis of landform is very complex and is the resultant product of many factors viz. rock structure, lithology, slope, drainage system, altitude, vegetation, climatic factors and spatial arrangement of some of the physiographic and geomorphic elements. There are certain natural laws which govern the geomorphic processes along with the human activities in certain cultural land scapes.

Topographic features, structures and texture indicate that the state had experienced a severe diastrophic disturbances in its short geological history. In fact the state could not escape the impact of the Orogenic forces which affected the adjoining areas. The State's major structural trend mainly to its northern parts is almost north-south, parallel to the regional tectonic lineaments. The plunge of the fold is mostly rolling and curvilinear. The geological and geomorphological set-up reveal that ridges are anticlinal and the valleys are synclinal which are again parallel to the regional strike and axial planes of the folds. The structural hill ranges are forming the most important barriers to the erosional processes.

> "In 1846 the prominent English Geologist Ransey, studying the uplands of south-wales, noted that all the ridges and peaks have approximately the same altitude, and look as if they have been cut out of a more or less level plane, which Ramsey considered once formed the uplands surface. It truncates the steeply-dipping and folded strata and thus has nothing to do with old foldings and dislocations, or indeed with internal build at all. On the contrary, it is a varience with internal build and must be due to a degradational process."[1]

Davisian theory goes beyond Powell and Dutton in as much as it is also applicable to folded areas and asserts that whole land undergoes planation. Rivers incise gradually to reach the profile of equilibrium, and at the same time valley sides are increasingly levelled and

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[1]A. Hettner, The Surface Features of the Land, Mac-Millan London, (1972), pp.70-71.

flattened unit they scarcely rise above the horizontal surface.

In this tropical humid region where both physical and chemical weathering are dominant processes of landscape sculpturing, drainage system plays the most vital part for both transportation and deposition of the weathered materials. In this monsoon dominanted region with high rainfall, running water is the main agency in shaping the relief and landforms, which is also partly responsible for the progressive dissection and degradation of the higher lands. Important Geomorphic processes operating in the region under study are weathering, fluvial erosion, mass wasting and human interference. In this chapter it is an attempt to study, investigate and reveal these natural geomorphic laws under the impact of tropical vegetation and climate. An attempt is also made to review the occurence and distribution of remnant surfaces of the region. Climatic geomorphology encompass this notion of time and not only deals with both temporal relationship of landforms, but also with time spans for which particular processes have persisted in particular places.

CLIMATE AND THE RELATIONSHIP
OF RAINFALL TO CONFIGURATION

"The monsoon is a flow pattern of the general atmospheric circulation over a

> wide geographical area, in which there is a clearly dominant wind in one direction in every part of the region concerned, but in which the prevailing direction of wind is reversed (or almost reversed) from winter to Summer and Summer to Winter."

- CHANG CHIA-CH'ENG(1959)

Climate (Monsoon)

According to the W. Kppen's world-wide classification system (1923, 31)[2] the State of Tripura and its adjoining vast areas come under 'A_f' category,

Where A means tropical rain Climates,

F means, driest month has an average

$\geq$ 60 mm. rain.

In fact climate of the region may be symbolised as 'A_f'$_{sw-m}$

where Sw-m means south-west monsoon.

The south-west monsoon is best known because rainy season is associated with it. The Himalayas and other mountain ranges modify the monsoon. During third week i.e. late May and early June the monsoon arrives to the region with heavy rain and hail storms. According to John G. Lockwood there are 6 average number of tropical storms in every

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[2]H.H. Lamb, Present, Past and Future, "Fundamentals and climate now" (1972), Vol. I, pp.509-515.

monsoon period in the Bay of Bengal region.

Tropical storms and Cyclones

It vary from slowly circulating masses air with scattered cumulonimbus clouds to violent and severe storms. World meteorological organization has classified low pressure system as follows :-

i) A tropical depression,

ii) A tropical storm, and

iii) A tropical cyclone.

A tropical cyclone is a storm of tropical origin with a small diameter (some hundred km) minimum surface pressure (less than 900 mb), very violent wind, and torrential rain sometimes accompanied by thunder storms.

Seasonal changes of monsoon is given in the Table-3.1 to indicate the nature of rainfall throughout the year.

TABLE - 3.1

NATURE OF MONTHLY RAINFALL UNDER THE IMPACT OF S-W MONSOON(1978)

Monsoon Period	Actual Rain fall in cm.	Deviation from normal rainfall in p.c.
1	2	3
(A) Winter Monsoon Period 1.1.78 to 28.2.78		
January	Nil	-100
February	0.2	- 93.0

1	2	3
(B) Pre-Monsoon Period 1.3.78 to 31.5.78	95.4 cm	
March	4.0	-25.9
April	20.9	+19.4
May	70.5	+118.9
(C) South-West Monsoon Period 1.6.78 to 30.9.78	144.6 cm	
June	64.8	+50.0
July	35.9	+ 7.1
August	19.1	-40.1
September	24.8	+ 3.3
(D) Post Monsoon Period 1.10.78 to 31.12.78	10.4 cm	
October	10.1	-28.4
November	0.3	-93.0
December	- Nil -	-100.0

Source: Directorate of Agriculture, Govt. of Tripura, Agartala, 1978 Volume, pp.21-38.

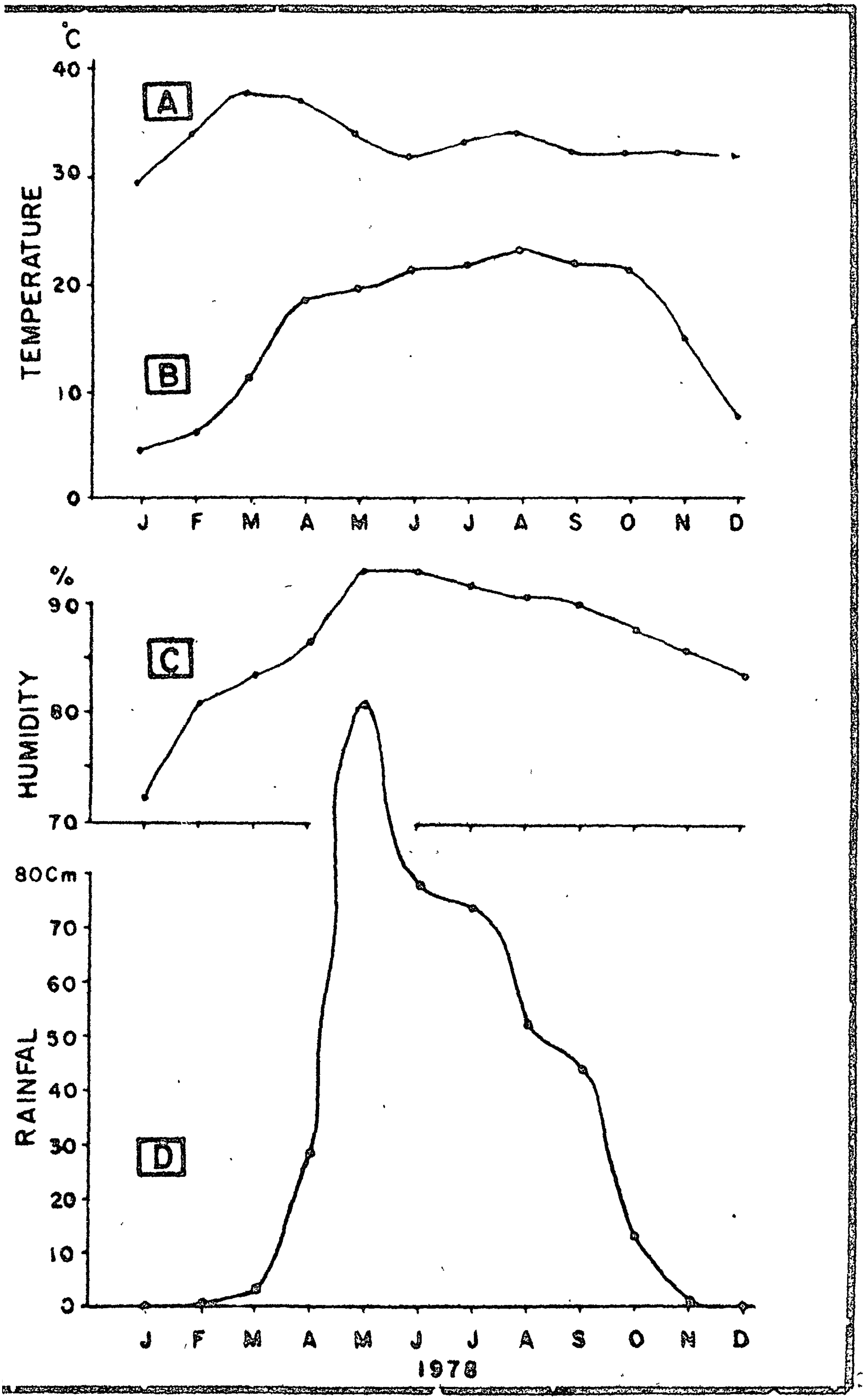

°C
40
30
20
10
0
TEMPERATURE
A
B
J F M A M J J A S O N D
%
90
80
70
HUMIDITY
C
80Cm
70
60
50
40
30
20
10
0
RAINFAL
D
J F M A M J J A S O N D
1978

FIG.1

TABLE - 3.2

MONTHLY TEMPERATURE, HUMIDITY AND RAINFALL OF AGARTALA

Period	Temperature in degree centigrade		Average Humidity in p.c. at 9.30hrs	Rainfall in cms
	Highest	Lowest		
1978				
January	29.0	4.4	72.00	-
February	33.5	6.0	80.50	0.50
March	37.2	11.1	83.20	3.0
April	36.6	17.6	86.40	27.6
May	34.0	18.8	92.80	110.6
June	31.7	21.1	92.80	76.2
July	32.3	21.6	91.53	74.6
August	33.3	22.8	90.22	50.7
September	32.2	21.5	89.76	43.8
October	32.2	21.1	87.38	12.8
November	31.7	14.4	85.90	1.0
December	31.1	7.2	83.28	-
TOTAL	394.8	187.6	1035.77	400.9
Mean	32.9	15.63	86.31	

Source: Directorate of Statistics and Economics, Govt. of Tripura, Agartala, QuarterlyBulletin, (1978), pp.6-9.

It is seen that south-west monsoon does not flow continuously over the region from late May to October due to frequent breaks in Upper-troposphere, mainly due to the change of the high wind speed which is closely associated with the sub-tropical jet streams from the highlands of central Asia. The Tibetan plateau is an enormous block over 4,500 m. altitude about 2,000 km long and about 600 km wide in the west, about 1000 km wide in the east, which affects atmosphere as a (a) mechanical barrier and (b) as a high level heat source.

Rhythm of rainfall, Temperature and Humidity

It is observed that the important climatic factors in the State are rainfall, temperature and humidity. The highest temperature remains almost above 30°C for the Summer months and the lowest temperature reaches as below as 4°C in the winter months, Table 3.2 whereas relative humidity remains more than 65 per cent throughout the year. During the winter there is very insignificant rainfall and is dry.

Average of highest annual temperature of Agartala is 37.7°C, and lowest annual average is 8.41°C, average annual relative humidity is 75.86 per cent and average annual rainfall is 231.07 cm (Table 3.3). For the whole state average annual rainfall is 234.67 cm, though average annual rainfall of 10 different meteorological observations, locating at the sub-divisional headquarters show that rainfall ranges from 204.69 cm at Udaipur to 267.05 cm at Dharmanagar.

It is observed that there is a great variation of humidity for example in 1978 average monthly humidity increased from 72.00 per cent in January to 92.80 per cent during June-July, which means that the humidity is directly related to the thermal condition and precipitation of the region. Again from Table-3.3 it is clear that there is a great difference in annual rainfall from year to year in all the sub-divisions. The rainfall of Agartala ranges from 130.3 cm in 1972 to 400.80 cm in 1978 and average annual rainfall of Tripura 175.90 cm in 1950 and 303.50 cm in 1977, which represents that generally quantum of rainfall is increasing with the lapse of time. (Table-3.1). This may be due to the cloud brusts and intensification of south-west monsoon in the region which brings maximum moisture. Rainfall varies in intensity from south-west to north-east, highest being at Dharmanagar sub-division.

TABLE - 3.3

ANNUAL TEMPERATURE, HUMIDITY AND RAINFALL AT AGARTALA

Year	Highest	Lowest	Humidity average in p.c. at 9.30 hrs	Rainfall in cms
1	2	3	4	5
1950	34.4	8.33		173.8
1951	35.0	10.00		170.0
1952	34.4	12.78		228.7
1953	36.1	11.10		246.2

Contd....

1	2	3	4	5
1954	36.1	10.0		186.3
1955	37.8	9.4	76.20	198.3
1956	39.4	8.9	69.50	284.0
1957	41.7	11.1	64.60	160.7
1958	38.9	12.2	65.47	179.1
1959	36.1	13.3	69.93	257.0
1960	37.2	12.8	68.02	254.2
1961	35.6	15.6	71.02	191.4
1962	41.1	6.7	68.20	163.4
1963	38.9	7.8	68.67	242.3
1964	38.3	6.1	68.28	286.2
1965	40.6	7.2	66.04	254.0
1966	39.6	8.0	76.95	238.0
1967	38.0	6.5	80.58	219.6
1968	39.4	5.2	84.52	224.7
1969	37.6	7.8	86.87	187.0
1970	37.2	5.4	87.39	185.1
1971	37.8	6.4	84.30	245.2
1972	NA	NA	80.19	130.3
1973	37.7	5.9	77.78	251.9
1974	36.3	5.9	77.40	229.0
1975	39.0	5.7	81.76	320.3
1976	39.0	3.0	80.24	310.1
1977	35.0	8.0	80.39	283.4
1978	37.2	4.4	86.35	400.8
TOTAL	1055.49	235.52	1820.65	6700.90
Mean	37.7° C	8.41°C	75.86	231.07

Source: Directorate of Statistics and Economics, Govt. of Tripura, Agartala, Quarterly Bulletins and some Basic Statistics of Tripura (1951-1978), pp.5-11.

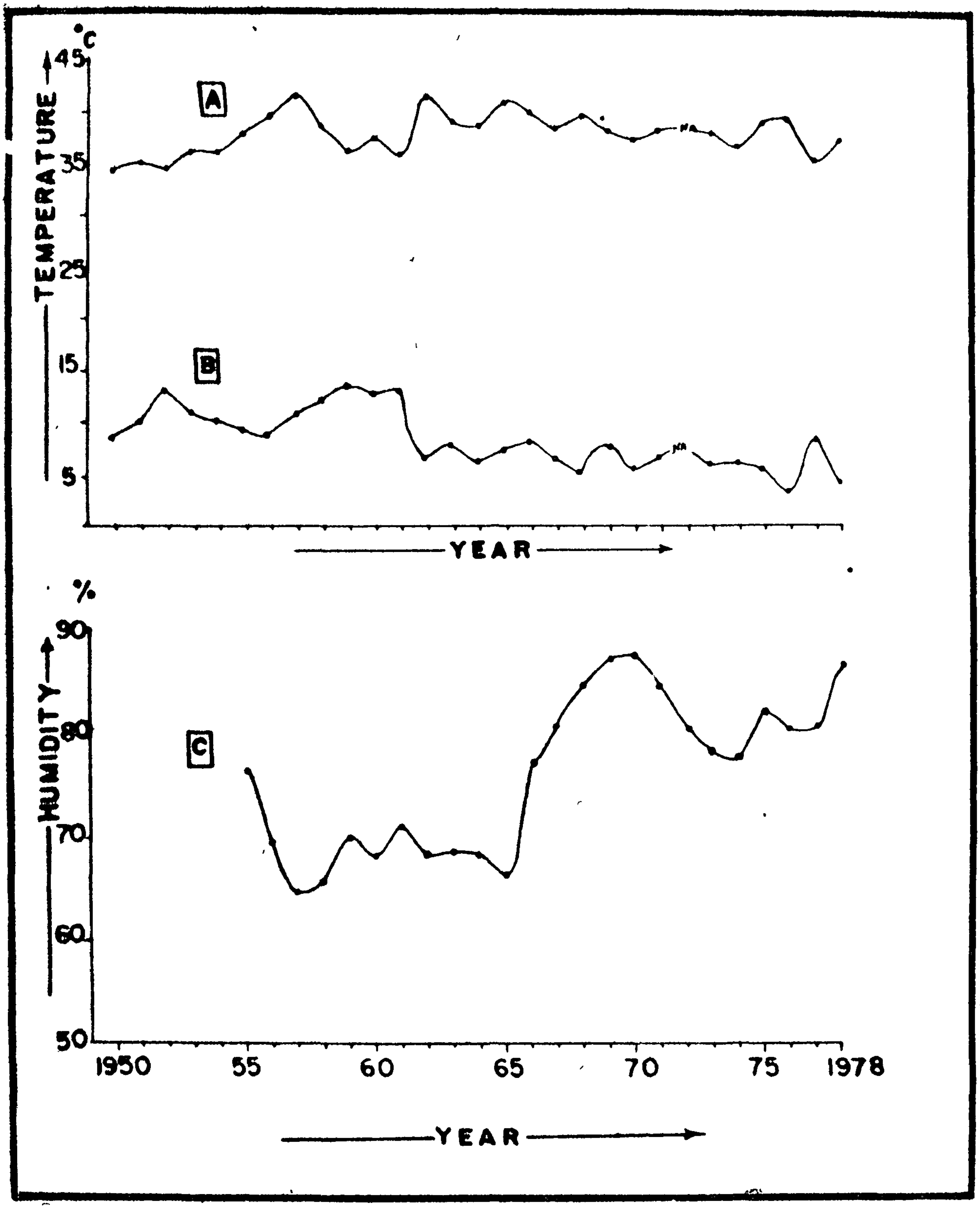


FIG.2 A. HIGHEST TEMP. B. LOWEST TEMP.
C. AVERAGE HUMIDITY AT 9-30 hrs.

TABLE - 3.4

SUB-DIVISIONWISE ANNUAL RAINFALL IN TRIPURA

Year	Sadar (Agartala)	Amarpur	Belonia	Dharma-nagar	Kaila-shahar	Kamal-pur	Khowai	Subrum	Sona-mura	Udai-pur	Tripura (Average)
1	2	3	4	5	6	7	8	9	10	11	12
1950	173.8	90.3	196.4	228.1	181.1		110.3	231.5	202.3	169.1	175.9
1951	170.0	126.0	261.0	276.4	262.0		122.5	254.5	247.5	203.1	213.7
1952	228.7	164.1	219.1	231.6	189.8		187.4	266.3	345.4	221.3	228.2
1953	246.2	198.3	294.6	305.9	208.4		119.1	319.0	386.3	249.8	258.6
1954	186.3	232.0	304.1	227.1	N.A.		224.5	235.9	354.8	195.9	245.1
1955	198.3	194.1	253.3	277.4	285.1		97.0	247.8	297.1	153.4	222.6
1956	284.0	284.4	289.3	301.2	325.7		259.2	291.4	282.3	186.8	278.3
1957	160.7	340.2	234.0	265.7	211.7		168.0	197.1	186.2	139.1	211.4
1958	179.1	179.9	225.2	273.6	175.2		215.0	158.7	248.9	176.4	225.3
1959	257.0	225.5	299.8	290.4	313.6		312.5	250.5	318.4	194.5	209.4
1960	254.2	204.3	292.6	239.3	218.2		206.8	213.5	NA	231.3	228.3
1961	191.4	225.4	284.4	247.2	242.3	193.0	210.2	273.2	NA	181.9	225.7
1962	163.4	181.4	250.7	234.0	200.1	225.1	246.6	176.2	145.9	134.5	206.8
1963	242.3	256.1	NA	256.5	281.3	228.6	249.7	NA	223.1	221.9	228.8
1964	286.2	236.6	NR	325.6	247.2	254.3	238.3	NA	285.3	272.6	268.3
1965	254.0	94.0	NR	236.4	227.3	185.8	172.7	242.8	233.7	158.3	200.6

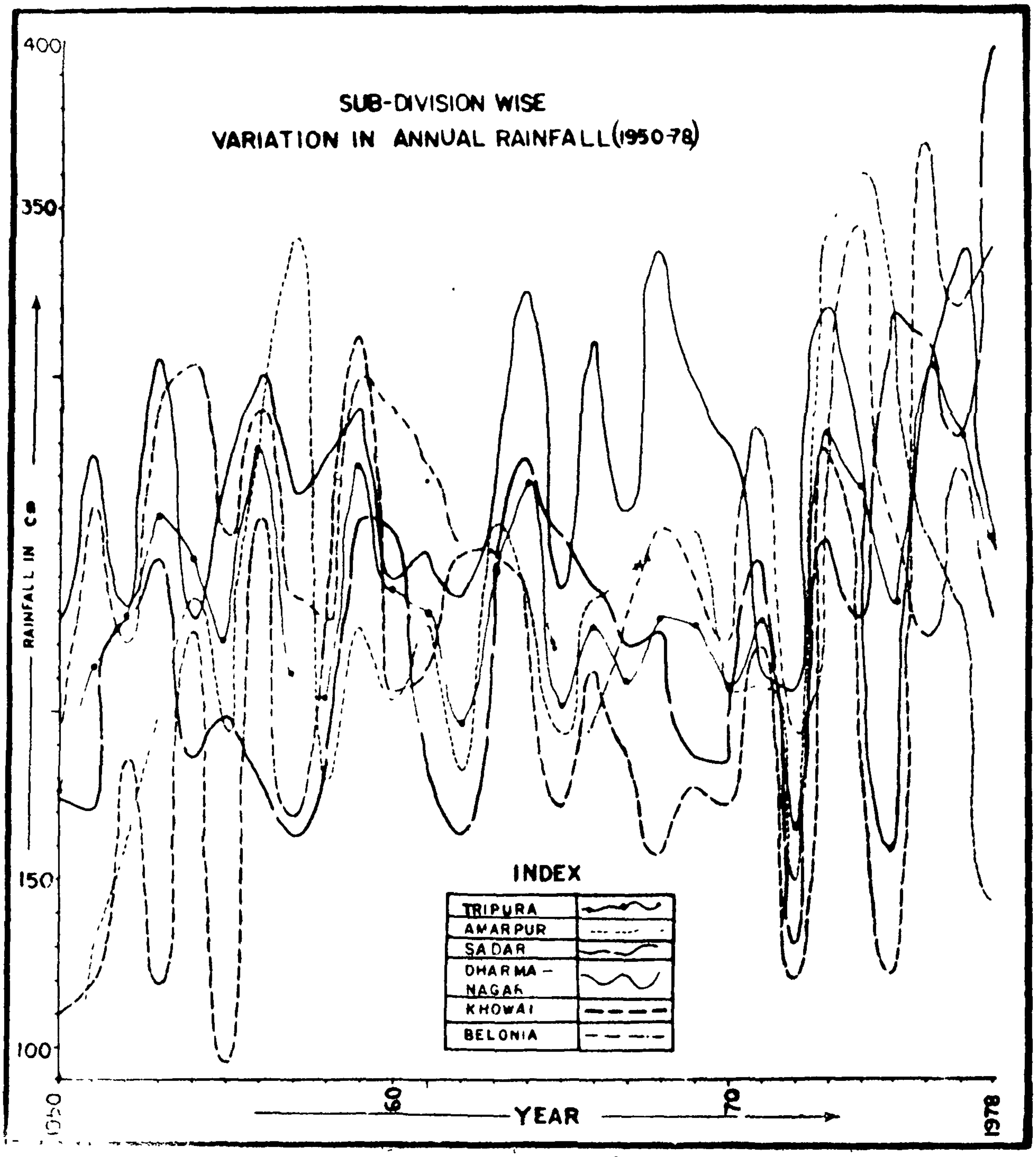
Table contd..

Table-3.4 contd.

1	2	3	4	5	6	7	8	9	10	11	12
1966	238.0	234.2	192.9	310.5	208.5	281.2	212.4	179.3	203.5.	192.2	225.3
1967	219.6	NA	220.9	261.2	217.8	263.6	189.5	177.3	206.2	146.1	211.4
1968	224.7	NA	254.2	337.8	252.3	248.0	156.0	192.1	188.3	201.3	228.3
1969	187.0	253.5	254.1	300.2	232.7	230.8	177.1	253.3	175.1	193.2	225.7
1970	185.1	201.5	219.4	281.4	204.8	198.9	171.2	274.6	164.6	166.3	206.8
1971	245.2	206.8	284.9	215.3	323.9	217.1	220.3	264.7	NA	182.7	228.8
1972	130.3	148.7	193.7	206.9	212.6	NA	121.3	150.1	NA	137.9	164.8
1973	251.9	342.6	248.6	320.6	357.7	219.5	279.1	259.5	235.1	256.5	283.8
1974	229.0	361.5	344.0	246.4	258.2	191.4	245.5	268.3	282.8	254.8	268.2
1975	320.3	287.5	257.3	160.3	212.0	188.3	122.1	257.2	225.1	290.0	232.0
1976	310.1	251.2	220.8	301.6	339.9	320.8	370.1	301.9	239.7	387.7	305.5
1977	283.4	231.4	272.3	339.2	349.0	279.1	321.0	295.5	227.6	232.1	283.0
1978	400.8	143.3	228.5	246.6	237.2	247.1	337.0	213.9	241.0	214.3	250.9
Mean of 29 years	231.07	218.32 (a)	253.67 (b)	267.05	245.50 (c)	233.68	209.05	237.80	245.85 (d)	204.69	234.67

(a) Average of 27 years, (b) Average of 26 years (c) Average of 17 years)

Source: Quarterly Statistical Bulletins, published by the Statistical Department, Government Tripura, Agartala, Vol. I to Vol. XII, pp. 6-9 of each bulletin.



SUB-DIVISION WISE
VARIATION IN ANNUAL RAINFALL(1950-78)
400
350
150
100
RAINFALL IN CM
INDEX
TRIPURA
AMARPUR
SADAR
DHARMA-NAGAR
KHOWAI
BELONIA
1950
60
70
1978
YEAR

FIG 3-A

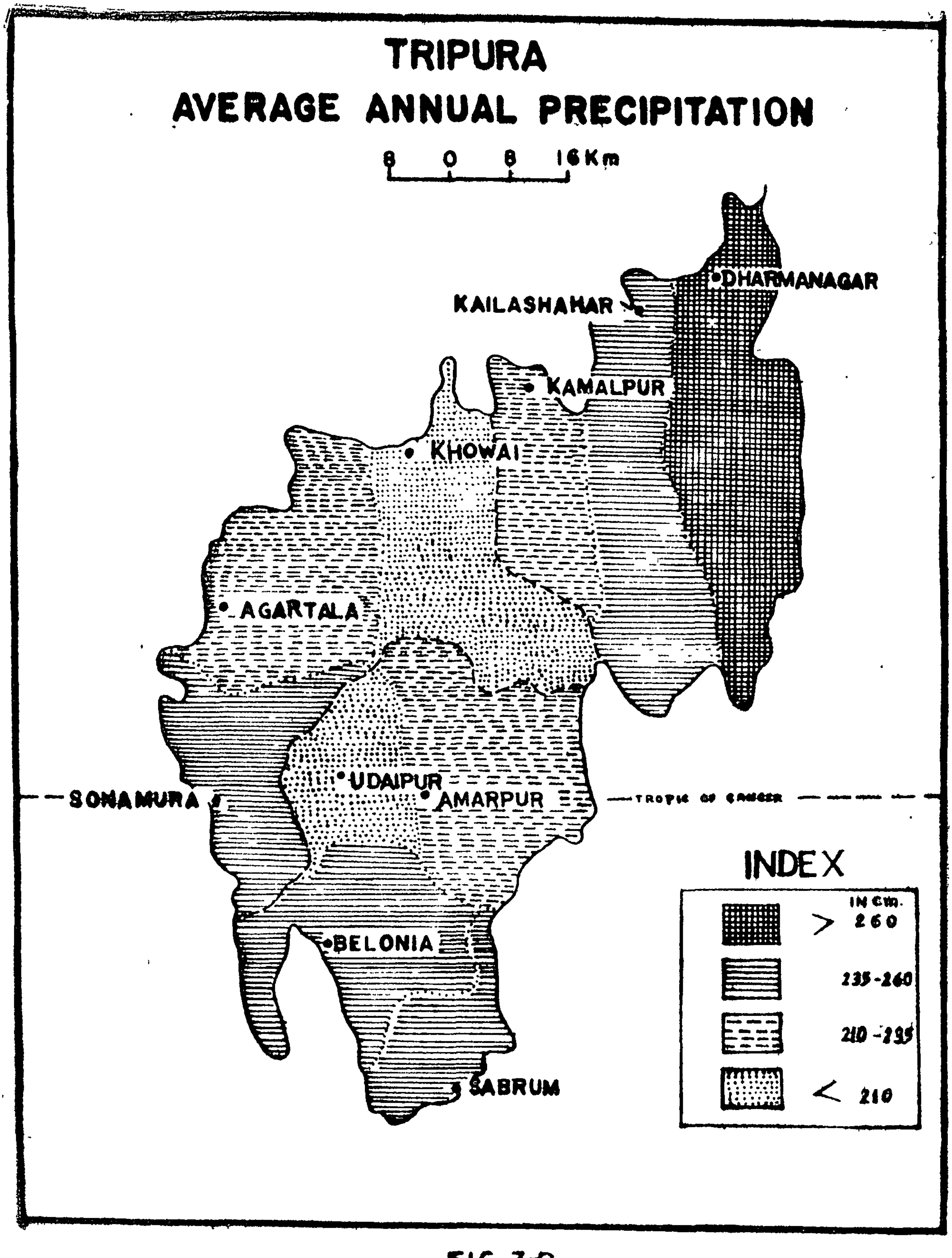

TRIPURA
AVERAGE ANNUAL PRECIPITATION
8 0 8 16Km
DHARMANAGAR
KAILASHAHAR
KAMALPUR
KHOWAI
AGARTALA
UDAIPUR
AMARPUR
SONAMURA
TROPIC OF CANCER
BELONIA
SABRUM
INDEX
IN Cm.
> 260
235-260
210-235
< 210

FIG. 3-B

The Khowai sub-division has an average annual rainfall of 209.05 cm, whereas it had experienced 122.10 cm in 1975 and 370.10 cm in 1976. The rainfall in Kailashahar is steady in comparison to other sub-divisions of the State as such there is maximum number of tea plantations.

The Relationship of Rainfall to Configuration

Over this tropical part of the Indian sub-continent, the bulk of the rainfall comes from south-west monsoon showers, thunder storms. The high altitudinal hill ranges act as a barrier in the north-eastern part of Tripura. The major topographic features of the region are being reflected by the rainfall distribution pattern. Generally there are two different types of topographic features viz: (i) in the west Tripura alluvial plains and (ii) in the eastern part rugged topography with hill ranges. The axes of the high rainfall belts coincide with the high altitudinal land, Hill slopes facing south-west at an altitude of about 150 m at and around Sona Mura receives an average annual rainfall of 245.85 cm. The amount of rainfall increases with the increase in altitude from south-west to the north-east, leading to about 1000 m in altitude around Jampui hill range of Dharmanagar Sub-division. This sub-division lying in between Sakhan Tlang and Jampui hill ranges receives about 267.05 cm

THE RELATIONSHIP OF RAINFALL TO CONFIGURATION

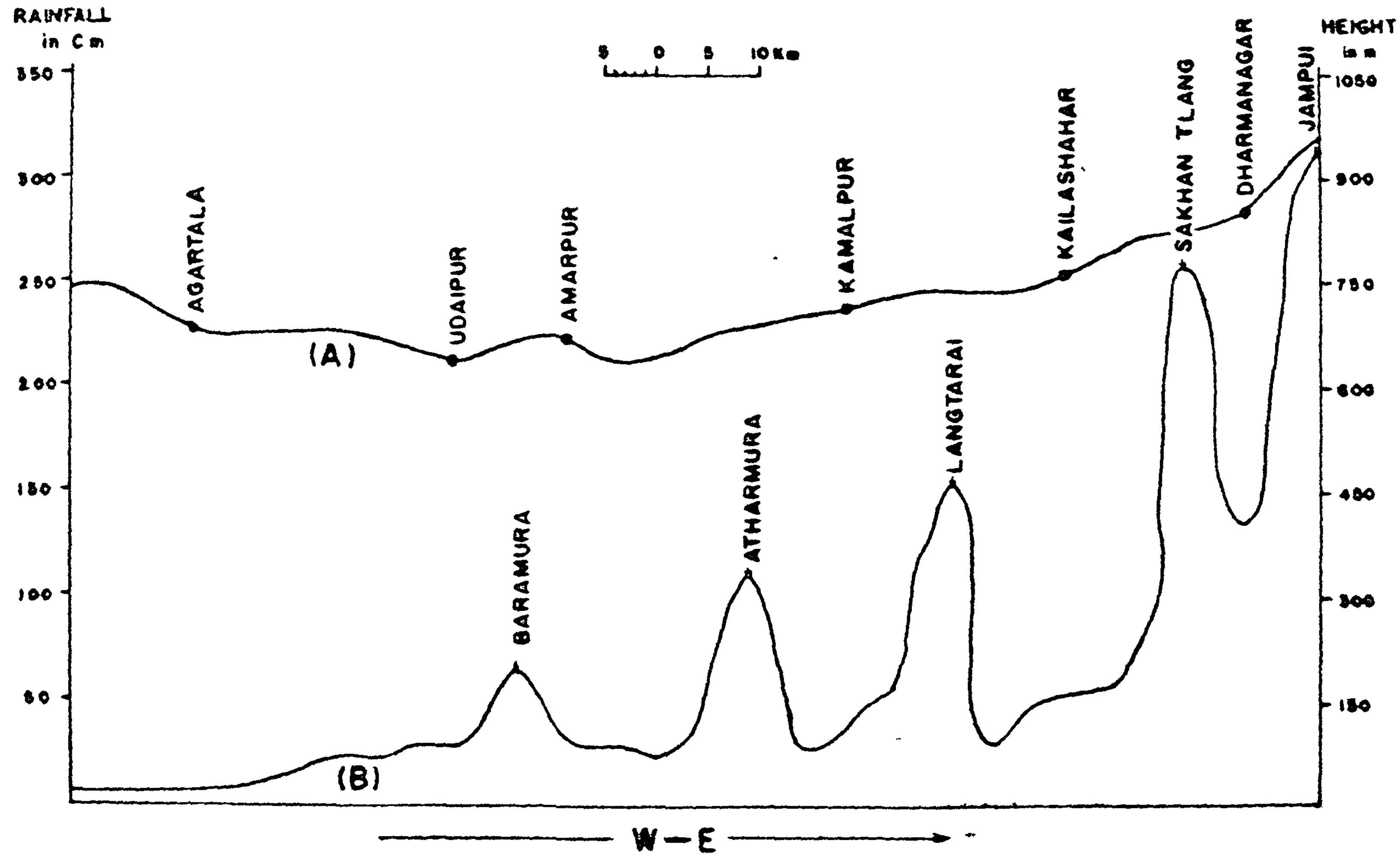


FIG. 4(A) RAINFALL (B) ALTITUDE, ALONG 23° 50° N. LATITUDE
— AFTER DALE, (1959) —

per annum in contrast to the 234.67 cm average annual rainfall for the state as a whole.

Khowai Sub-division is situated at a low altitude, which is also located in the rain-shadow area in the north-western part of Tripura has the lowest average annual rainfall i.e. 209.05 cm. Thus it is seen that windward sides of the hill ranges receive more rain in comparison to the leeward sides.

Mechanisms under the direct influence of climate are dependent on various stages of the morphogenic processes viz. - (i) erosion, (ii) transportation and (iii) deposition. In two different ways climate influences the processes viz. (i) in the nature of the processes (qualitative) and (ii) in their intensity (quantitative). Direct influence of climate on chemical weathering normally increases with temperature, humidity and abundance of water. Heat activates all the reactions and geomorphic processes. The well known law of Van't Hof indicates that a temperature increase of 10^{o}C multiplies the rate of reversible reactions by about 2.5 times. For example in lime-stone topography carbondioxide (Co_2) is more soluble at low temperature.

A profile of topography along 23°50' N. latitude (Fig. IV-B) has been prepared and in a smooth graph joining average annual rainfall of six observatories of six respective sub-divisions are represented. (Fig. IV-A). The rainfall graph also represents the locations of six respective sub-divisional headquarters in relation to topography, which represents that generally rainfall quantum increases with the increase in altitude. The monsoon hits the high altitudinal places of Jampui and Sakhan and in the adjoining regions of eastern Tripura. It is interesting to note that all the Sub-divisional headquarters are located on the important river banks having fertile alluvial landscape which are respectively developed by the rivers in their lower reaches and is lying in between the hill ranges.

EROSION RATES AND CLIMATES, HYDROLOGICAL VARIABLES AND SEDIMENT YIELD

Erosion Rates and Climate

The rate of erosion is the quantity of material actually removed from the soil surface per unit time and area, and this may be governed by either the transparting power of overland flow or the actual rate of erosion, whichever is smaller (Horton, 1945, p.277).[3] The

[3] R.E. Horton, Erosional Development of Streams and Their Drainage basins; hydrological approach to quantitative Morphology, (1945), pp.275-370.

main erosional factor is the run off, which is very active on vegetation-free slopes. The rate of erosion primarily depends on the following factors :-

i) the climate,
ii) the configuration of the relief,
iii) the presence of vegetation,
iv) the degree of cultivation of the area, and
v) Human activities.

In Tripura loose unconsolidated materials are carried by the surface waters and unconsolidated to consolidated materials are removed by the rivers from their catchments to their lower reaches. Spatial variations in landform assemblages are temporal in nature and is due to change both seasonally and in terms of flash floods and storms. Foster and Meyer (1972)[4] derived the following equation expressing an inter-relationship between detachment by runoff and sediment load.

$$\frac{\text{detachment rate by flow}}{\text{detachment capacity by flow}} + \frac{\text{Sediment load by flow}}{\text{transport capacity of flow}} = 1$$

Hydrometeorological Variables and Sediment Yield

Factors like rainfall, slope length, slope steepness soil erosibility are of geomorphic significance. In the study region a large proportions of annual sediment loads

[4] G.R. Foster and L.D. Meyer, A Closed-form Soil Erosion equation for upland areas in Sedimentation, H.W. Shen (Ed.) (1972), p.

are carried by floods during the monsoon. Each flood provides a set of data. Due to obvious reasons 'flood-load model' based study as suggested by Negev (1972)[5] has not yet been undertaken by the geomorphologists. Negev suggests that a flood-oriented model of suspended sediment discharge will serve as a convenient tool for quick estimates of annual loads, which according to him is an effective tool for studying the factors influencing soil erosion and sediment transportation.

Process based measurement helps to overcome the data problem, it helps in better understanding of how regolith and rock materials are eroded and redoposited and the application of this understanding to the interpretation of correlative deposits, paleosols and erosional landforms at a variety of scales.

In case of the uplands of Tripura the erosion process is initiated by the detachment of particles by raindrop impact and their transport by thin flow to rills, where sediment transport and flow detachment is done by runoff. Again due to high fluctuation of temperature, the rainfall-runoff relationship is mainly affected by

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[5] M. Negev, Suspended Sediment discharge in Western Watersheds of Israel, State of Israel Hydrological Service, Hydrological paper (1972), p.73.

the thermal condition. The nature of erosion differs from one basin to the other due to the difference in thermal condition, Humidity, precipitation, runoff characteristics, catchment areas, seasonality, slope, vegetation, sediment yields, relief, lithology and river energy etc.. In Tripura cyclonic storms during the monsoon play an important role in determining the annual sediment yield. Thus climatic seasonality is clearly of great geomorphic significance, which also effects the dynamics of ecosystems.

FLUVIAL EROSION

The study of the fluvial geomorphic cycle in Tripura helps in understanding the geomorphic features which have developed by the fluvial action. The litho-stratigraphy has also played an important role in the development of the present landscape. Through the study of the development of erosion surfaces, the evolution of present drainage system and landforms can be traced.

The loose weathered materials in the form of coarse sand and soil particles is washed by the running water. Different rock structure at different altitudes and environment led to the development of differential weathering and the running water acts as an important transportation agent. The rate of transportation depends on the nature of slope, altitude, amount of precipitation, nature of vegetation, thermal condition etc.. In the State the weathered materials are being continuously carried out from highlands and flatish uplands to the low-lands in the form of coarse sands, silts and clay materials and are deposited mainly along the main channels, in the flood zones of rivers, whereas fine and very fine materials are deposited in the plains just adjacent to the plains of Bangladesh. Weathered and eroded materials of south-eastern parts of Tripura is transported to the western part of the State by the fluvial action of the Gumti river. The process of differential weathering, mass-wasting, sheet-wash and landslides are significant in the eastern Tripura.

In the western part a vast alluvial landscape has been developed under the long continuous impact of monsoon, where both rain, hailstorm and wind acted simultaneously and vigorously in modifying the landforms in contrast to the structural hills of the east Tripura. Thus fluvial erosion is not only important in general lowering of the land surface, but also in shaping the topographic features of landforms of the inter-stream areas.

Recent landscapes are the erosional in nature and

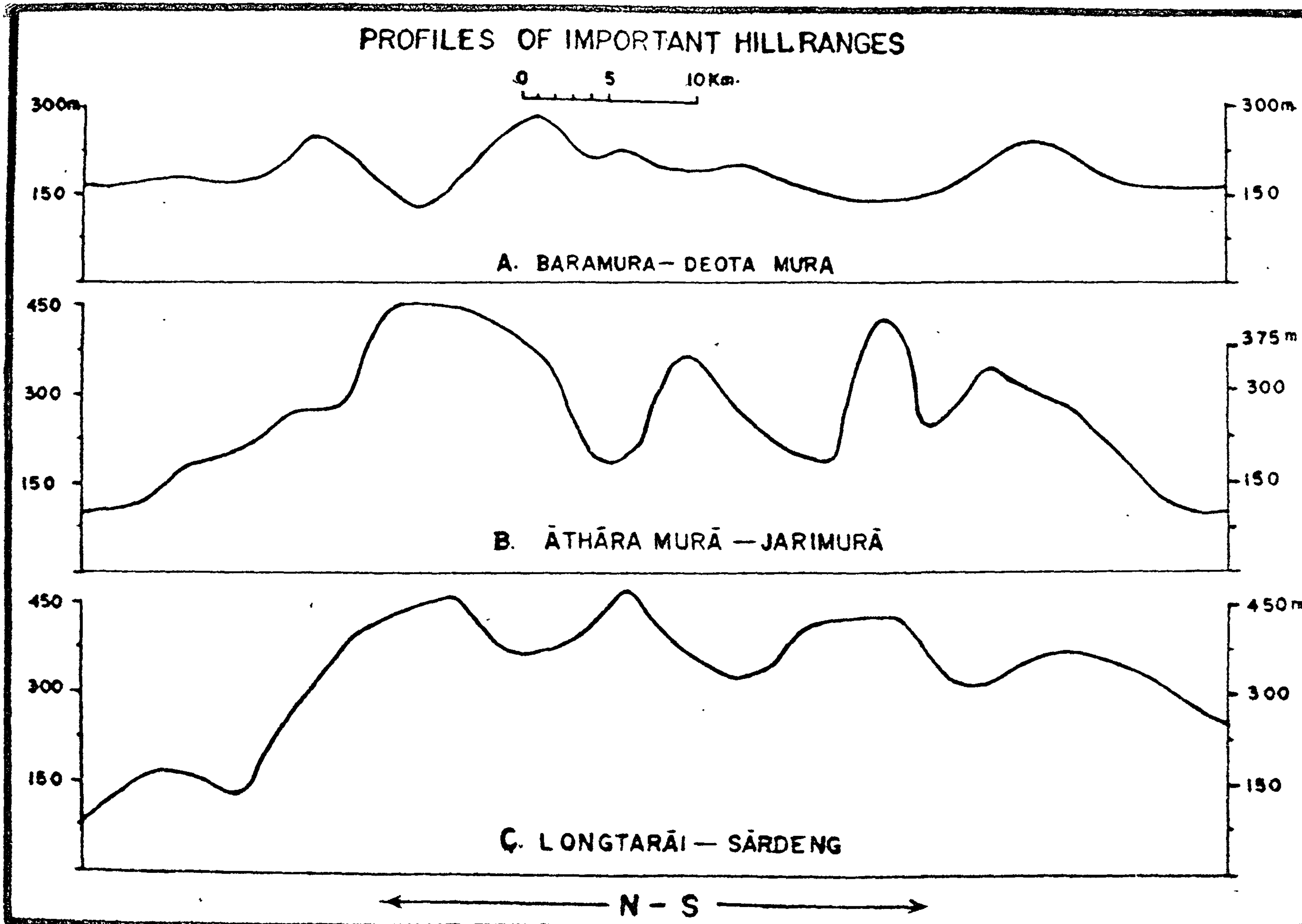
PROFILES OF IMPORTANT HILLRANGES
0 5 10 Km.
300m.
150
300m.
150
A. BARAMURA – DEOTA MURA
450
300
150
375 m
300
150
B. ĀTHĀRA MURĀ – JARIMURĀ
450
300
150
450 m
300
150
C. LONGTARĀI – SĀRDENG
N – S

FIG. 5

and are produced by the fluvial action. The climatic factors with heavy rainfall during the monsoon favours the fluvial action of streams due to the increase of the hydraulic energy in the upper reaches. During rainy season, the streams flow with high velocity having high erosive capacity. Weathering and erosion processes on the hill-slopes are strengthened by the action of gullies and rills, particularly along the folded and faulted regions. Even winter, dry streams become very active in discharging waters from the adjoining areas. Soil erosion in the forest fegion is comparatively less due to the resistance offered by the vegetation to rain and tree roots to erosion.

Influence of geologic structure has been marked in cases of only few old rivers viz., (1) Khowai, (2) Manu and (3) Gumti. Headward erosion is prominent in the eastern part. The major rivers and their numerous streams have dissected and is also dissecting the region, which is responsible for removal of each folded wrapper. With the progress of cycle the outstanding physical features were gradually destroyed as it happened in case of lower reaches of the Gumti river. In the case of north flowing rivers discharge of volume of water during the rainy season is more. In the upper reaches both headward erosion and valley deepening

deepening is intense Development of floodplains is distinct only in the lower reaches of Khowi, Manu and Juri. Most of the valleys are 'V' shaped and the inter-stream areas are not so extensive. The ridges control their flow and as such water level increases from the valley bottom to about 6-7 metre during the peak period of rain in the mouth of June-July.

In the western part the valley bottom along the main channel is like ' ' shape where development of flood plain and river terraces are distinctly visible.

Part of Khowai River Basin

The Khowai river is the third important river of the State just after Gumti and Manu river. It occupies an area of about 1181 sq. km. valley length 60 km., channel length 104 km. with catchment perimeter 240 km. In this figure (Fig. VI) an area of about 736 sq. km. has been represented to show the nature of adjustment of the drainage system with slope, litho-stratigraphic structure, the nature of erosion and process thereof.

The Khowai river originates from Longtarai hill at an altitude of about 480 m. Numerous stream viz. Balu Chara, Asu chara, Tintaiya chara, Chhao chara etc joins together and form Khowai river which flows to the west and corsses Athara Mura near about Riyangbari at an altitude of about 380 m. The river had maintained its western course after crossing Athara Mura for a considerable length, then near Karkaribari village at an altitude of about 60 m the river turns to the north where Athara Mura in the east and Bara Mura in the West controls its flow to the north and ultimately joins Dhaleswari river in Bangladesh. In between Bara Mura and Athara Mura there are some prominent Bills viz. Brahma Bil, Sardu Bil, Champlal Bil, Malakachi Bil etc.

Athara Mura and Longtarai are less resistant ridges in comparision to Sakhan and Jampui. Core area is formed by thinly bedded gray Siltstone, soft sandstone and some shale bands. Whereas in the Bara Mura anticline dissection is very much pronounced and is widely exposed. Average slope ranges mostly 0-20^{O} and crest zone more than 20^{O}.

Thus it is seen that each broad lithological units are closely related to the respective slope category. The catchment areas of the rivers receive high annual rainfall ranging from 204.69 cm to 267.05 cm from one area to the other. The eroded materials of the upper reaches are continuously carried to the lower parts where enormous deposits of sands are taking place, which is responsible for smoothening of hill slopes. In the southern part of the Khowai basin, the shape of the valley is like "V" which has turned progressively wider in its lower reaches where the shape of the valley is like "U", which is also a common phenomena to all the north flowing rivers. The same phenomena has been explained in the chapter on slopes under the 'Slope cycle'.

Headward erosion by the streams is significantly visible in the field as some of which has been represented in the Figure-VI. The erosion processes are gradually crippling towards the structural hills, which is mainly limited on the undulating plains with intermittent hills of old alluvium of pleistocene period. Generally, gully erosion is pronounced in areas without vegetation or areas where deforestation has taken place due to Jhum cultivation, for settlement, construction or otherwise. Climatic factors viz. rainfall, hailstorms, cyclones, floods etc. intervenues through the process of fragmentation, that is weathered under the combined influence of physical, chemical and biological agents. The weathered materials are being transported under the joint action of different processes viz (i) dissolution (ii) solifluction (iii) run off or creep as a bioclimatic processes in combination with the azonal processes which forms dialectic unity. There are also some sudden changes in relief by way of mass wasting under the influence of gravity where supporting rock-structure is weak and landslides etc., directly vary with the hydraulic energy of the stream, slope, altitude and lithology, whereas the amount of rainfall in space and time remains almost same. Valley deepening is nolonger there, because the downward limit is already satisfied which is presently serving as a local base level. Thus with the lapse of time areas under the recent formations with very gentle (0-5^{o}) slopes is progressively increasing with similar decrease in the surrounding areas of old alluvium of pleistocene formations. Similarly areas under other older formations are also liable to decrease and in due course there will remain only bare hills of resistant rocks as a shallow lowlying hills like Sona Mura and Gojalia of the western Tripura.

The intensity of fluvial erosion in the region depends on the structure, lithology of rocks and climate. Amongst the climatic factors as mentioned above the intensity and amount of rainfall is a major one. During the peak of monsoon (June-July), the fluvial action becomes vigorous. The hill ranges, uplands and scarps have outcrops of bare rocks come under the intensive fluvial action. Along the steep sides of hill ridges, weathered materials are washed away during the rainly season. The water channels follow the weak points of underlying rocks and water flows in gullies or in sheet-flow over the surface. Chemical weathering is prominent a small pocket of limestone topography in Dharmanagar Sub-division's southern part. The lithology, thickness variations, facies change structures and spatial arrangements. Within the Surmas are indicative of sedimentation that had been taking place with sedimentary upheaval and sinking of orthotectonic front. The occurances of mineral oil and gas in the Surmas which lie in the frontal range indicates that the deposition might have taken place in the shelf or off-delta area. This may be a result of deformation in response to the tectonic evolution. Sharp increase in elevation is being indicated by the breaks-in-slope on the margin of hill ranges mainly in the Athara Mura and Bara Mura indicates the mineralogical changes. At the end of the geotectonic cycle major parts of geo-syncline had been transformed into land. Intermittant hills in the valleys are developed mostly due to the post-Miocene deposits and also as river terrace deposits.

Fluvial Erosion

The most significant geomorphic features in the study region are the erosional deposits. Careful examination and interpretation of the erosional deposits are helpful in tracing the geomorphic history of the region. The State of Tripura reveals that the western part of Tripura is closely connected to the grand base level of the Bay of Bengal and the eastern Tripura is connected to this grand base level through some local base levels. Thus erosional deposits are supported by different levels above the sea level. Different rock types are standing at various altitudes and are of varying resistence capacity in respect of the fluvial erosion, and weathering. Thus identfification and correlation of erosional deposits are different from one part of the region to the other. The intensity of erosion is directly correlated with the geological age of a region.

The development of different erosional deposits has been associated with the Himalayan upliftment in different periods,in different intensity. Initial rocks formed at the base of the region during the oligocene period i.e. 40 million years ago. The dipping of slopes are smoothing down towards Bangladesh in the north, west and south. In the easternmost part dipping faces to the west and gradually smoothen after each successive hill ridge and lastly merges to the grand base level in the westernmost part where slope is 0-5^{o}.

Headward erosion by the rivers and streams is significantly visible in the field. (Fig. VI). The prpcess of erosion is gradually crippling towards the structural hills, which is mainly limited on the updulating plains with intermittent hills of old Alluvium of pleistocene period. It is observed that broad lithological units are developed due to the deposition and aggradation of eroded materials from the upper lands and hills. Various phases of crustal movements are also responsible for the development of salient relief features of the region. Recent deposits are taking place surrounding the shallow remanent hills and lower parts of the hill ridges. Due to the intensive contemporary erosion, Bhuban rocks of oligo-Miocene period remains as the old remnant surfaces, where few rock exposures are observed.

With the help of morphousetric techniques and field investigations it is found that erosional deposits had taken place in different intensity at different geological periods which are tabularised below

TABLE - 3.5

NATURE OF EROSIONAL DEPOSITS

Sl No	Formation	Period	Approximate Altitude in Metre
1	Recent	Holocene and recent	Upto 50 m
2	Old Alluvium	Pleistocene	50 - 150
3	Tipam	Pliocene	150-250
4	Boka Bil	Mio-pliocene	250 - 450
5	Bhuban Y	Oligo-Miocene	450 and above

Recent formation is still intensive throughout the study region. The ranges in altitude for different erosional deposits of different period represents the general picture. In fact these limits vary from one river valley to the other. The Bhuban deposits are higher in the eastern part, where as the Recent deposits are higher in the western part of the State.

PART OF KHOWAI RIVER BASIN

FLUVIAL PROCESS

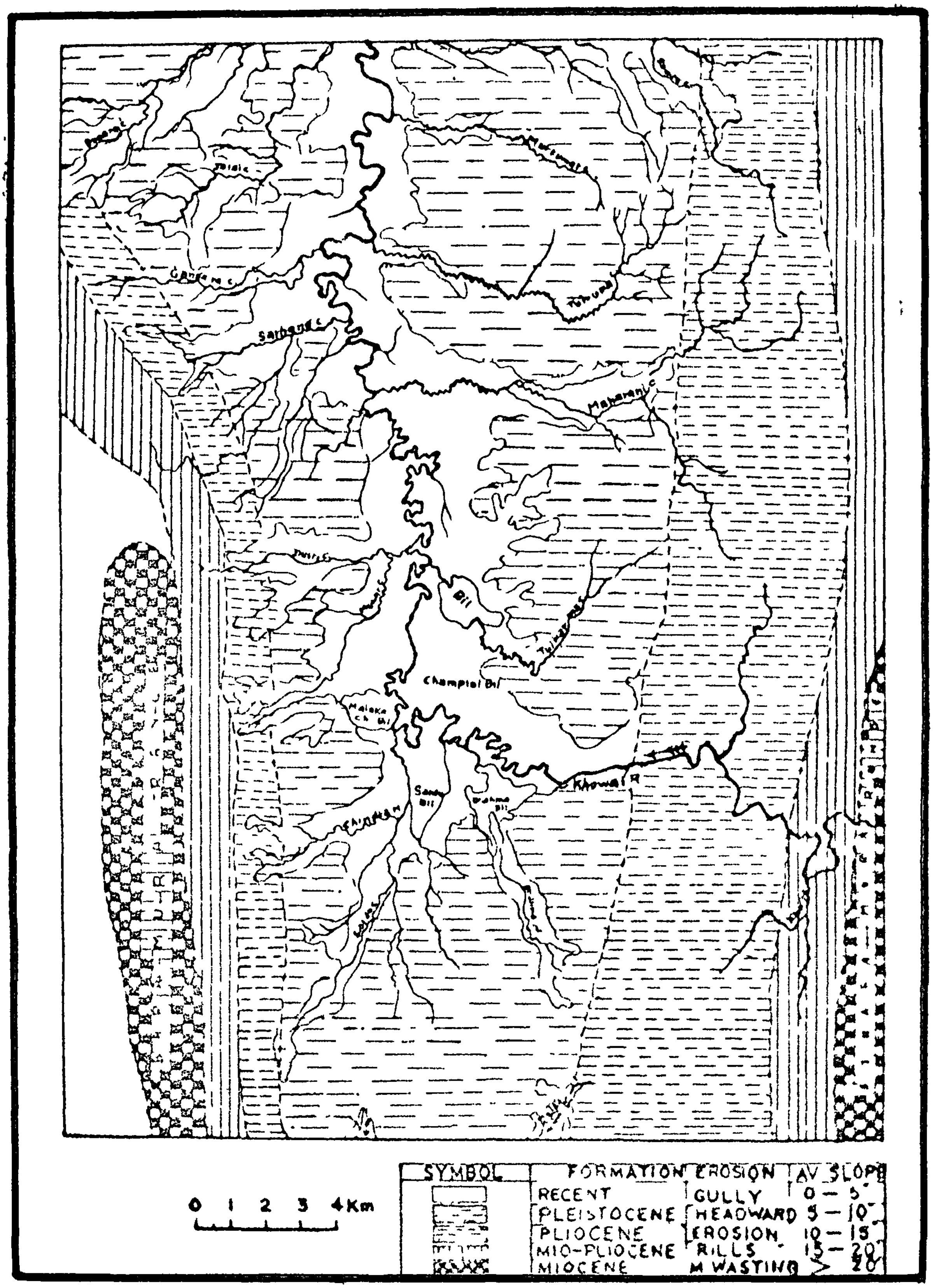

FIG 6

GEOMORPHIC PROCESSES AND DEVELOPMENT OF LANDFORMS

> "Rivers and valleys have a special place, for it is impossible to treat the development of landforms, or to describe existing forms in a rational manner, without constant reference to the valleys that have been worn to them and to the rivers by which the waste is washed along the channel in the valley floor."
>
> – W M DAVIS (1900)

Evolution of Landforms

Emergence of the study region from the sea bed was the primary state of the development of the land. Due to internal built major folding appears to have taken place in sub-merged geo-synclines which may be due to the block-movements, general upliftment and subsidence. The earlier processes of degradation and deposition operating prior to major tectonic activities may be traced through the rock composition, structural hills and their arrangements. Sedimentary rocks of the structural hill ranges are mostly tilled as evidenced by the rock exposures due to landslides as well as erosion. Thus the development of the present land surface implies the successive cumulative effect of processes that have beem taking place during the last geological periods. With the lapse of time the changes caused by exogenic forces became greater and greater. Major landforms might have developed during the oligo-Miocene period and the successive stages of modifications are taking place into a series within the conformity of geological periods. There is no volcanic activity in this region. In the Tripura region the landforms of the western part are of homogeneous and in the eastern part are mostly heterogenous. Most likely the history of the land surface begins with its emergence from below sea level and its attaining an elevation to an altitude of about 1000 m during the Himalayan movements.

Destruction at the lowest portions of early land-surface due to tectonic activities and impact of paleo-climatic conditions are likely to be responsible for the development of narrower valleys at the uplands of the east. Broad elevated land-surfaces surrounding the structural hill ridges indicates the development of differential landscapes. (Table 3.5). It seems that due to large-scale degradation of the land mass,steepy hills are loosing the equilibrium of the topography.It is most likely that the destructive forces (exogenic and endogenic) had crossed the threshold of resistance and as a result dissections are taking place at random. Due to large-scale folding and faulting modifications of the previous landscapes are taking place. They completely transform the internal build and destroy the stream channels and valleys of the older surfaces. In that case only powerful rivers viz. Gumti and Khowai had maintained their courses in the face of the upheaval to become surviving (antecedent) rivers of the new landscape.

Evolution of landforms had taken place on the geological structure of the region which had acted as a controlling factor. The geomorphic processes of the region had left their distinctive imprints upon these evolved landforms, some of imprints are locally termed as - Muras, Tillas, Nadi, Gang, Charra etc.. Thus it can be said that different erosional agencies which have been working in the region had prodyced a sequence of distinctive landforms which are polycyclic. In the State of Tripura the landforms have developed under the combined impact of both climate and structural features, as such the geomorphology of the region is dependent on both the structural geomorphology and climatic geomorphology.

Climatic factors intervenes through the process of fragmentation, that is weathered under the combined influence of physical, chemical and biological agents which again is transported under the combined action of different processes viz - rills, gully, runoff or creep. "Normal conditions of relief is formed by running water."[6] The sculpture is effected by the processes of rain and rivers, of weather and water, of heilstorms and cyclones. Southern part of Dharmanagar sub-division where low grade lime stones are located is affected by chemical composition under the influence of rainwater. Thus evolution of streams and rivers determines the genesis of landforms, they also determine the base-level of slope development. Thus the form of slopes as developed are the outcome of all the combined effects of the processes.

Weathering

The geological succession in Tripura shows that there are very few rock exposure at the surface. The surface layer of lithologic structure is unconsolidated silt, sand, clay, decomposed vegetable matters and coarse river sand. Soil cover is mainly weathered under

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[6] A. de Lapparent, 3rd Edn. (1970), p.66.

the influence of monsoon. The main factors which affect weathering are as follows -

1. Climate,
2. Lithological characteristics of soil and clay,
3. Structure, and
4. Vegetation.

Out of all the physical factors the role of climate particularly that of monsoon rainfall has maximum impact on weathering. Weathering is more intense in the zones of folds, faults and other neo-tectonics. The climatic factors, like temperature, rainfall, cyclonic wind, Humidity etc. decide to a great extent the nature and intensity of weathering. Generally rainy season lasts for four to five months i.e. May to September. The rainy season brings cyclones, hailstorms which causes damage to houses, crops and vegetation and accelerates the process of weathering. Land slides are also taking place along the altitudinal hill ranges with steep slopes, mainly under the impact of heavy rainfall.

The Nature of Fluvial Erosion

Soil erosion during the Pleistocene and Recent period is very much significant. The role played by climatic factors on this part of the morpho-climatic play ground is therefore important in the elaboration of the relief. There has been no reorganisation of the drainage system during the quaternary, and the streams functioned continuously and even deposited much more alluvium during the cold in comparison to the temperate tropical stages.

The evolution of the relief is strictly by the dissection of Neogene erosion surface. The valleys are poorly graded with stretches of flat bottomlands and the hill ranges are steep sided. The moderately steep-slopes (10-15^{o}) having most of the tributaries of main rivers are depositing fine sediments along their meanders, while main channel meanders within 10^{o} slopes are responsible for the deposition of coarse sands. The imported unconsolidated sand masses forming coalescing fans are spread at the mouth of the ravines in the depressions.

Interfluves are characterised by a dissection into ridges, convey at the crest, concave at the base, convexo-concave in between the top and the base and becoming more ramified due to soil erosion. Hill side slopes are marked by slightly incised torrents. Alternate ridges with narrow concave valleys are the evidence of the pleistocene periglacial actions.

The ravines characterise the stage of youth in the upstream areas in the east and the quiet reaches the town-stream area is the stage of maturity. Gullies have a morpho-climatic significance in the region.

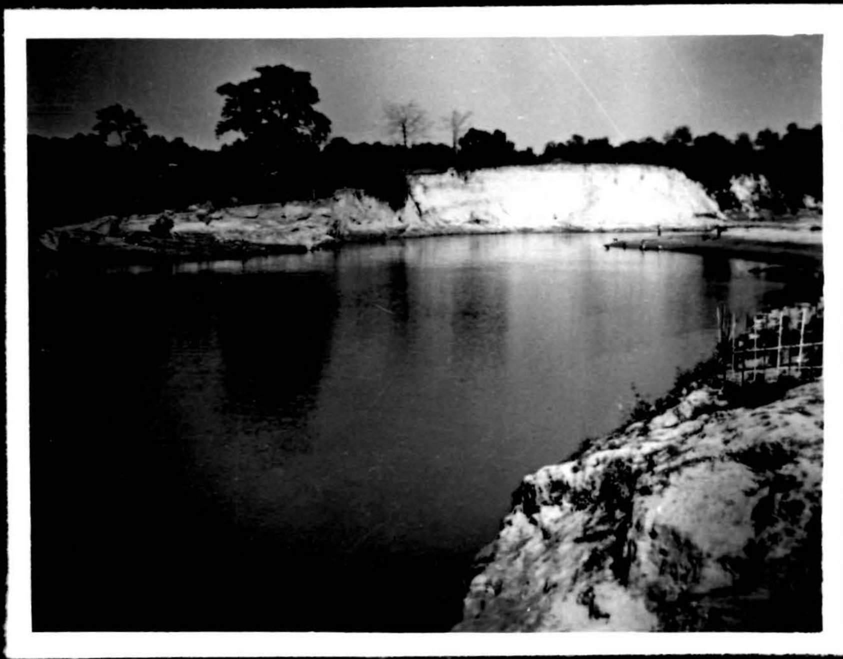
In Tripura region Tillas (small hills) lying in between river valleys and hill ridges are lacking any incision. These hills are of convex shape and without much relief. The long profiles of the water courses are very irregular, slightly inclined bottom-lands. The abundant rain water which leave it fall into the embayments surrounding it and successively drop to the lower embayments are indicative of the levels of the floors of the embayments at different elevations.

The streams other than main streams are hardly incised. The waters of south-west monsoon rush down the margins of the embayments or the water shed zones of the central and eastern Tripura without cutting any valleys. The average gradient is almost same as that of the slopes in the source region of the rivers and as such the minor streams descend the slopes without incising them and becomes dry in the winter. Some higher order streams at high lands are also dried up, their beds are only visible, because of the absence of vegetation, such streams leave a trace in the topography. The rivers in the region narrow down into a fractured zone and follows a rightanged course. The hard sandstones are located in the hill ridges where the streams originate and as such though there are certain rock exposures, the stream energy is not sufficient to pull the load to the mainstream. As a result exposed sedimentary rocks are displaced from in Situ and lying on the nearby places. The weathered and fragmented materials are only washed way and small pebbles of sand stones are carried upto the foot hills by the small streams along the steep slopes. There is no pebble in the river beds of Tripura only sand deposits, though there is continuous erosion of sandstones in the hills and along the river banks at certain places of steep-slopes.

The absence of pebbles, the rareness of sandstones is a sure indication of the absence of mechanical abrasion in the river beds. As a result heavy sand and silt deposition on the river beds is taking place, resulting in decrease of hydraulic energy. Point-bar and channel-bar deposits are distinctly at random developing in the region which are distinctly visible during the off rainy season. During the peak period of monsoon the water-level rises upto 6 to 7 metres above the winter water level. The streams and rivers attain sufficient energy to pull down weathered materials along with some portion of early sand deposits to the low lying areas. Thus each valley specially in between the ridges has been cut by its main streams mostly at rightange to the main channel is responsible for widening of the valley. Areal extent of terraces and flood plains are progressively increasing due to the accumulation of weathered materials, with the lapse of time.

Vegetation with-holds an important part of rain water, facilitates the infiltration of another part, and thus vigorously opposes the gullying of slopes by runoff. With the decrease of forests gully erosion has considerably been increased. The residual shallow hills and hill ridges in the western part of Bara Mura hill range, with other residual reliefs has shrunk with a concomitant noticeable decrease in slope. The topographic features that have developed between the hill ranges specially in the eastern part may partly be assimilated to the normal cycle of erosion. The evolution of the features are generally the result of slope retreat, folding, faulting in addition to the progressive lowering of the relief by fluvial processes.

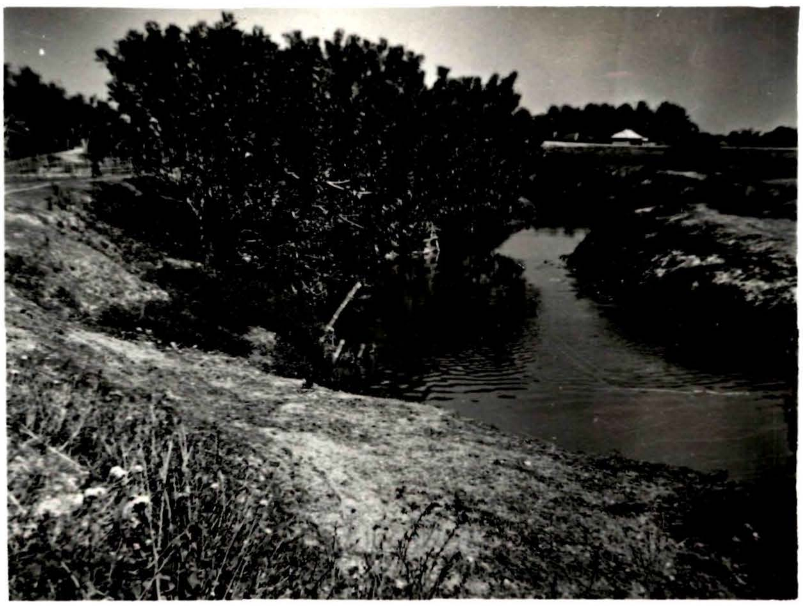
The profile of the water courses is quite dependent on the geological structure and lithological formation. Water runs primarily on the surface of resistant rocks of sandstone and drops into a river valley and descends a pre-existent slope nearby the Alluvium plains of the region and its adjoins.



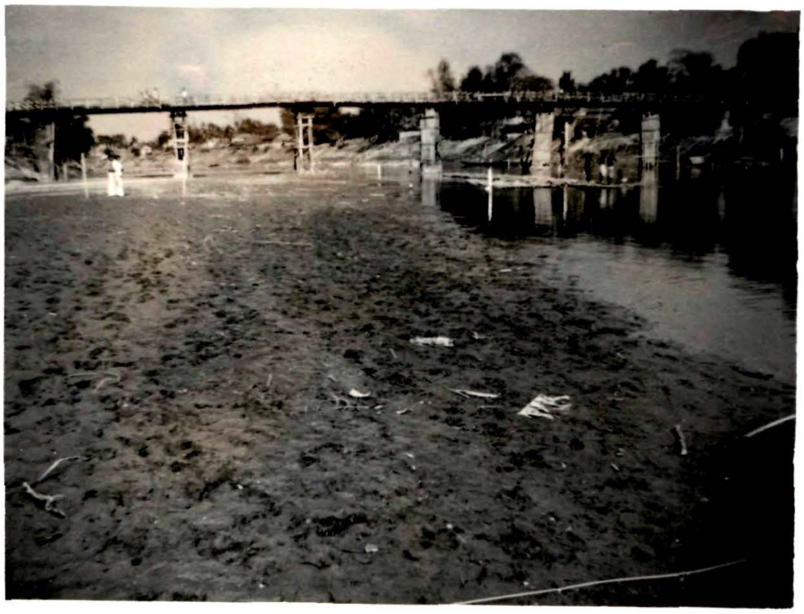
1. A view of the wide and flatish Gumti river bed, at its lower reaches near Udaipur, during the pre-monsoon period, white patches indicate the imprints of Soil erosion.

2. A view of the sand deposits and development of a river terraces of Khowai river.

3. A view of Gumti river near Udaipur : flatish river bed during winter.



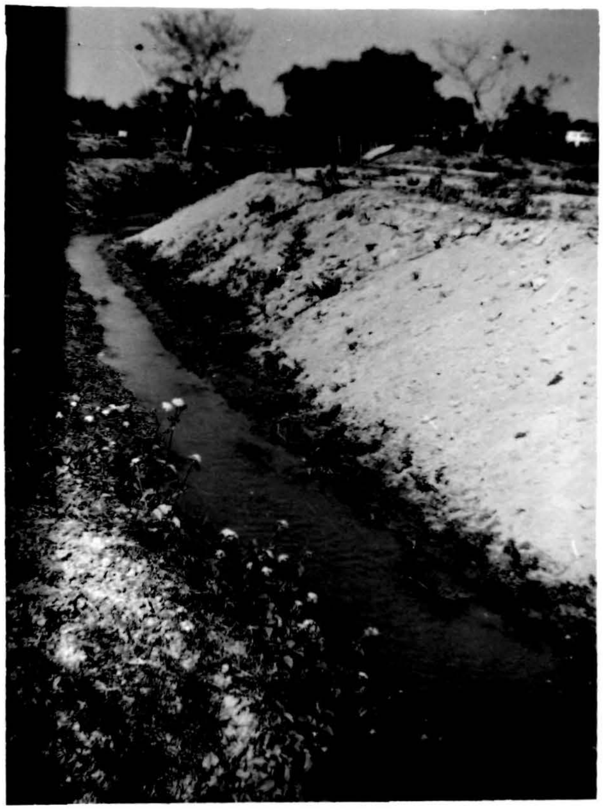
4. The nature of gully erosion by a tributary of Haora river.



5. Water gauges in Manu river near Kailashahar.

6. A view of enormous sand deposits in the lower reachesof Manu river near Kailashahar.

7. A view of the layers of recent deposits on the bed of river Khowai.



8. A view of Lakshmi Charra originating in Unokuti Hill joining Manu river on the southern side of Kailashahar.

CHAPTER - IV

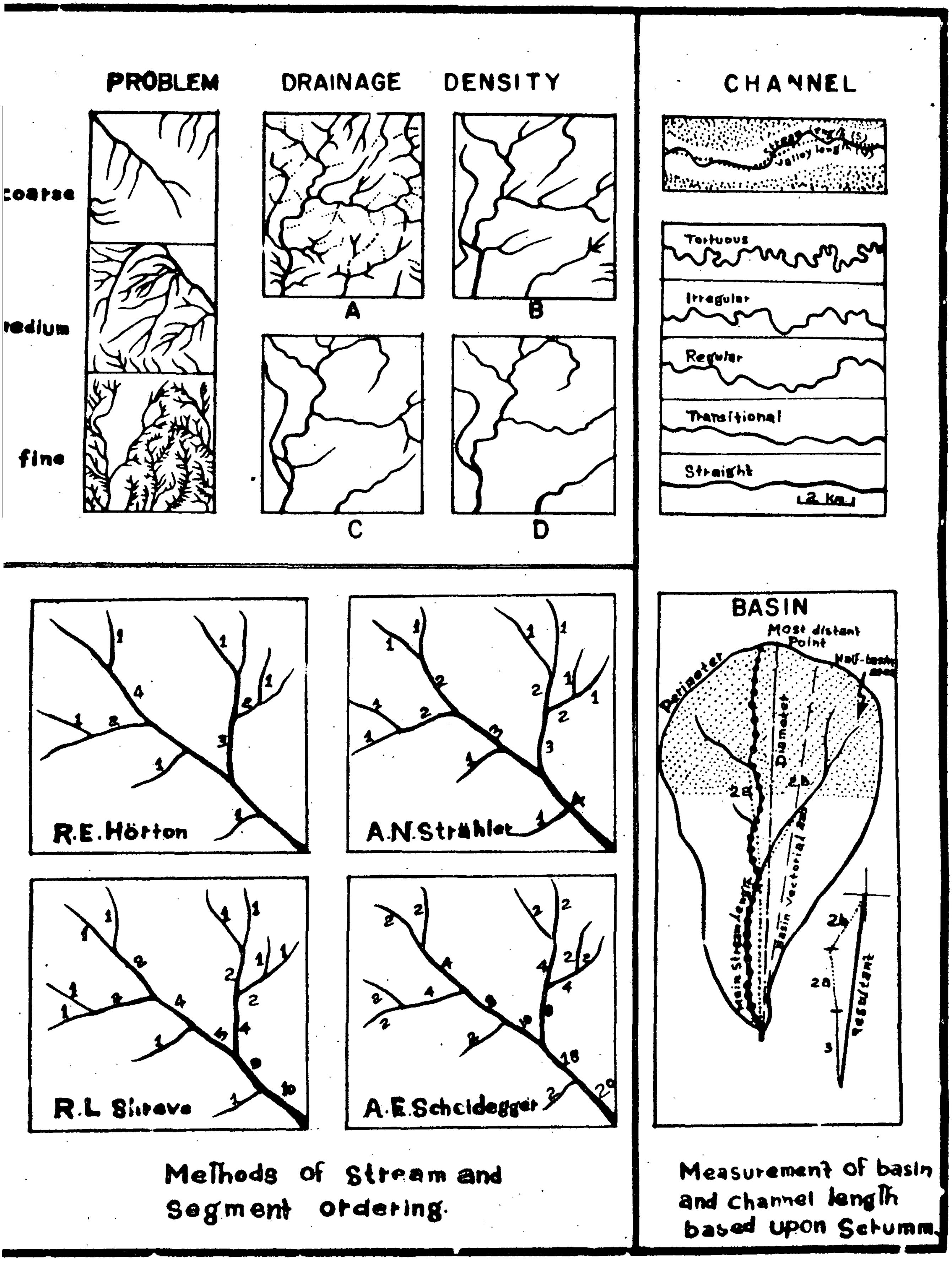

PROBLEM
DRAINAGE DENSITY
coarse
medium
fine
A
B
C
D
CHANNEL
Tortuous
Irregular
Regular
Transitional
Straight
2 Km
BASIN
Most distant Point
Perimeter
Diameter
R.E.Hörton
A.N.Strähler
A.E.Scheidegger
Methods of Stream and Segment ordering.
Measurement of basin and channel length based upon Schumm.

FIG.1

QUANTITATIVE ANALYSIS OF TWELVE SMALL SELECTED BASINS

"Quantitative techniques, supported by Statistical analysis, provide a standardized, rigorous, conservative and objective framework for the investigation of many of the problems of earth Science." -

- R J Chorley (1954)

In Tripura the ruins of the uplands and hills are being carried out off in-situ by the streams and rivers as a part of its continuous process. The conventional qualitative, descriptive and deductive study was replaced by the modern scientific, mathematical and quantitative analysis of the drainage basins; which is capable of providing hydrologists, agro-climatologists and agro-economists with numerical data of practical utility. In this new orientation R.E. Hortones[1] work was further developed by strahler (1950, 1952, 1956, 1958), Schumm (1956), Melton (1957) and many others.

This chapter deals with quantitative analysis of landform mainly in respect to the stream segments that are

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[1] R.E. Horton, Erosional Development of Streams and their Drainage Basins : "Hydro-Physical Approach to quantitative Morphology;" Bulletin of the Geological Society of America 56 (1945), pp.285-370.

developed in relation to the watersheds. For this study both perennial and non-perennial stream segments of all the basins are included for the purpose of quantitative analysis. In this Chapter all the initial minor streams are treated as first order streams. Whereas two first order streams joining together forms the Second order and the two second order streams joining together forms the third order stream and so on. (Fig. I)

Though various authors have suggested various methods of ordering system of stream segments Horton's method has been used. The junctions of each order to its higher order is considered as a point of bifurcation. The ratios of such junction for any particular order of stream to its higher order is termed as the Bifurcation ratio. For this purpose, the number (Nu) of all the stream segments are counted according to the hierarchical orders and tabulated. The length of stream segments are measured, tabulated and also their various inter-relationships are determined with the help of spectrum-7, Computer, for the purpose of the analysis. Both linear and areal aspects of the drainage basins are analysed, interpreted to reveal the geomorphic characteristics of the morphometric variables under this study. The interpretation is mainly based on the Sinuosity indices, drainage density (Dd), Stream frequency(S_F), slope etc.

The drainage basin is being delimited by its watershed, which again serves as the perimeter of the basin. For any particular geomorphic region there is a definite relation in between the area and perimeter of the river basins. An attempt is also made to find out this relationship in case of the study area i.e. Tripura. The length of the main stream (master stream) from the mouth to the source is termed as the channel length (C_L). The straight line horigontal distance from the mouth of the master stream to the most distant point on the perimeter (LC) is significant in determining the shape of the basins. In the present study, the data of various attributes of both linear and areal aspects of the basins have been derived and calculated from the available toposheets of one inch to one mile and two centimetre to one kilometer and the results drawn so far have been verified by the field work.

The distinct morphometric characteristics requires the determination of their relative positions on their relative hierarchical scale of stream segments. "This has required the assignment of a level of relative order of magnitude to each segment in a stream segment hierarchy, determined by sequential arrangement of tributaries with respect to the main trunk."[2]

[2]K.J. Gregory and D.E. Walling, Drainage Basin Forms and Processes, Arnold Publishers Ltd., (1973), p.46.

According to Leopold (1969), stream order is defined as a measure of the position of a stream in the hierarchy of tributaries. Play-fair was the first Geomorphologist who recognised the unitary features of the geometry and process presented by the erosional drainage basin. Davis (1899) has described the drainage basin as a leaf and the streams as the veins of that leaf. The formulae and notations used for the purpose of the computations of sinuosity Indices are given below :

i) $C.I. = \frac{C_L}{Air\ L}$

Where C.I = Channel Index
C.L.= length of the channel
Air_L = (A_L) short distance between the source and mouth of the river.

ii) $V.I. = \frac{V_L}{Air\ L}$

Where V.I = Valley Index
V_L = Length of the valley between the base of the valley walls.

iii) H.S.I.= % equivalent of $\frac{C.I - V.I}{C.I - 1}$

Where H.S.I. = Hydrolic Sinuosity Index

iv) T.S.I = % equivalent of $\frac{V.I - 1}{C.I - 1}$

Where TSI = Topographic Sinuosity Index.

v) $S.S.I = \frac{C_L}{V_L}$

Where SSI = Standard Sinuosity Index.

Modified form of Horton's scheme as given by Strahler have been used for the morphometric analysis of the drainage basins. (Fig. I).

ORDERING OF THE SELECTED BASINS

Scale of the maps used for the ordering of the drainage net-work plays a vital role in deciding the accuracy of the orders of stream segments. Generally larger the scale of map better the result, because of the fact that in large scale maps the details of streams, finger-tip tributaries and even rills are correctly depicted on such maps. Even large-scale contour map may be used for the determination of the streams. The problem of stream ordering is very much felt in our country (India) because the large scale maps viz.1: 15,000 or 1: 25,000 etc. are not available for the purpose of researchwork. The field work may be helpful in the verification and investigation of smaller streams but lack of necessary facilities for field mapping pose a serious problem for the purpose. There may be some departures from the different laws of drainage network as postulated by Horton and Strehler.

Out of twelve selected basins for the purpose of this study seven has been taken from two centimeter to one kilometer (1: 50,000) topo-sheets of the Survey of India and the rest five have been taken from the one inch to one mile map (1: 63,360). The twelve small selected basins have been ordered according to Strahler's scheme of ordinal scale of strain ordering and stream segments of different orders are represented in (Fig. II A & B). Out of the twelve small basins[3] - seven basins are: Juri N.(2), Kanchan C (3), Pati C(4), Ekjan C. (9), Mailak C (10), Kakri N. (11) and Bengeswar Gang (12) are of fifth order and the rest five basins are - Andhar C.(1), Dhanai C. (5), Tuichakma C. (6), Garam C(7), Ganga Rai C(8) are of fourth order. The small basins are selected from all the interesting parts of the study region to coverup the whole region. The correlated picture of these basins may reflect the picture of the region.

Ordering of the streams is done by arithmetical figures against the order of the basins and all the streams segments of each order have been counted and represented in Table-4.1. It is distinctly clear from the table that Kakri Nadi of West Tripura district tops the list having 351 stream segments which is the largest and Tuichakma Chara consists of least number of stream segments.

It is apparent from Table-4.1 that there is a close

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[3]Numbers in the parenthesis against the basis indicate their serial numbers as presented in all the table in the text.

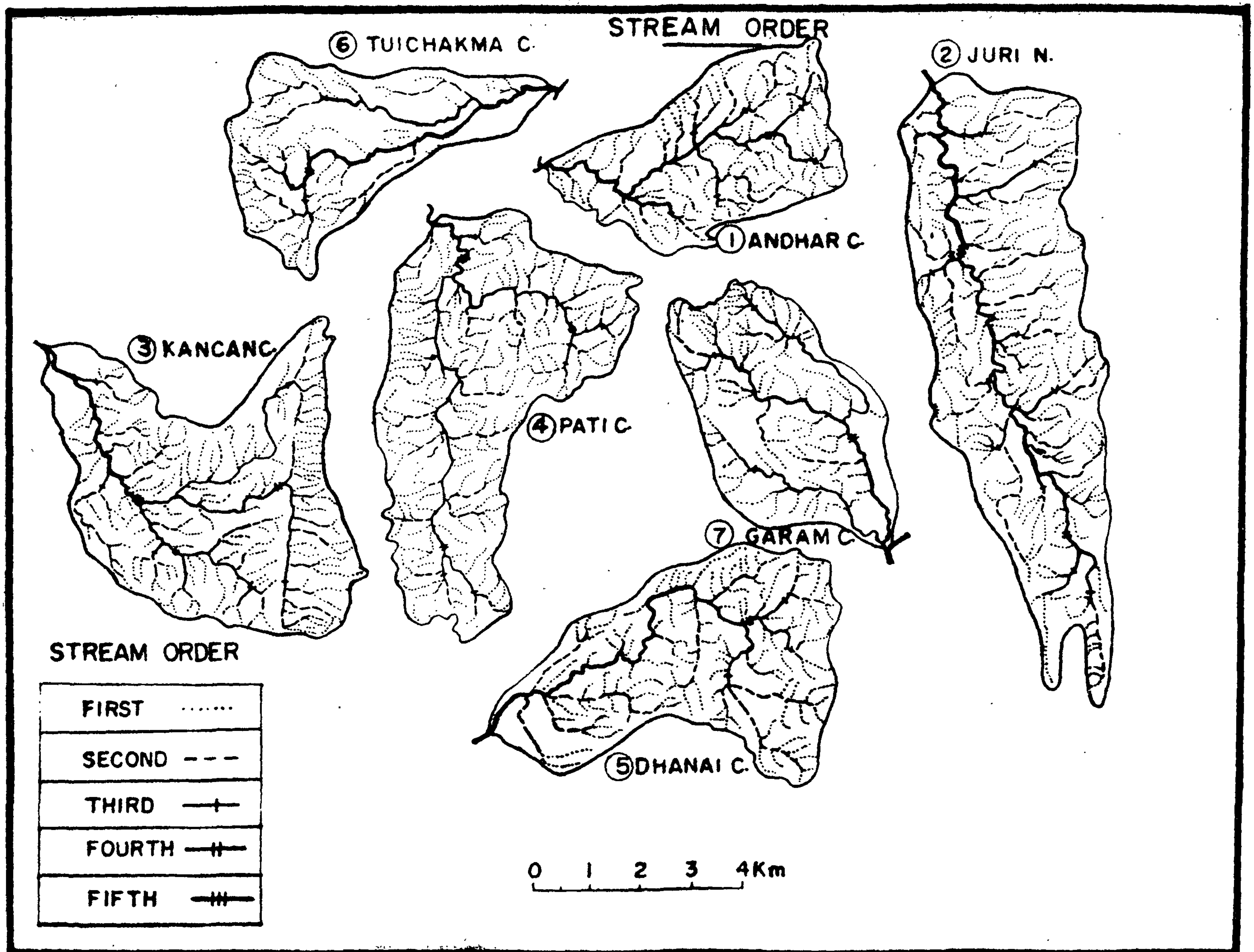

STREAM ORDER
⑥ TUICHAKMA C.
② JURI N.
① ANDHAR C.
③ KANCANC.
④ PATI C.
⑦ GARAM C.
⑤ DHANAI C.
STREAM ORDER
FIRST
SECOND
THIRD
FOURTH
FIFTH
0 1 2 3 4Km

FIG-2-A

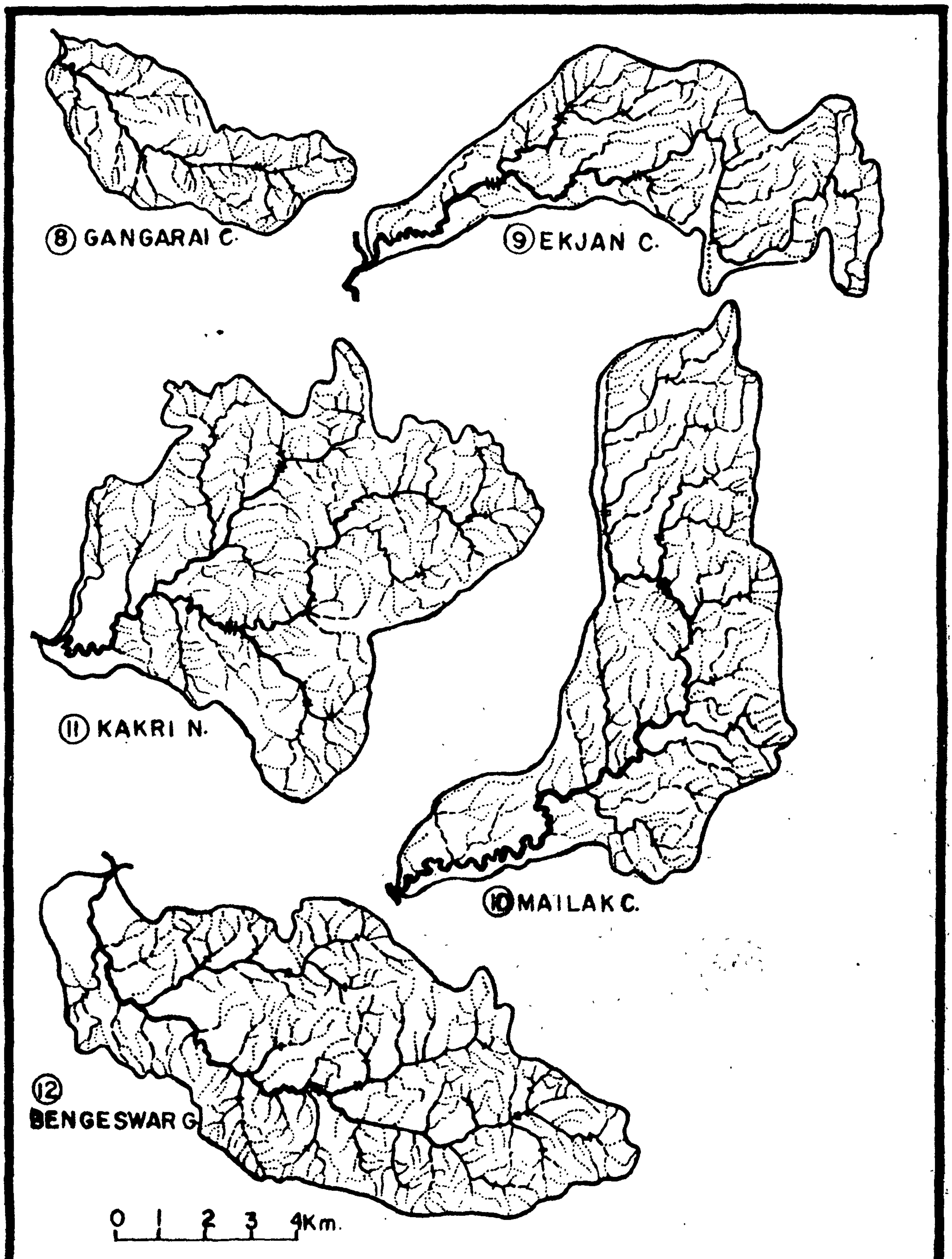

⑧ GANGARAI C.
⑨ EKJAN C.
⑪ KAKRI N.
⑩ MAILAK C.
⑫ BENGESWAR G.
0 1 2 3 4Km.

FIG. 2-B

relationship between the area of the basin and number of stream segments. Kakri Nadi occupies the first position in respect to area and also first position in respect to the number of stream segments. Similarly Tuichakma occupies its lowest position in respect to both number of stream segments and also by area, even all the stream segments of individual order is also lowest out of the twelve small basins. Kakri Nadi, Bengeswar Gang and Mailak Chara respectively occupies their first, second and third position both in respect to number of streams segments and area. Only distinct exception to the rule of direct relationship between the area and stream segments are observed in case of Juri and Ekjan Chara. Though Ekjan Chara's position is fourth in respect to area, in relation to the number of stream segments its position is seventh. Juri Nadi occupies its fifth position in respect to area but fourth by the number of stream segments. All other streams are also nearly maintaining the relationship between its number of stream segments and area with marginal differentiation. It is clear from the Table-4.1 that the number of stream segments of any given order will be fewer than for the next lower order and more numerous than for the next higher order.

LAW OF STREAM NUMBER

There is definite relationship between the orders of the basins and numbers of stream segments. Harton and Strahler have propounded an inverse geometric series of the numbers of stream segments and orders and have stated "that the number of stream segments of successively lower orders in a given basin tends to form a geometric series beginning with the single segment of the highest order and increasingly according to constant birfurcation ratio." They have recommended the following equation of stream number[2]:

$$N_u = R_b^{(K - u)}$$

where, N_u = Number of Stream Segments of a given order

R_b = Constant bifurcation ratio

K = highest order of the basin

When the number of stream segments of different orders are plotted on a semi-logarithmic graph paper, a straight line of regression representing negative exponential function model is obtained. Though Strahler's ordinal scale of stream ordering differs significantly from the Horton's scheme of ordering, yet Strahler's system also produces the same inverse geometric series of numbers of stream segments.

TABLE - 4.1

NUMBER OF STREAM SEGMENTS (Nu)

Sl No	Basin	N_1	N_2	N_3	N_4	N_5	Total of N_1 to N_5	Area in Sq. km.
1.	Andhar C	80	19	5	1	-	105	14.54
2.	Juri N	160	40	11	3	1	215	32.31
3.	Kanchan C	148	33	6	2	1	190	25.08
4.	Pati C	149	38	7	3	1	198	24.92
5.	Dhanai C	111	20	3	1	-	135	20.08
6.	Tuichakma C	67	17	3	1	-	88	14.23
7.	Garam C	79	19	3	1	-	102	15.08
8.	Ganga Rai C	91	22	5	1	-	119	16.23
9.	Ekjan C.	130	24	5	2	1	162	34.48
10.	Mailak C	182	40	9	2	1	234	56.20
11.	Kakri N.	277	59	11	3	1	351	61.09
12.	Bengeswar Ganj	252	64	14	3	1	334	60.50

In the present study, stream number (Nu) have been plotted against orders on a semi-logarithmic graph using the following equation of negative exponential function model as suggested by Strahler. The regression coefficients (b) for each of the basins have been calculated and the same have been represented on the graphs (Fig. III).

$$Y = a_e^{-bx}$$

$$Log_e Y = Log_e^{a} - Bx + 1(\text{Episton})$$

where, Y = number of stream segments

X = stream order (u)

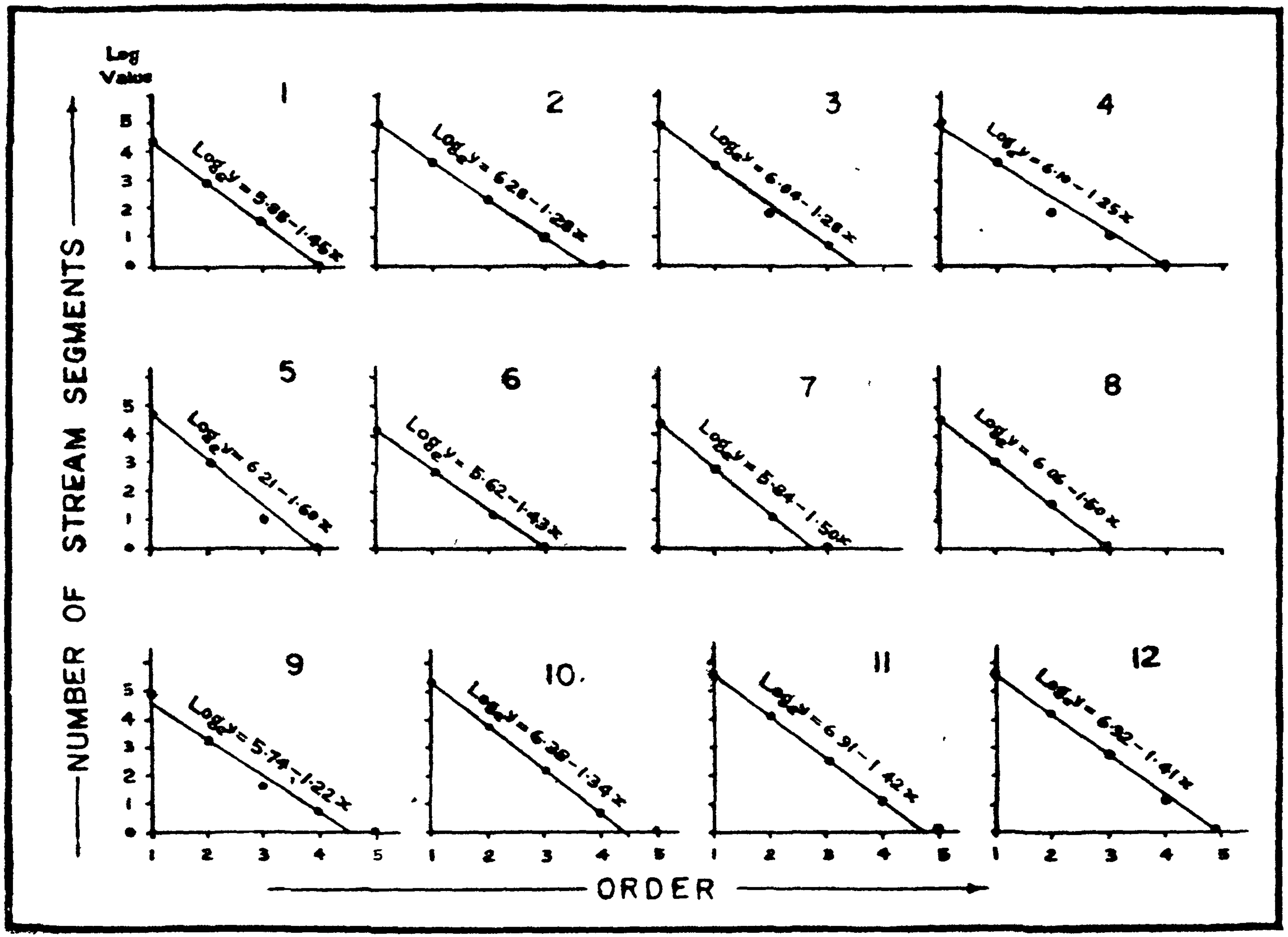
a = Constant and

b = regression Co-effdcient.

The stream orders of any basin and their respective stream segments as represented in the graphs shows that there exists a close relationship. There is a perfect geometric progression in case of three fourth order basins viz. Andhar charra, Tuichakma chara and Ganga rai charra.

Explanation

Semi-logarithmic graph (Fig.III), reveals that, when the number of stream segments in its log value are



Log Value
NUMBER OF STREAM SEGMENTS
ORDER
1
2
3
4
5
6
7
8
9
10
11
12
Log_e y = 6.28 − 1.28x
Log_e y = 6.10 − 1.25x
Log_e y = 6.21 − 1.60x
Log_e y = 5.62 − 1.43x
Log_e y = 5.84 − 1.50x
Log_e y = 5.74 − 1.22x
Log_e y = 6.91 − 1.42x

FIG. 3

101840

plotted against successive orders of stream segments, the graph for the four 5th order basins viz. Juri Nadi, Rabi Chara, Kakri Nadi and Bengeswar Gang have indicated almost a straight line. Other three 5th order basins viz. Kanchan Chara, Mailak Chara and Ekjan chara have indicated a straight line from 1st order to 4th order segments with minor deviation of 5th order. It proves, that stream segments of the various orders are proportional to the orders except the deviation of the 4th order stream segments of Pattichara and deviation of 5th order segments of three 5th order basins.

Out of the five fourth order basins for two basins, viz. Andhar Chara's, Ganga Rai Chara graphs are perfectly of straight line, which represents perfect proportionality of the stream segments of various orders. Graphs for the three other, fourth order basins are of almost in a straight line, except deviation of 3 rd order stream segments of Dhanai chara and Tuichakma chara and deviation of 4th order stream segments of Garam chara. There is no gross deviation of stream segments of any particular order of any basin. Whatever marginal deviation from the straight line exists that is due to the combined effect of various factors viz. underlying rock structure, unfavourable conditions of topography, location in between the ridges, amplitude of folding and faulting, altitude and gradient etc.. The surface drainage system is well developed but not well integrated due to the differential topographic conditions that prevail in a small region of 10,477 square kilometer area. The small basins have developed within the micro Geomorphic units, reflects perfect linear relationship to almost linear relationship as indicated by the graphs. (Fig. III).

STREAM LENGTH

The stream length is another morphometric parameter of the drainage basin of greater significance as it helps in calculation of drainage density and its mathematical analysis of geomorphological aspects in relation to other geomorphic parameters. The stream length of different orders all the 12 basins have been measured in kilometers and represented in Table-4.2 Total lengths of various orders are significant in finding out their mean values ($\bar{L}_u$). The mean values of various orders of all the 12 basins are computed and tabulated in Table-4.3. It is clear from the table that 1st order stream segments have the least mean length of the individual basin, and this mean value increases with the increase in order. Generally all the stream follow this postulation except some departures in case of two basins out of the 12 basins. Juri Nadi has its 2nd order mean stream length 0.83 and 3rd order mean stream length 0.75 i.e. departure from the postulation by only 0.08 km (8m). Thus only gross violation of this postulation is done by the Garam Chara.

Where $\bar{L}_2$ is 0.44 km. where as $\bar{L}_1$ is 0.48 km. and $\bar{L}_3$ is 3.68 km. whereas the highest order i.e. 4th order is 2.35 km. This means in case of this basin mean length of 1st order is higher than the mean length of 2nd order and the mean length of 3rd order is higher than that of the 4th order stream segments. This is mainly due to the structural control on the streams. The location of this basin is on the eastern side of the Bara Mura hill range where many springs are located. Just on the hill slope there is a spring and at the central location of the basin i.e. Garam chara is a hot spring. As a result underground water has dominated the ground water (rain) and as such less number of lengthy first order streams have developed. Moreover slope of this basin varies from moderately steep (10^o - 15^o) to very steep (more than 20^o) is also responsible for non-development of first order streams of short length. Thus combined effect of geology, lithology, slope, springs are responsible for the development of the 1st order stream in comparison to the 2nd ordered streams.

TABLE - 4.2

STREAM LENGTH (Lu)

Sl No	Name of the Basin	Length in Kms					Total
		L_1	L_2	L_3	L_4	L_5	
1.	Andhar C	34.74	9.08	5.52	5.90	-	55.25
2.	Juri R.	75.75	33.15	8.30	7.10	3.95	128.25
3.	Kanchan C	67.87	21.30	6.30	5.15	3.15	103.77
4.	Patic (Machhmara C)	71.05	25.25	5.50	7.90	2.35	112.05
5.	Dhanai C.	50.50	18.15	4.95	7.30	-	80.90
6.	Tui Chakma C	33.15	17.75	5.70	6.00	-	62.60
7.	Garam C	37.90	8.30	11.05	2.35	-	59.60
8.	Gangarai C	44.50	13.00	5.50	6.50	-	69.50
9.	Ekjan C	72.00	26.00	12.00	6.00	5.00	121.00
10.	Mailak C.	102.00	34.00	22.00	5.50	15.00	178.50
11.	Kakri N.	138.00	44.00	20.00	16.00	7.00	225.00
12.	Bengeswar Gang	164.00	52.00	18.00	11.00	11.00	256.00

Harton (1945) has postulated a law of positive geometric progression between cumulative mean lengths and stream orders wherein the cumulative mean lengths of stream segments increase geometrically with successive increase in stream orders with constant length ratio. The positive exponential function model is expressed through the following equation:

$$L_u = L_1 \, R_L^{(U-1)}$$

where, L_1 = The mean length of the 1st order

$$R_L = \frac{L_u}{L_{u-1}} = \text{Constant length ratio}$$

As because of the fact that the constant length ratio seldom exists, as is evident from Table-4.3, this model is also rarely applicable to the natural stream system. Significant variations in length ratios are noticed in all the twelve small drainage basins. When log values of all the cumulative mean lengths of all orders of stream segments are plotted on the ordinate against the orders on the abscissa a straight line of positive exponential function is derived. (Fig. IV). The regression lines for all the 12 basins have been drawn on the basis of the following regression equation:

$$Y = a_e^{bx}$$

$$\text{Log}_e Y = \text{Log}_e a + bx + U$$

Where Y = Cumulative Mean length

X = Order (U)

b = Coefficient of regressions, and

a = a constant.

Explanation

The Fig. IV reveals that, when the cumulative mean stream lengths are plotted against successive orders of the streams, the graphs for 5th order basins indicate almost a straight line with exception to Kanchan Chara and Ekjan chara. In case of Kanchan Chara only 5th order stream segment marginally deviates from the straight line and in case of Mailak chara both 4th and 5th order stream segments deviates from the straight line, while 1st, 2nd and 3rd order segments are in a perfect straight line.

Out of the five, 4th order basins Dhanai chara and Tuichakma chara represents a straight line. Third order streams are marginally out of the graph line in case of Ganga Rai chara and 4th order is out of the straight line formed by the other order. Only irregularity is seen in case of the Garam chara where 1st and 4th order segments are joined and 2nd and 3rd order streams are in the two side of the straight line formed by joining the 1st and the 4th order segments.

TABLE – 4.3

MEAN STREAM LENGTH(Lu)

Sl No	Basin	$\bar{L}_1$	$\bar{L}_2$	$\bar{L}_3$	$\bar{L}_4$	$\bar{L}_5$	$\bar{L}$
1.	Andhar C.	0.42	0.48	1.10	5.90	-	0.53
2.	Juri R.	0.47	0.83	0.75	2.37	3.95	0.60
3.	Kanchan C.	0.46	0.65	1.05	2.58	3.15	0.55
4.	Pati C (Machhmarh)	0.48	0.66	0.79	2.63	2.35	0.56
5.	Dhanai C.	0.45	0.91	1.65	7.30	-	0.60
6.	Tuichakma C.	0.49	1.04	1.90	6.00	-	0.71
7.	Guram C.	0.48	0.44	3.68	2.35	-	0.58
8.	Ganga rai C.	0.49	0.59	1.10	6.50	-	0.58
9.	Ekjan C.	0.55	1.08	2.40	3.00	5.00	0.75
10.	Mailak C.	0.56	0.85	2.44	2.75	7.50	0.76
11.	Kakrai N	0.50	0.75	1.82	5.33	7.00	0.64
12.	Bengeswar Gang	0.65	0.81	1.29	3.66	11.00	0.77

TABLE - 4.4

CUMULATIVE MEAN LENGTHS (Km)

Sl No	Name of the Basin	$\bar{L}_1$	$\bar{L}_1+\bar{L}_2$	$\bar{L}_1+\ldots+\bar{L}_3$	$\bar{L}_1+\ldots+\bar{L}_4$	$\bar{L}_1+\bar{L}_2+\ldots+\bar{L}_5$
1.	Abdhar C	0.42	0.90	2.00	7.90	-
2.	Duri R	0.47	1.30	2.05	4.42	8.37
3.	Kanchan C	0.46	1.11	2.16	4.74	7.89
4.	Patic	0.48	1.14	1.93	4.56	6.91
5.	Dhanai C	0.45	1.36	3.01	10.31	-
6.	Tui Chakma C	0.49	1.53	3.43	9.43	-
7.	Garam C	0.48	0.92	4.60	6.95	-
8.	Gangarai C	0.49	1.08	2.18	8.68	
9.	Ekjan C	0.55	1.63	4.03	7.03	12.03
10.	Mailak C.	0.56	1.41	3.85	6.60	14.10
11.	Kakra N.	0.50	1.25	3.07	8.40	15.40
12.	Bengeswar Gang.	0.65	1.46	2.75	6.41	17.41

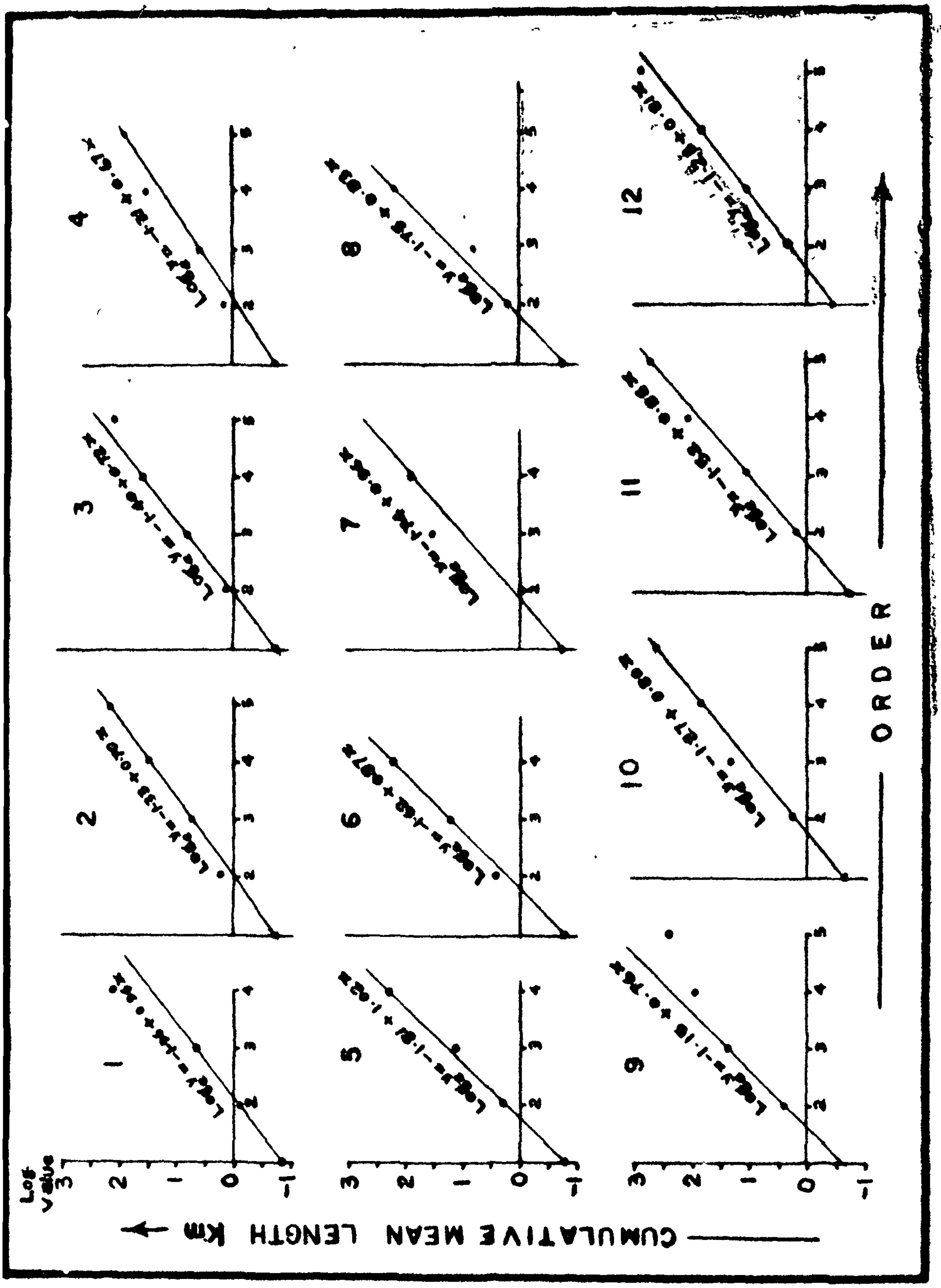


FIG. 4

The deviation of the cumulative stream lengths from the straight line are the impact of various factors. Stream length data from all these twelve basins represent that like the first "law" of drainage composition, geometric regularity is not maintained peffectly for some of the basins as mentioned above. The deviation from the straight line show that, the stream network within the valley is not fully developed. The Fluvial hierarchical relationship is not there for some of the basins, as manifested in the laws of stream numbers, due to difference in geologic structures, lithology, variation in rainfall. Moreover, the stream lengths from the toposheets are measured as if projected on to a horizontal plane. There may be some error in lengths of streams due to instrumental error, personal error and error in map etc.. These technical factors sometime hinders the researcher in getting the exact lengths of various orders of the stream segments.

BIFURCATION RATIO

Bifurcation ratio (R_b) is related to the branching pattern of the drainage net-work. The bifurcation ratio, for a given density of drainage lines, is very much controlled by the shape of the basin and shows very little variation (3 to 5) in homogeneous bedrock from one area to another. Where structural effects cause basin elongation, however, this value may vary appreciably. Apart from influencing the landscape morphometry, the bifurcation ratio is an important control over the 'peakedness' of the run off hydrograph.[4] The bifurcation ratio is defined as the ratio of number of segments of a given order (N_u) to the number of segments of the higher order(N_u+1) and is expressed in terms of the following equation:

$$R_b = \frac{Nu}{Nu + 1}$$

where, Nu = Number of streams of a given order

Nu+1 = Number of streams of the next higher order

Marked regional variation in bifurcation ratios are due to differences in climatic conditions geological and structural characteristics of rocks, relief features and stage of basin development. Horton (1945) has postulated that bifurcation ratio varies from 2.00 in the flat or rolling basins, to 3.00 to 4.00 in the mountainous highly dissected basins. Strahler (1964) has observed that 'because the bifurcation ratio is a dimensionless property and because drainage systems in homogeneous materials tend

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[4] R.J. Charley, The Drainage Basin as the Fundamental Geomorphic Unit, in Fluvial Processes (ed) (1969), p.34.

TABLE – 4.5

BIFURCATION RATIO

Sl No	Name of the Basin	N_1/N_2	N_2/N_3	N_3/N_4	N_4/N_5	Mean (Colm 3 to 6)	Area in sq.km.
1.	[?] C	4.21	3.83	3.00	–	3.74	14.54
2.	Duri ?	4.00	3.64	3.67	3.00	3.58	32.01
3.	[?]anchan C	4.40	3.35	3.00	2.00	3.74	23.00
4.	Dhdi C ([illegible] C)	3.32	3.40	2.33	3.00	3.07	24.52
5.	[?] C.	5.55	6.60	3.00	–	5.07	21.08
6.	Tukchokra C.	3.94	5.57	3.00	–	4.20	14.23
7.	Lasari C.	4.10	6.33	3.00	–	4.50	13.08
8.	[?] C	4.14	4.40	3.0	–	4.31	16.23
9.	Tikjan C.	8.42	4.83	2.5	2.00	5.08	34.43
10.	Nailak C.	4.38	4.44	4.30	2.00	3.97	[illegible]
11.	Hakri N.	4.69	5.36	7.67	3.00	4.13	61.09
12.	Gongos at Geng	3.94	4.57	4.50	3.00	4.00	[illegible]

to display geometrical similarity, it is not surprising that the ratio shows only a small variation from region to region.'.

The bifurcation ratios of all the 12 small selected basins have been calculated and tapresented in Tabld-4.5. The average bifurcation ratios (R_b) of the 12 small selected basins vary from 3.58 to 5.07. The average bifurcation ratios (R_b) of 11 basins confirm the observations of the eminent geomorphologists with special reference to Horton. The average bifurcation ratios of these 11 basins range in between 3.58 to 4.50. The only exception to this is the Dhanai chara a tributary of the Gumti river. This departure is the result of elongated shape of the basin. This basin occupies an area of about 20.84 square kilometer, and its channel length is 15 kilometer, whereas its valley length is 11 kilometer and air length is only 8 kilometer. Its course is comparatively zig-zag. The bifurcation ratio of $N_1/N_2 = 5.55$ and $N_2/N_3 = 6.66$ both are highest of the same group out of all the 12 basins.

Giusti and Schneider (1965)[5] have advocated that bifurcation ratios within a region decrease with the

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[5] E.V. Giush, and W.J. Schneider, The Distribution of Branches in River Networks, U.S. Geol. Survey, Prof. (1965), Paper 422G.

the State and is highest in the alluvium plains of low altitude in the West Tripura, where slope is very gentle to gentle. This means R_b decreases with the increase of steepness of topography (slope). It can be postulated for the state of Tripura that the bifurcation ratio is inversely related to the relief, its dissection and sgructure.

Giusti and Schneider (1965)[6] have further propounded that "basins of equal order but variable areas tend to have the smallest bifurcation ratios in tne smallest areas, the ratio increases with increasing areas upto a certain size beyond which the bifurcation ratios tend to become constant."

There are 5 basins of 4th order and the areas of the basins vary from 14.23 to 20.08 sq. km. and R_b vary from 4.20 to 5.07 and the relationship of area and R_b is perfectly in the cronological order i.e. value of R_b incbeases with the increase of the basin area of the basins of the same order. There are 7 basins of the 5th order of which R_b varies from 3.58 to 4.18 and area varies from 24.92 sq. km. to 61.09 sq. km. and they are also in the cronological order of their area-bifurcation relationship

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[6] E.V. Giusti, and W.J. Schneider, Op.cit.,

TABLE - 4.6

RELATION BETWEEN BIFURCATION RATIO AND AREA

Sl No	Basin	Area of the Basin in Sq.km.	Average R_b	$K=\frac{R_{bn}}{A_n}$	Order of the Basin
1.	Andhar C	14.54	4.34	0.30 (0.298)	4th order
6.	Tuichakma C	14.23	4.20	0.30 (0.295)	-do-
7.	Garam C	15.08	4.50	0.30 (0.290)	-do-
8.	Ganga rai C.	16.23	4.51	0.28 (0.278)	-do-
5.	Dhanai C.	20.08	5.07	0.25 (0.252)	-do-
2.	Juri R.	32.31	3.58	0.11 (0.111)	5th order
3.	Kanchan C.	25.08	3.76	0.15 (0.150)	-do-
4.	Pati C.	24.92	3.67	0.15 (0.147)	-do-
9.	Ekjan C.	34.48	3.68	0.11 (0.107)	-do-
10.	Mailak C.	56.20	3.87	0.07 (0.069)	-do-
11.	Kakri N.	61.09	4.18	0.07 (0.068)	-do-
12.	Bengeswar Gang	60.50	4.04	0.07 (0.067)	-do-

Serial number of the basin as is indicated in all other basins has been indicated for grouping of the basins in 4th and 5th order.

$K=R_{bn}/A_n$ has been used by the author, which is based on the hypothesis developed by Guesti and Schneider (1965), Paper 422.

with a very negligible deviation. The deviation is in respect to the relation of lowest area and lowest R_b, it would have been less than 3.58 but it is more than the lowest R_b by 0.09 only. This minor deviation in the cronological relation of the Area and R_b may be attributed to the instrumental error, personal error in addition to the variation in geological structure of the north-eastern Tripura which is very much complex and vary within a short distance. This can easily be postulated for the state of Tripura that $R_b \propto A$ where R_b = bifurcation ratio and A = Area.

Thus mathematically the postulation of Giusti and Schneider is represented to indicate the relationship of the bifurcation ratio and the area of any particular order within a certain limit. An attempt is also made to find out the constant value by using the formula given below:

$$R_{bn} \propto A_n$$

or $R_{bn} = KA_n$

or $K = \frac{R_{bn}}{A_n}$ Where R_{bn} = Bifurcation ratio of any basin of nth order

or $K \propto \frac{1}{A}$ An = Area of the basin of nth order

or $A \propto \frac{1}{K}$ K = a constant for nth order basins

From the Table-4.5, it is seen that value of K for Andhar chara, Tuichakma chara and Garam chara is 0.30 and all are having almost equal area. Again 3 other basins viz. Mailak chara, Kakri N. and Bengeswar gang has 0.07 R_b and all are of almost equal area. Ekjar chara and Juri Nadi have 0.11 R_b and almost equal area, similar is the case of Kanchan chara and Patichara. Thus iti is postulated that in Tripura Area is inversely related to K i.e. (R_b/A) for the basins of any particular order.

SINUOSITY INDICES

The shape of the open link in terms of geomorphic structure of drainage lines involves the calculation of departure of observed path (O_L) from the expected path (E_L) of a stream from its source to its mouth. It is supposed that the expected path of the river will be in a straight line. The calculation of such deviations presents a great problem because "it is not always clear where the terminating points for the observations should be located."[7] Practically, the straight line path of a stream is never possible because it is affected by a number of causative factors which force the drainage line to deviate from its straight line expected path. The factors include Geological and hydrological controls,

[7]Hagget and Chorley, Fluvial Process in Geography, (1969), p.59.

dip angles, slopes, absolute relief, relative relief, degree of dissection, stage of valley development, etc. Sinuosity indices of the drainage lines help in studying the effect of terrain over river course and vice-versa.

The sinuosity indices of streams have been very much in use in understanding the geomorphological character of a region. The usual approach is to derive the index as a ratio between the channel length (C_L) of a reach and its valley length, thus, limiting the use of streams which have developed flood-plains. This restricts the analysis to speaking of hydraulic action as the sole performer of sinuosity limited to matured and old streams. As a result, the young streams whose valleys and channels are coincident, give the sinuosity index as unity thereby suggesting complete topographic control of the streams, which is an obvious flow in interpreting topography in relation to the character of drainage, because of hydraulic action that exists in most of the youthful streams owing to structural controls, rejuvenation and greater amount of precipitation in the catchment area. All streams with a value of unity are not sinuous, i.e. straight, because all streams have some amount of departure from a straight line course in what-so-ever stage and reach they are.

TABLE - 4.7

SINUOSITY INDICES

Sl No	Basin	C.L in km	Air_L in Km	V_L in km	C.I. (3/4)	V.I. (5/4)	H.S.I. $\frac{CI-VI}{CI-I}$	T S I $\frac{VI-I}{CI-1}$	CL/V_L (3/5)	Remarks
1.	Andhar C	7.90	6.30	7.10	1.25	1.12	0.520	0.480	1.111	
2.	Juri R	15.0	12.25	13.00	1.23	1.06	0.739	0.261	1.152	
3.	Kanchan C	11.05	7.10	8.70	1.56	1.22	0.607	0.393	1.273	
4.	Pati C (Machhmara)	9.85	8.30	8.70	1.19	1.05	0.737	0.263	1.136	
5.	Dhanai C	11.85	6.30	8.70	1.88	1.38	0.568	0.432	1.364	
6.	Tuichakma C	7.90	5.50	7.10	1.43	1.28	0.349	0.650	1.111	
7.	Garam C	7.50	6.30	7.10	1.19	1.12	0.368	0.632	1.056	
8.	Gangarai C	9.00	6.50	8.00	1.38	1.23	0.395	0.605	1.125	
9.	Ekjan C	24.00	11.50	19.00	2.09	1.65	0.404	0.596	1.263	
10.	Mailak C	26.00	16.00	20.00	1.62	1.25	0.597	0.403	1.300	
11.	Kakri N	17.00	11.00	14.00	1.55	1.27	0.509	0.491	1.214	
12.	Bengeswar Ganj	22.00	14.00	17.50	1.57	1.25	0.204	0.439	1.257	

Smart and Surken (1967) measred the unsystematic deviations from a straight line paths and curves of considerable symmetry, whose dimensions were proportional to the size of the channel and they recognized two types of shapes of a drainage line viz. (i) Wandering and (ii) Meandering. The Wandering path may be calculated by relating to the length of the observed path (O_L) to the length of the expected path (E_L). Schumm (1956) after measuring the deviations from a straight line path presented 5 categories of channel sinuosity viz., (i) Straight = O_L/E_L = 1.00 (ii) Transitional (iii) Regular, (iv) Irregular and (v) Tortous = (OL/E_L) = > 2) (Fig. I).

Muller 1968[8] modified the difficulties found in Schumm's method and presented his model of sinuosity index. The model explains the effect of hydraulic and topographic controls on the courses of the streams. He measured the length of the channel (C_L), the length of the valley between the base of the valley walls (V_L) and the shortest distance between the source and mouth of the river (Air_L) and presented his model.

The present study aims at the application of Muller's

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[8] J.E. Muller, An Introduction to the Hydraulic and Topographic Sinuosity Index, A.A.A.G., Vol. 58, No.2 (1968).

model of sinuosity indices for all the 12 basins of Tripura The river courses are classified into three categories on the basis of the standard sinuosity index viz. (i) Straight course (SSI = 1.00) (ii) Sinuous course (SSI = 1.00-1.50) and (iii) Meandering course (SSI = $>$ 1.50)

It is apparent from the Table-4.7 that the channel Index (CI) and valley Index (VI) of six of the basins viz Andhar chara, Juri Nadi, Pati Chara, Tuichakma chara, Garam Chara and Ganga rai chara have both CI and VI less than 1.50, whereas CI of Ekjan chara has highest C.I out of all the basins.

S.S.I of Juri Nadi and Tuichakma chara has equal sinuosity Index of Sinuous Course i.e. 1.111 and all the 12 basins are within the second category of SSI i.e. 1.00 to 1.50 indicating sinuous course of the streams.

The H.S.I and T.S.I are the valuable morphometric tools which help in determining the controlling factors of sinuosity. From the table-4.7 it is seen that 4 basins viz. Tuichakma chara, Garam C. Ganga rai chara and Ekjan chara has the high topographic sinuosity index ranging from 0.60% to 0.65% and the rest 8 basins have TSI ranging from 0.26% to 0.49%. This indicates that 4 basins as mentioned above are in their early stage of basin development.

Lowest Topographic sinuosity index is indicated by the Juri N. and Pati chara i.e. 0.26% which means that these two are the oldest amongst all the twelve basins. Similarly Tuichakma may be described as the youngest. The 6-basins viz. Juri Nadi (0.74%), Kanchan chara (0.61%), Pati chara (0.74%), Mailak chara (0.60%), Dhanai chara (0.57%) and also Kakri Nadi (0.51%) are of high percentage of H.S.I. indicating their mature stage of basin development.

LINEAR AND AREA ASPECTS OF THE BASINS

Drainage Density

It is recognised as a topographic characteristic of fundamental significance. The stream network density is a sensitive parameter which in many ways provides the link between the form attributes of the basin and the processes operating along the stream course. Uniformity of the D_d means proportional flow of streams to the length of water course in a basin, because channel flow is much more rapid than the alternative flow on, or beneath slopes. The extent and density of the network reflect topographic, lithological, pedological and vegetational controls, and because they also incorporate the influence of man.

Use of maps of varying scales and degree of detail, or photographs taken at different seasons, produce divergent results, especially in areas where seasonal stream flow is marked characteristic and the definition of drainage lines not always without ambiguity.

Thus, figures such as those given by Selvey (1967-A)[9] show that measures of drainage density may vary by a factor of 10^3, and are very difficult to compare. Lithology and relief development as well as climate and vegetation cover, area major controls. Thus, in semi-arid areas drainage density over poorly consolidated shales may rise into hunds reds of Kilometer of terrain, whilst in humid temperate areas with a forest or woodland vegetation cover, figures tend to vary from 1.8 - 5.6 km/km^2 (Selbey 1968).[10] For the present study, the drainage density of 12 small selected drainage basins have been calculated by using the following formula as suggested by Horton (1945)[11]

$$D_d = \frac{\sum_{i=1}^{K} \sum_{J=1}^{N} Lu}{Au}$$

Thus, Dd is simply the ratio of total channel segment lengths cumulative for all orders within 6 basin to the basin area. Drainage density of the 12 basins ranges

[9] Doornkamp and King, Numerical Analysis in Geomorphology - An Introduction, (1971), p.372.

[10] M.J. Selbey, Morphometry of Drainage Basins in Areas of Pumice Lithology, (1968), pp.169-74.

[11] R.E. Horton, Op.cit., p.283.

from 3.18 to 4.50 km/Km^2. The lowest Dd is of Mailak chara i.e. 3.18 km. per Km^2 whereas the highest Dd is of Pati-chara i.e. 4.50 km. per Km.^{2} Regions of high permeability, low relief, dense vegetation cover may be responsible for the low Dd of Ekjan chara (3.51 km. per km.^{2}) and that of Mailak chara (3.18 km. per Km^2). Impermeable sub-surface materials, sparse vegetation and mountain relief, is responsible for the high drainage density. (Fig. V A & B).

Peltier (1962)[12] in pilot study undertaken from the analysis of large numbers of topographic maps, found that there was a much steeper rise in drainage density with increasing mean slope in tropical areas than any other climatic zone. Since increasing mean slope will usually be accompanied by increase in absolute attitude, local relief and valley side slopes, it is likely that total precipitation amount and regolith type and depth will be major factors accounting for these figures.

In the present study also the impact of above elements are clearly noticed. It is noticed from the relief map that it increases from the west to the east along with the increase of altitude and varied topography.

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[12] L.C. Peltier, Area Sampling for terrain Analysis, (1962), pp.24-28.

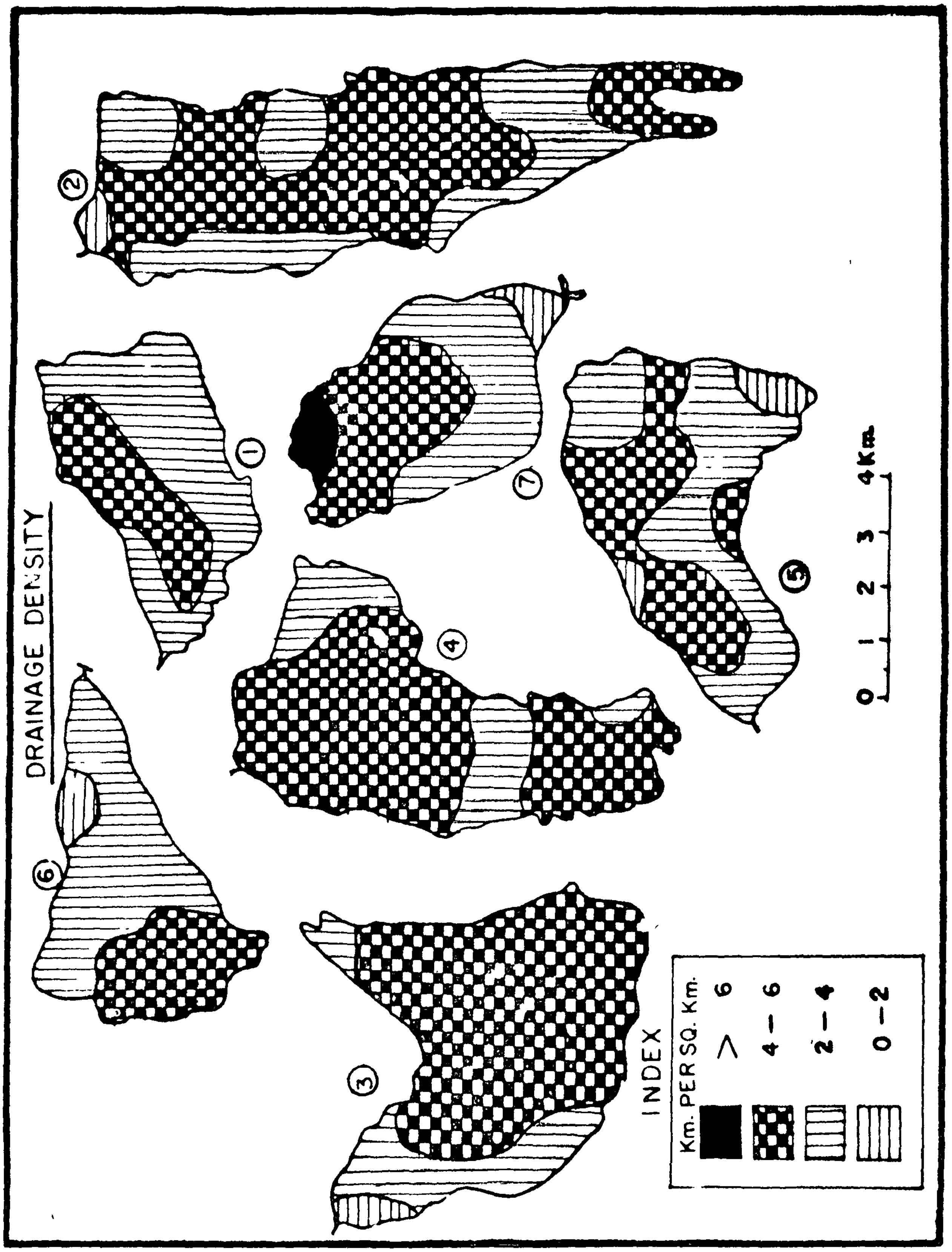
DRAINAGE DENSITY
1
2
3
4
5
6
7
INDEX
Km. PER SQ. Km.
> 6
4 — 6
2 — 4
0 — 2
0 1 2 3 4Km.

FIG.5-A

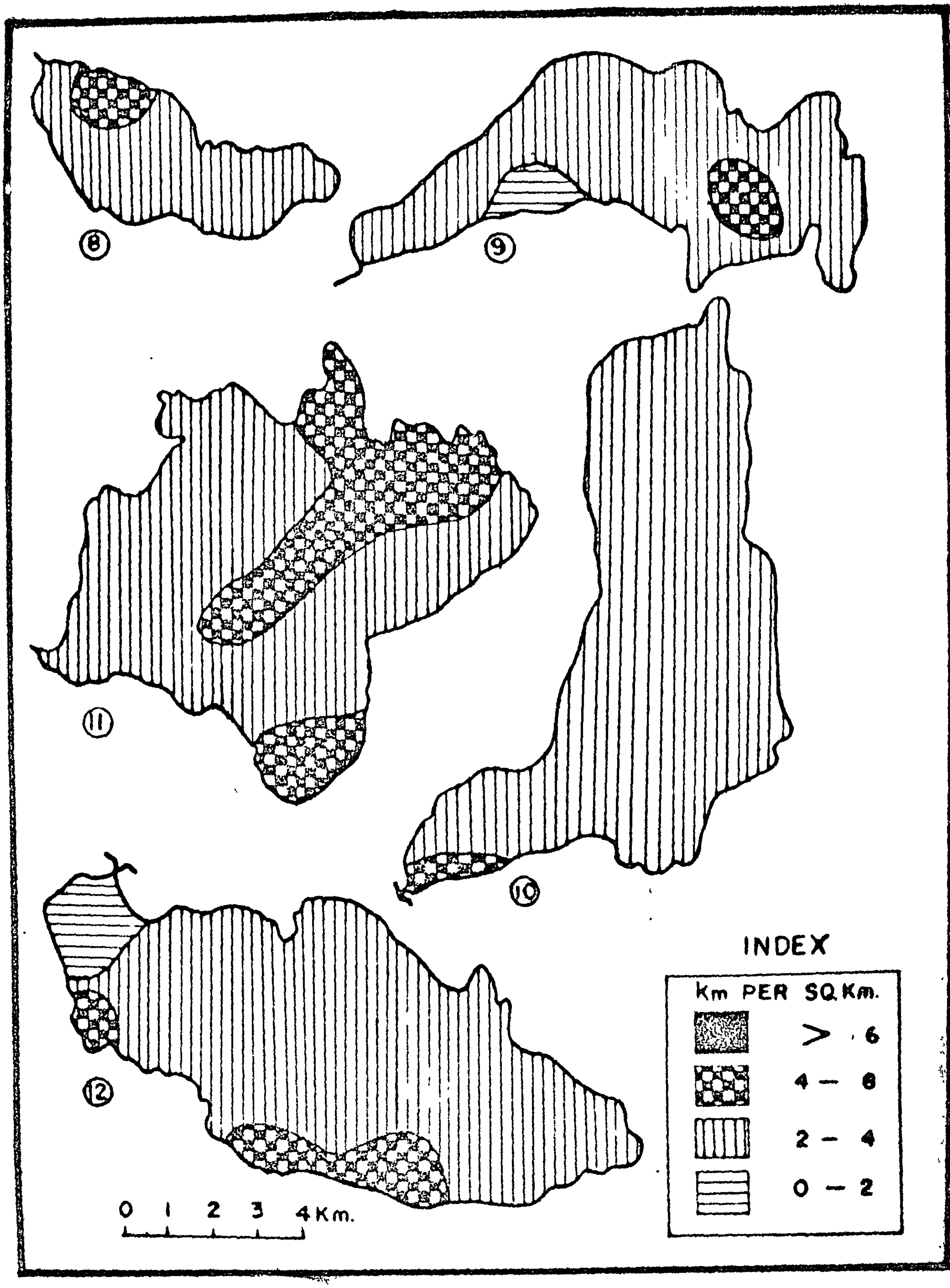

FIG.5-B

Drainage density is very closely related to the texture, structure and geologic formation of the areas where the streams adjust their course in the initial stage and develops with the lapse of time.

Drainage density of Tripura has been calculated with the help of the formula as referred above. For the purpose of mapping from categories viz. (i) Coarse, (ii) medium, (iii) High and (iv) Very High are done and accordingly isopleths are drawn. These categories are done for the micro-level analysis of the study area. Drainage density may be defined for this study as the streamlength in Km. per square km. and the categories range from 0-2, 2-4, 4-6, and more than 6 respectively for coarse, medium, High and Very High. From the Table-4.8 it is seen that out of 12 basins, 4 basins has no coarse Dd; out of the rest except Bengeswar Gang (4.26 sq. km) and Ekjan chara (2.65 sq. km.) all other 6-basins have very negligible area under this category. Under the medium category area varies from 21.93% to 97.8%. Another Chara of Dharmanagar Sub-division in the North Tripura district has 65.96% of its area under this category and it has no area under the coarse category. Four basins have more than 80% area under this category viz. (i) Gangarai C. (87.68%), (ii) Ekjan C. (84.77%), (iii) Mailak C. (97.80%) and (iv)Bengeswa

TABLE - 4.8

DRAINAGE DENSITY (Km Per Sq. Km) AREAL ASPECTS

Sl No	Basins	Area in Sq. km.	8 - 2 (Coarse)	2 - 4 (Medium)	4 - 6 (High)	7 - 6 (Very high)
1.	Andhar C.	14.54	-	9.59 (65.96%)	4.95 (34.04%)	-
2.	Juri R.	32.31	0.55 (1.70%)	12.50 (38.69%)	19.26 (59.61%)	-
3.	Kanchan C.	25.08	0.82 (3.27%)	5.50 (21.93%)	18.76 (74.80%)	-
4.	Pati C	24.92	-	5.85 (23.48%)	19.07 (76.52%)	-
5.	Dhanai C.	20.08	1.50 (7.48%)	10.20 (50.80%)	8.38 (41.72%)	-
6.	Tuichakma C	14.23	1.00 (7.03%)	8.73 (61.35%)	4.50 (31.62%)	-
7.	Garam C.	15.08	0.95 (6.30%)	6.70 (44.43%)	6.00 (39.79%)	1.43 (9.48%)
8.	Gangarai C.	16.23	-	14.23 (87.68%)	2.00 (12.32%)	-
9.	Ekjan C.	34.48	2.65 (7.69%)	29.23 (84.77%)	2.60 (7.54%)	-
10.	Mailak C.	56.20	- (	54.96 (97.80%)	1.24 (2.20%)	-
11.	Kakri N.	61.09	-	43.14 (70.62%)	17.95 (29.38%)	-
12.	Bengeswar C.	60.50	4.26 (7.04%)	50.64 (83.70%)	5.60 (9.26%)	-

Figures within parenthesis indicate area in percentage to the total area of the basin.

Gang (83.76%) and 3-basins viz. Andhar C. Dhanai C. and Tuichakma C. has more than 50% of their area under the medium category. The rest 5 basin have also areas under this category ranging from 21.93% to 44.43%. Thus it is seen that maximum areas of the basins are under this category. High D_d prevails only in the basins of the North Tripura District viz. Pati chara (76.52%), Kanchan Chara (74.80%), Juri Nadi (59.61%) whereas the lowest area under this category is covered by the Mailak Chara of the South Tripura district i.e. (2.20%). The basins of the West Tripura district ranges their areas in % from (9.26%) to 41.72%, whereas the 3-basins lying in the South Tripura district has the minimum percentage of their area in this category with exception to Garam Chara (39.79%) viz. Mailak C. (2.2%), Ekjan C. (7.54%). It may not be the out of place to mention that Garam chara is an exception to the general rule which is followed by the other 11 basins due to various factors viz. Baramura hill range forms its watershed in the South-Western part at an altitude of 259m, some prominent hot-springs are present under this basin, sharp difference in geological structure in its source area (Tipam) and in its mouth (Surma) where it joins the Gumti River. Very high drainage density is available only in case of Garam chara i.e. also only 1.43 sq. km. area i.e. 9.48% of its total area which lies only in its source.

Thus it is observed that in this region Dd is either medium or high. Again if the grouping is done according to the classification given by the Strahler and Smith there exists only two categories i.e. Coars and medium. In Tripura steepness of slope increases from West to East or more precisely from South ~~to~~ West to North-East. Space occupied by the basins are less in comparison to the basins of West Tripura. Within this small area there exists varied geological structure.

Andhar chara is situated in an area where slope ranges from 0-5^{o} and Dupitila Group of rocks whereas in the southern side of this basin there are 3 more basins viz. Muri N, Kanchan C and Pati chara lies in the category of 5-10^{o} slope and geologically of Tipam and Surma formations. Moreover altitude of these three basins are higher in comparison to the Andhar chara. The factors as stated amongst others are mainly responsible for Andhar chara's low percentage of area i.e. 34.04% in comparison to 3 other basins of the same district, whereas these 3-basins consists of 59.61% to 76.52% of their areas under the high Dd i.e. 4-6 km. per sq.km.

Similarly Bengaswar Gang has highest area (4.26 sqk.km.) of the coarse (0-2) category of drainage density due to its graded course in the mouth area where it joins the Haora River. The area under the basin is geologically of Tipam formation and also of very low altitude about 20m and texture is coarse. Average rainfall of the Sonamura Sub-division of the West Tripura during the recent years is about 100 cm[13] less in comparison to the average rainfall of Dharmanagar Sub-division of the North Tripura district, which means rainfall increases from the South-west to North-East, just like slope. Thus, general observation is that Drainage Density increase from the South-west to the North-East of the state of Tripura. Dd is highly correlated to S_F (0.73) and has positive relation to R_b (0.12). It has negative relation to all other 20 variables Table-4.12 which ranges from -0.004 to L_4 to -0.99 to CCM which has an inverse relation to it.

With relation to texture ratio, Smith(1950)[14] and Strahler (1957)[15] described drainage density values (i) less than 5.00 as coarse (ii) between 5.00 to 13.7 as medium (iii) between 13.7 and 155.3 as fine, and (iv) greater than 155.3 as ultra-fine (Fig. V-A & B). As texture may also be represented by the relative closeness of the drainage net work i.e. Dd. Thus a high Dd results

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[13]Mean of 21 years rainfall of Agartala is 212.72cm, of Sonamura 242.37cm and that of Dharmanagar is 268.90cm (1950 - 1973, data for 1958, 1958, 1960 not available).

[14]K.G. Smith, Standards for Grading Texture of Erosional Topography (1958), pp.655-668.

[15]A.N. Strahler, Quantitative Analysis of Watershed Geomorphology, Vol. 38 (1957), pp.914-918.

in fine texture and a low Dd in coarse texture. The Table-4.8 reveals that all the 12-basins have less than 4.5 drainage density and belongs to the coarse category as classified by Smith.

Constant of Channel Maintenance

Schumm (1956)[16] used the inverse of drainage density as a property termed CCM.

$$\text{Thus CCM} = \frac{A_u}{\sum_{i=1}^{K} \sum_{i=1}^{N} L_u} = \frac{1}{D_d}$$

Specifically, the CCM tells the number of sq. miles or kms. of watershed surface required to sustain 1 linear mile or Km of channel. For the present study, the CCM for all the 12 basins have been computed and represented in the Table-4.9.

It is seen that Mailak chara requires 0.31 sq. km. of watershed surface to maintain 1 km. length of stream, is the highest and the Pati chara requires the lowest area i.e. 0.22 sq. km. to maintain 1 km. length of stream. There exists an inverse relationship between the CCM and Dd. Relief controls both Dd and CCM i.e. higher the relief higher is the drainage density and lower is the CCM value

[16] S.A. Schumm, Op.cit., pp.597-646.

TABLE - 4.9

DRAINAGE DENSITY, CONSTANT OF CHANNEL MAINTENANCE AND STREAM FREQUENCY

Sl No	Basins	Dd (Km/Km^2)	CCM (1/Dd)	SF (N/A)
1.	Andhar C	3.80	0.263	7.22
2.	Juri N.	3.97	0.252	6.65
3.	Kanchan C.	4.14	0.242	7.58
4.	Pati C.	4.50	0.222	7.95
5.	Dhanai C.	4.03	0.248	6.72
6.	Tuichakma C.	4.40	0.227	6.18
7.	Garam C.	3.95	0.257	6.76
8.	Gangarai C.	4.28	0.234	7.33
9.	Ekjan C.	3.51	0.285	4.67
10.	Mailak C.	3.18	0.314	4.18
11.	Kakri N.	3.68	0.272	5.75
12.	Bengeswar Gang	4.23	0.236	5.52

Y

and vice versa. In this study all the small basins are within the conformity of the Schumm's formula for $CCM=\frac{1}{Dd}$. There is high negative correlation between Dd and CCM i.e. -0.99. Constant of channel Maintenance (CCM) ranges its value from 0.222 to 0.314. Pati Chara has the lowest CCM (0.222) and Mailak chara has the highest CCM (0.314) whereas reverse is the case of drainage density for both the basins. Almost all the characteristics of Dd reversely stands for the CCM because of their mathematical inverse relationship i.e. Dd $\propto \frac{1}{CCM}$

Stream Frequency (F_S)

Horton (1945)[17] introduced S_F for channel frequency. F_S as the number of stream segments per unit area. Melton (1958)[18] analysed in detail the relationship between drainage density and stream frequency, both of which measured the texture of the drainage net, but each of which treats a distinct aspect. He derived the equation:

$$F = 0.694\ D^2$$

And from this the dimensionless number F/D^2, which tends to approach the constant value 0.694 despite as variations in linear scale. Stream frequency is calculated by the total number of streams in a drainage basin divided by the total area of the basin. For the small arbitrary units S_F is calculated by the total number of streams in an unit area in a given drainage basin.

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[17] Ibid., p.285.

[18] M.A. Melton, Geometric Properties of Mature Drainage Systems and their representation (1958), pp.35-54.

$F_S = N/A$

where F_S = the stream frequency

N = total number of streams in an unit area

and A = the unit area.

Method of Study

For the present study the later method has been applied. Seven basins viz. Andhar chara, Juri N., Kanchan Chara, patichara, Dhanai Chara, Tuichakma chara and Garam chara has been traced from the 2Cm = 1Km i.e. 1: 50,000 scale map and the rest five basins has been traced from a" = 1 mile i.e. 1: 63,360 scale of map as because map of 1: 50,000 is not available for the whole study area. Any way for this paper all the calculations are done in matric system. For the 1:50,000 basins the basin areas are divided into 1 Cm grid lines and for the 1: 63,360 scale of map the grid lines are done in ½" difference. For the first 7-basins as tabulated for all purposes number of streams crossing per 1 square km. is directly achieved and for the other 5-basins number of streams crossings were divided by 0.66 to achieve the stream crossings per square km. Then for all the basins the S_F are grouped into the 4 categories viz. (i) 0-4, (ii) 4-8 (iii) 8-12 and (iv) 12 and above and accordingly isopleths area drawn. Areas under each basin for each category has been measured with the help of plainmeter and also the percentage of all the areas under each S_F category are computed and tabulated in the Table-4.10.

LINEAR AND AREAL ASPECT OF STREAM FREQUENCY

(i) Coarse (0-4)

In this category percentage of area of individual basin varies from 6.45% to 21.14%. In respect to area 2.4 sq. km. area occupied by 0-4 S_F category of Ekjan chara- out of 34.48 sq. km. of its total area, whereas 11.88 sq.km. is the highest area occupied by this category of S_F out of 56.20 sq. km. of area of Mailak chara. Mailak chara has highest area under 0-4 S_F group both in respect to actual area and also in respect to percentage of area to total area. Out of 12 basins,6 basins viz. Andhar C, Pati chara, Tuichakma chara, Garam chara, Gangarai chara and Kakri Nadi has no area under this category.

(ii) <u>Medium</u> (4-8 SF)

The category of S_F is prevalent in all the basins where actual area of individual basin varies from 0.95 to 56.60 sq. km. In percentage also the basins occupy their position between the (3.79%) and highest (93.55%) percentage

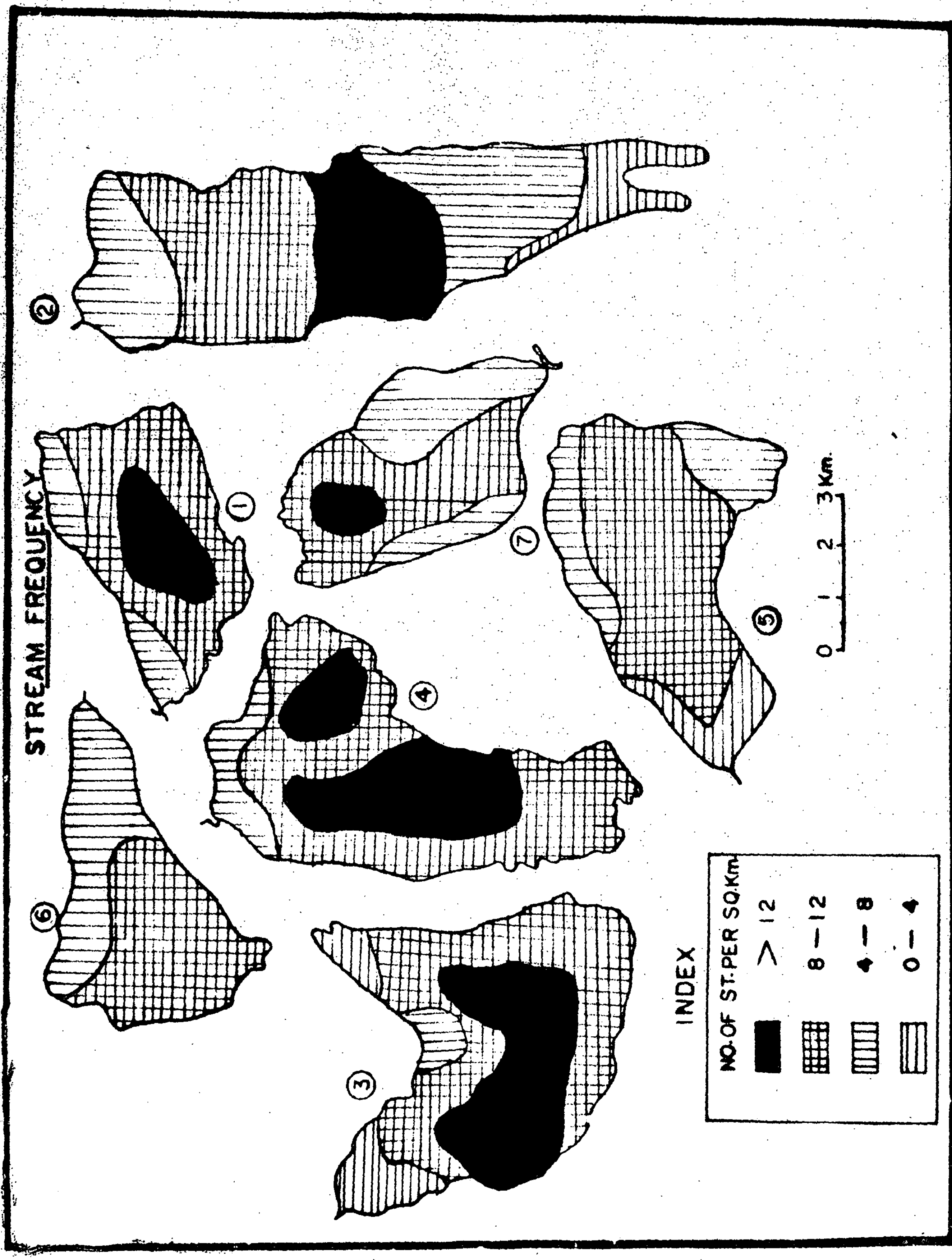
STREAM FREQUENCY
INDEX
NO. OF ST. PER SQ.Km
> 12
8 — 12
4 — 8
0 — 4
0 1 2 3 Km
1
2
3
4
5
6
7

FIG. 6-A

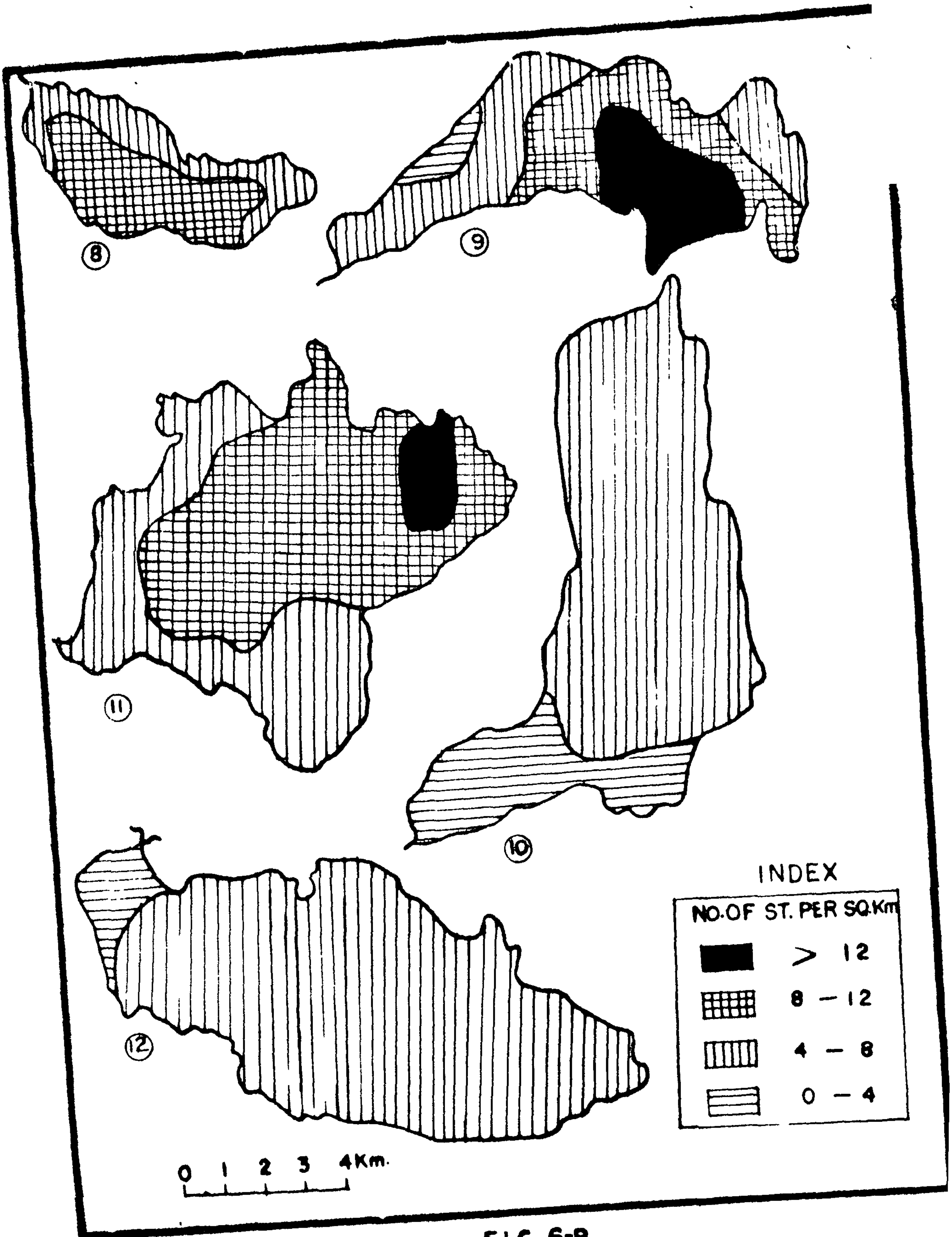

FIG. 6-B

TABLE - 4.10

LINEAR AND AREAL EXTENT OF STREAM FREQUENCY

Sl No	Basins	Area in Sq. km.	Coarse (0 - 4)	Medium (4 - 8)	High (8 - 12)	Very High (12 and above)
1	Andhar C	14.54	-	1.25 (8.60%)	9.70 (66.71%)	3.59 (24.69%)
2	Juri Nadi	32.31	4.15 (12.84%)	12.20 (37.76%)	10.00 (30.95%)	5.96 (18.45%)
3	Kanchan Chara	25.08	3.00 (11.96%)	0.95 (3.79%)	11.89 (47.41%)	9.24 (36.84%)
4	Pati "	24.92	-	3.20 (12.84%)	12.72 (51.04%)	9.00 (36.12%)
5	Dhanai "	20.08	2.50 (12.45%)	4.40 (31.91%)	13.18 (65.64%)	-
6	Tuichakma "	14.23	-	6.50 (45.68%)	7.73 (54.32%)	-
7	Garam C "	15.08	-	6.50 (43.10%)	7.08 (46.95%)	1.50 (9.95%)
8	Ganga Rai "	16.23	-	6.65 (40.97%)	9.58 (59.03%)	-
9	Ekjan "	34.48	2.40 (6.96%)	15.04 (43.62%)	9.39 (24.23%)	7.65 (22.19%)
10	Mailak "	56.20	11.88 (21.14%)	44.32 (78.86%)	-	-
11	Kakri Nadi	61.09	-	20.80 (34.05%)	37.09 (60.71%)	3.20 (5.24%)
12	Bengeswar Gang	60.50	3.90 (6.45%)	56.60 (93.55%)	-	-

Figures within Parenthesis indicate area in percentage to the total area of the basin.

of area. It is seen that Kanchan chara occupies very small area i.e. 0.95 sq. km. (9.79%) of its total 25.08 (100%) sq. km. and Bengeswar Gang has 56.60 sq. km. (93.55%) of its 60.50 sq. km. area

(iii) <u>High</u> (8-12 S_F)

Two basins i.e. Mailak chara and Bengeswar Gang has not covered by this category. The least area occupied by the Garam chara is 7.08 sq. km. (46.95%) and highest by Kakri Nadi 37.09 sq. km. (60.71%). In respect to percentage, Ekjan chara has least percentage i.e. (24.23%) and Andhar chara has 66.71%. The basins under this stream frequency group has maximum area. Out of 10 basins under this S_F category 6 basins have more than 50% area under this category ranging from 51.04% of Pati chara to 66.71% of Andhar chara. The basins under the group are Andhar chara, Pati C. Dhamai chara, Tuichakma chara, Ganga Rai chara and Kakri Nadi. Other four basins Juri Nadi (30.95%) Kanchan chara (47.41%), Garam chara (46.95%) and Ekjan chara (24.23%).

(iv) <u>Very High</u> (12 and above)

In this category 5-basins have no account of their area viz. Dhanai chara, Tuichakma chara, Ganga Rai chara, Mailak chara and Bengeswar chara and all these basins are in South-West Tripura. Highest stream frequency is being observed in the basins of North Tripura District (Sl.Nos. 1, 2, 3 and 4) and lowest in the West Tripura district (Sl. 9, 10, 11 & 12). Similarly basins of the Central Tripura (Sl. Nos. 5, 6, 7 & 8) has intermediate S_F i.e. 4-8 and 8-12 categories in between 0-4 and 12 and above groups. In Tripura homogenity of rock structure and lithology decreases from South-West to North-East with increase of altitude and similarly complex city of rock structure increases. In other words structural, geological and lithological homogenity increases from East to West with the decrease of altitude, steepness, vegetation and rain. The amplitude of river valleys in the North, North-East are less in comparison to the western rivers, because the basins in the North Tripura are being bounded by the high parallel North-South trending ridges and again the ridges are being compressed by the compressional forces; and steepness increased due to folding and faulting. In some pockets of the North-East Tripura there is lime-stone of inferior quality with parallel and trellis drainage system. The combined affect of all the geomorphic elements that are stated and also that remained unstated are responsible for the development of the systematic differential stream frequency from South-West to the North-East and also in various parts of the State.

It is seen from the Table-4.10 that only 4-8, S_F category is present in all the 12 small selected basins of the study region. Again out of all these only 3-basins viz. Juri Nadi, Kanchan chara and Ekjan chara has all the categories of S_F. Kanchan chara of Kailashahar Sub-division of the North Tripura District has the highest area both in actual and in percentage under the very high S_F category i.e. 9.24 sq. km. (36.84%).

Analysis of Spatial distribution of Stream

Stream frequencies as classified and tabulated Table-4.8 into 4 categories are represented below :-

1) Coarse (0-4)
2) Medium (4-8)
3) High (8-12) and
4) Very High i.e. 12 and above.

The drainage density have also been classified into 4 categories Table-4.8 which are again given below to find out its correlation to the stream frequency i.e.

1) Coarse (0-2)
2) Medium (2-4)
3) High (4-6) and
4) Very High (6 and above).

Both Dd and S_F of all the 4th and 5th order basins are calculated and their average values are 3.94, 6.84 for the 4th order and 3.89, 6.04 for the 5th order basins respectively. It is observed that both Dd and S_F of 4th order basins are higher than that of 5th order basins. It is computed and found that D_d of the 4th order basins in comparison to the 5th order basins are higher by 29% but the S_F of 4th order basins are higher by 13.25%. Thus it can be said that lower order basins have higher stream frequency but higher drainage density.

From the Table-4.9 if a comparative study of Dd and S_F is done it is reckoned that basins having more than 7.S_F have more than 4 Dd with exception to Andhar chara. The reason of this exception is mainly geological structure and low altitude and low rainfall in this basin. Pati chara has highest 7.95 S_F which has also the highest drainage density. Similarly Mailak chara has the lowest stream frequency (4.18) which also has lowest drainage density (3.18). Average value of S_F for all the basins are calculated in respect to their location in the district and the results are tabulated below.

It is seen from the Table-4.11 that stream frequency of the basins locating in the South-Tripura district is lowest i.e. 5.20 and that of North Tripura district is the highest i.e. 7.35. Stream frequency of the West Tripura District is 6.30 which is almost mean of the lowest and highest value. Thus it can truly be mentioned that stream frequency (S_F) increases from the South-west Tripura to the North-East Tripura as the same phenomena is being observed for the Dd i.e. drainage density. The stream segments of the South-West Tripura are elongated and well developed in comparison to the streams of the North Tripura, which may be attributed to the degree of homogenity in the geological strata. West Tripura is homogeneous in its geological formation which is alluvium whereas complex geological formations are in the east Tripura. It can mathematically be stated that stream frequency (SF) increases from South-West to North-East where as the stream length (S_L) decreases (Table-4.11) Altitude of the basins increases from South-West (about 20 m) to North-East (about 800 m). It is seen that basins of low altitude has high Dd and low S_F and reverse is the case in case of the basins of the North-East Tripura i.e. high altitudional places. Thus it can be said that S_F is to some extent controlled by the altitude of the basins and the phenomena may be mathematically be represented as $SF \propto A$, where S_F = Stream frequency, A = Altitude of the basin area. This means that areas of high altitude

TABLE - 4.11

DISTRICTWISE AVERAGE DRAINAGE DENSITY (Dd) STREAM FREQUENCY (S_F) AND STREAM LENGTH (S_L)

Sl No	District	Sl Nos of Selected Basins	Average Dd	Average S_F	Average length of stream(Dd/S_F)
1.	North Tripura District	1, 2, 3 and 4	4.10	7.35	0.56 Km
2.	West Tripura District	5,6,8,11 and 12	4.12	6.30	0.65 Km
3.	South Tripura District	7,9 and 10	3.26	5.20	0.63 Km
4	Average of all the selected basins		3.83	6.28	0.61 Km

has less developed drainage system. The correlation metrix indicates high correlation between drainage density and stream frequency i.e. 0.73.

Factors Affecting S_F

There are two main factors that may affect the Sf viz. (i) Natural factors and (ii) Map factors.

Natural factors are such as -

(i) Climate

(ii) rock structure and its characteristics

(iii) Relief

(iv) Infiltration Capacity and

(v) Vegetation etc.

(vi) slope angle

Again map factors are of two types - viz. (i) Scale of map e.g. smaller is the scale of map larger is the scope of error (ii) Personal error of the map maker and instrumental error.

SLOPE (θ^{o})

The idea of cycle development, stresses, gradual change in the evolution of slopes from the high altitudinal places to the places of levelled surface. As in the case of peneplain the Davisian concept of 'Old age' indicates great areas of low land with minor undulations. Masses of more resistant rocks stand out as "erosional survivals" known as monadnocks. G.K. Gilbert (1877) has used the term 'Dynamic equilibrium' which indicates the fundamental modification of Davisian Geomorphology. He had emphasised on the active links between the process and form in explaining any particular land-form. Such an equilibrium may be indicated by constant angles of slope within a small region of uniform relief, rock type, climate and vegetation. Perrault first discovered that adequate supply of water and slope is the necessary condition for the initiation of a river.

In India automatic recording devices for measuring slope profiles are not available, at least for the research purpose. The system is a rotating drum on which the angle of slope and distance travelled are recorded as the instrument is pulled up or down. Slope profiles provide information about the angle of slope along a measured length within a complete profile.

Savigear (1960) had suggested 3 types of slopes i.e. (i) foot slope, (ii) back slope and (iii) crest slope.

Gregory and Brown (1966) had suggested that geomorphological units may be located with respect to 3 major slope types, viz.,

(i) Stream-side slopes (stream to a free face low-down the hill side)

(ii) Valley side slopes (stream side to the top of the valley side)

(iii) Summit slopes (from the top of the valley side slopes to the interfluve summit).

Method of Study

The method suggested by Wentworth (1930) and modified by Zakrzewska (1967) has been used for computation of slopes for all the 12 selected basins of which 5 basins are in one inch to one mile scale and the rest in two centimetre to one kilometre scale toposheets. The details of the method are as explained in the chapter on slopes. These two different methods are used for the preparation of the slope maps, because of the fact that the whole study region is not covered by the 1:50,000 scale of topographical survey.

Slope Analysis

All the values of slope units are calculated in degree and it is seen that the basin areas are covered by the 0-25^{o} slopes. Five groups of slopes-categories are tabulated in the Table-4.12.

(I) 0^{o} - 5^{o} (gentle)

(ii) 5 - 10^{o} (Moderate)

(iii) 10 - 15^{o} (Moderately steep)

(iv) 15 - 20^{o} (Steep) and (v) More than 20^{o}(very steep

TABLE - 4.12

AREAL EXTENT OF SLOPE UNITS

Sl No	Basins	Total area in Sq. km.	$0 - 5^0$ (Gentle)	$5 - 10^0$ (Moderate)	$10^0 - 15^0$ (Moderately Steep)	$15^0 - 20^0$ (Steep)	20 Very Steep
1	Andhar C	14.54	-	1.65 (11.35%)	7.39 (50.82%)	5.50 (37.83%)	-
2	Juri R.	32.31	-	-	4.65 (14.40%)	21.91 (67.80%)	5.75 (17.80%)
3	Kanchan C	25.08	-	-	10.15 (40.47%)	10.33 (41.18%)	4.60 (18.35%)
4	Pati C.	24.92	-	-	2.75 (11.04%)	9. 75 (39.12%)	12.42 (49.84%)
5	Dhanai C	20.08	-	1.80 (8.96%)	1.20 (5.98%)	3.68 (18.33%)	13.40 (66.73%)
6	Tuichakma C	14.23	-	1.00 (7.02%)	4.35 (30.57%)	5.50 (38.65%)	3.38 (23.76%)
7	Garam C.	15.08	-	-	3.50 (23.20%)	7.58 (50.26%)	4.00 (26.54%)
8	Gangarai C.	16.23	1.84 (11.34%)	8.45 (52.08%)	5.94 (36.58%)	-	-
9	Ekjan C.	34.48	-	3.30 (9.57%)	12.28 (35.62%)	12.40 (35.96%)	6.50 (18.85%)
10	Mailak C.	56.20	1.75 (3.11%)	5.60 (9.96%)	3.55 (6.32%)	18.80 (33.45%)	26.50 (47.16%)
11	Kakri N.	61.09	6.65 (10.88%)	30.59 (50.07%)	19.63 (32.14%)	4.22 (6.91%)	-
12	Bengeswar C.	60.50	26.40 (43.64%)	34.10 (56.36%)	-	-	

Figures within parenthesis indicate area in percentage under each slope category to the total area of the basin.

Out of the categories as mentioned above, Categories(iii) and (iv) cover maximum areas of all the basins except Kakri N. and Bengeswar Gang. (Fig. VII-A & B). Gentle slppe (0-5°) category is dominant in Bengeswar Gang i.e. 43.64% and Kakri Nadi, Gangarai Chara has respectively 10.88% and 11.34% of their total area. In case of Mailak chara gentle slope group is negligible, and other 8 basins have no account of this category. Similarly Moderate Slope (5-10°) category is prominently occupies 56.36%, 50.07% and 52.08% of Bengeswar Gang, Kakri N. and Gangarai chara respectively, which are located in the western most part of the State. Moderately steep (10-15°) slope category covers part of all the basins except Bengeswar Gang and in percentage area ranges from 5.98 to 50.82 i.e. of Dhanai chara and Andhar chara. Basins under this category has moderate percentage of areas i.e. 20-35 percentage are located in Central Tripura. Whereas steep (15-20°) and very steep 20° and above is very much dominant in the basins locating in the North-Eastern Tripura which ranges from 6.91 to 67.8 per cent.

CORRELATION OF DRAINAGE DENSITY, STREAM FREQUENCY AND SLOPE

Superimposition of Drainage density, Stream frequency and slope maps on the original map of the selected basins reveal that the basins of the North-East Tripura,

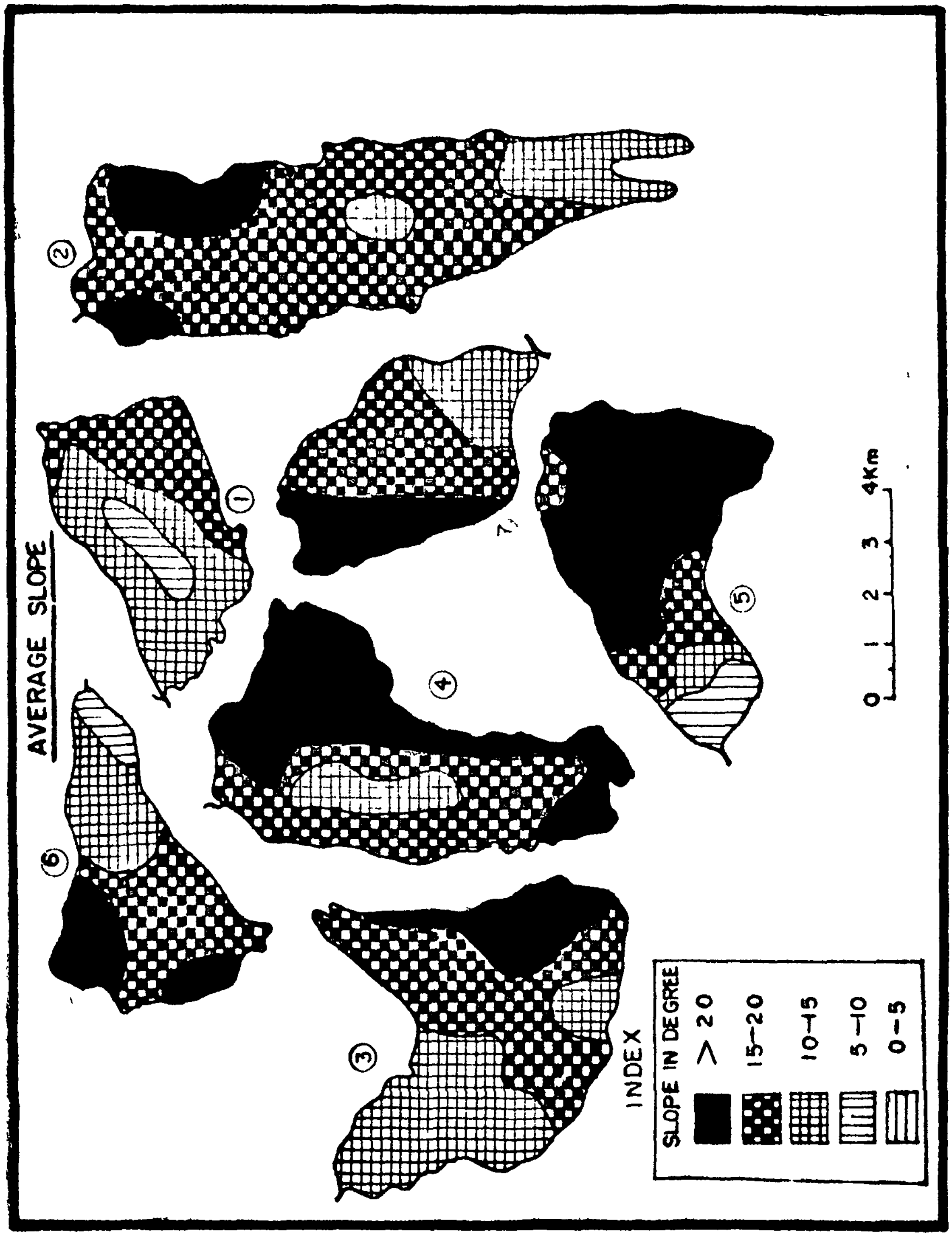
AVERAGE SLOPE
① ② ③ ④ ⑤ ⑥
INDEX
SLOPE IN DEGREE
> 20
15–20
10–15
5–10
0–5
0 1 2 3 4Km

FIG. 7-A

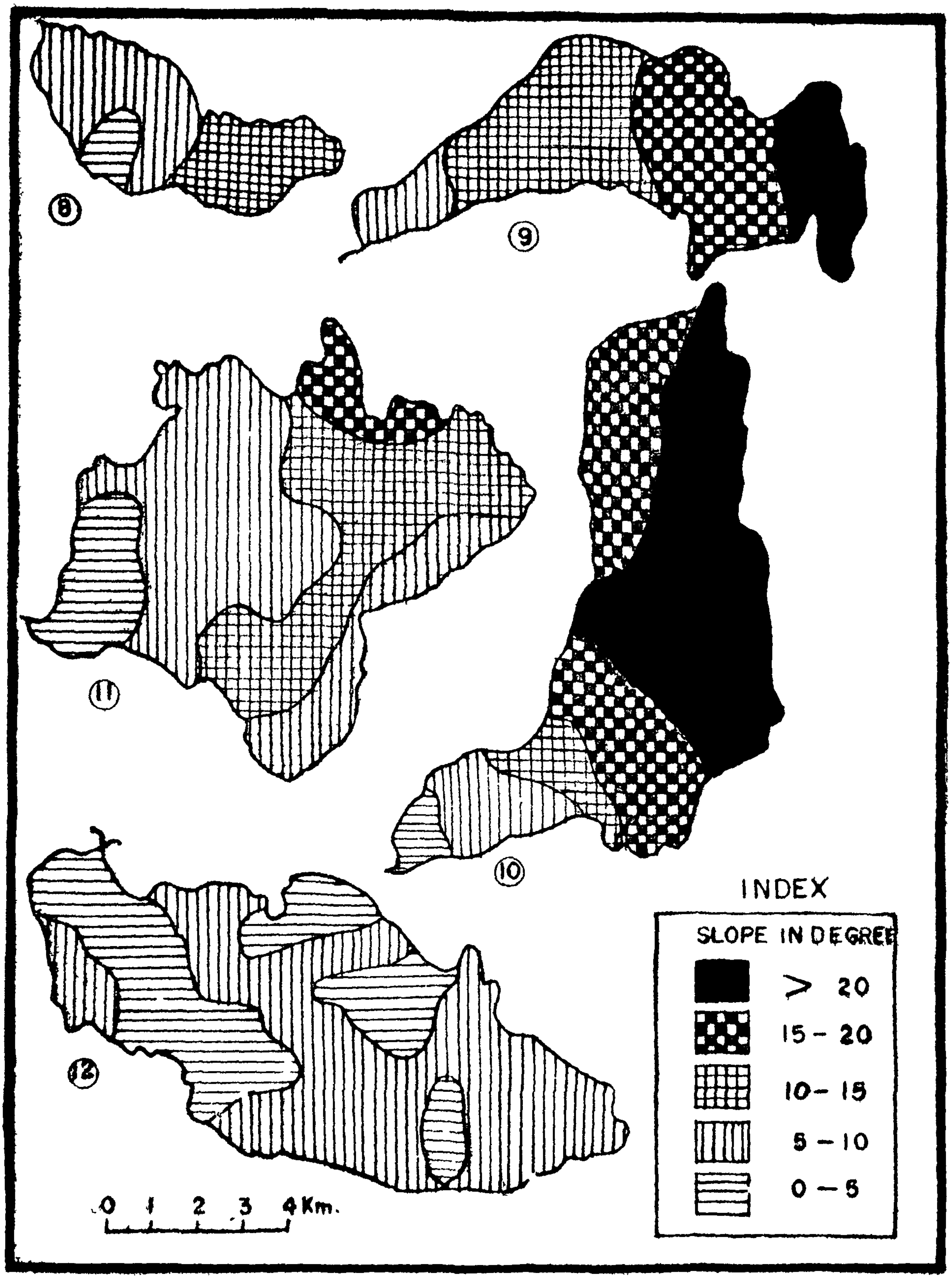

FIG. 7-B

Central Tripura and the South-western parts reflect different but systematic differential characteristics.

Andhar C., Juri R., Kanchan C. and Pati C. of the North Tripura have medium (2-4) to high (4-6) Dd, high and very high S_F with steep (15-20^o) and very steep i.e. above 20^o slope, with an exception to the Andhar chara which has moderately steep (10-15^o) and steep (15-20^o) slope. Tuichakma C. Garam C. Ekjan C and Mailak C. of the Central Tripurahas medium (2-4^o) and high (4-6^o) Dd, medium (4^o-8^o) and high S_F with moderately steep (10-15^o) to very steep slope i.e. more than 20^o. Ganga rai chara, Kakri Nadi and Bengeshwar Gang lies in the south-west part and has mainly medium Dd i.e. (2-4), medium and high S_F with gentle (0-5^o) to moderately steep (10-15^o) slope categories. Of which Ganga rai chara has only high S_F, Kakri Nadi and Bengeshwar gang has mainly medium S_F. Bengeshwar Gang has only gentle (0-5^o) and moderate (5-10^o) slope. If the entire state is divided into two parts viz. East Tripura and West Tripura it is seen that in the East Tripura characteristic angle lies in the category of 5-10^o, where as in the West Tripura it is 0-5^o. These slope categories are the out come of Surma and alluvium geological structures. Thus it is seen from the maps and concerned tables that Dd, S_F, slope intensity

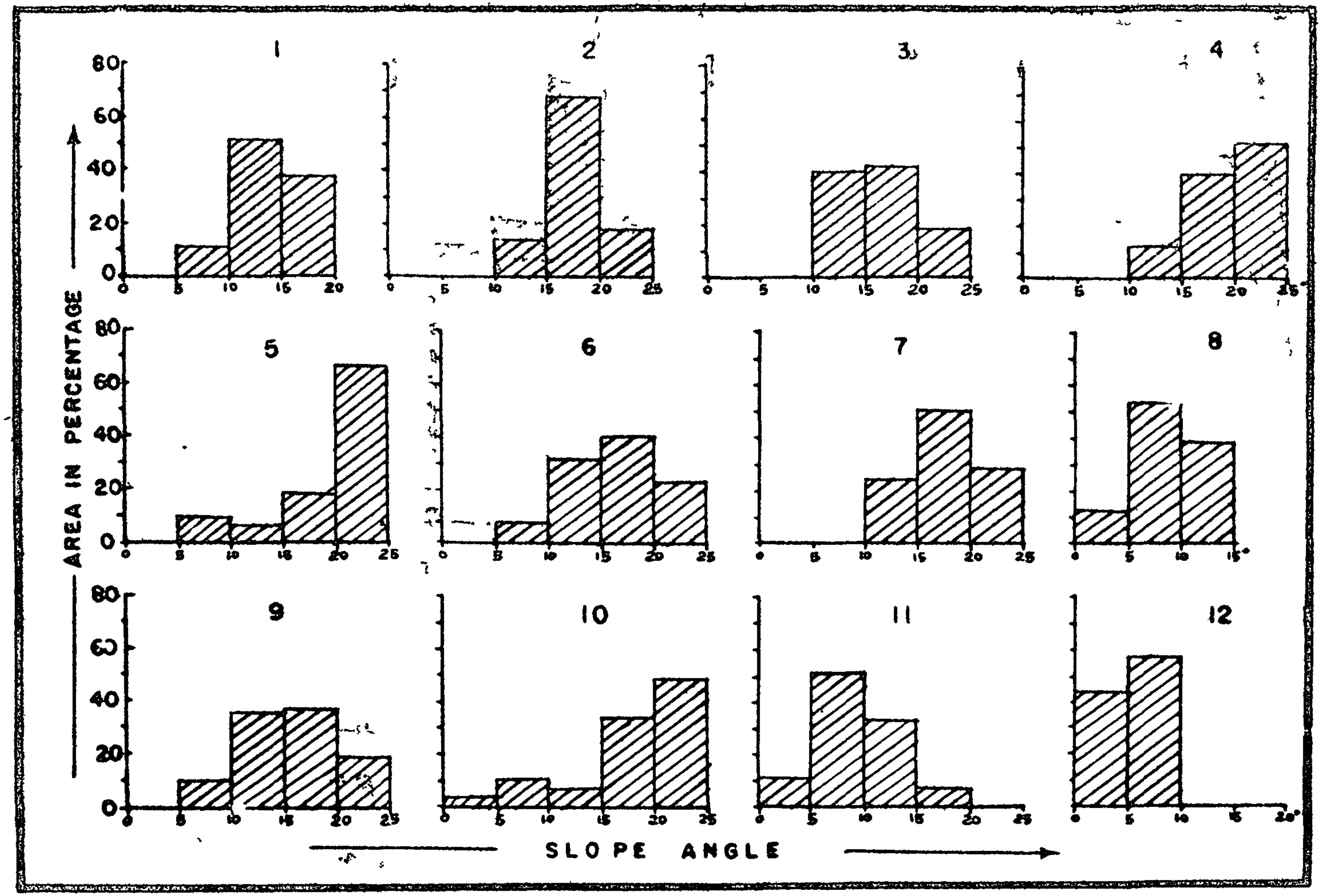

FIG. 8 ANGLE - FREQUENCY DISTRIBUTION OF SELECTED BASINS
—AFTER GREGORY AND BROWN (1966)

TABLE - 4.13

DATA MATRIX

Basin	N_1	N_2	N_3	N_4	N_5	L_1	L_2	L_3	L_4	L_5	Mean R_b	C.I.
1	2	3	4	5	6	7	8	9	10	11	12	13
Andhar C.	80	19	5	1	0	34.75	9.08	5.52	5.90	0	4.34	1.25
Juni N.	160	40	11	3	1	75.75	33.15	8.30	7.10	3.95	3.58	1.23
Kanchan C	148	33	6	2	1	67.87	21.30	6.30	5.15	3.15	3.74	1.56
Puti C.	149	38	7	3	1	71.05	25.25	5.50	7.90	2.35	3.67	1.19
Dhanai C.	111	20	3	1	0	50.50	18.15	4.95	7.30	0	5.07	1.88
Tuichakma C	67	17	3	1	0	33.15	17.75	5.70	6.00	0	4.20	1.43
Garam C.	79	19	3	1	0	37.90	8.30	11.05	2.35	0	4.50	1.19
Gangarai C	91	22	5	1	0	44.50	13.00	5.50	6.50	0	4.51	1.38
Ekjan C.	130	24	5	2	1	72.00	26.00	12.00	6.00	5.00	3.68	2.09
Mailak C.	182	40	9	2	1	102.00	34.00	22.00	5.50	15.00	3.87	1.62
Kakri N.	277	59	11	3	1	138.00	44.00	20.00	16.00	7.00	4.18	1.55
B.Gang	252	64	14	3	1	164.00	52.00	18.00	11.00	11.00	4.04	1.57

S_F = Stream Frequency, Dd = Drainage density R_b = Bifurcation Ratio V_L = Valley Length

N_u = Number of Stream, Ln = Link of particular order of stream C.I = Channel Index TSI = Topographic Sinuosity Index

SSI = Standard Sinuosity Index VI = Valley Index HSI = Hydraulic Sinuosity Index P = Perimeter

Table-4.13 contd.

Basin	V.I.	H.S.I.	T.S.I.	S.S.I.	Dd	CCM	Area	P	S_F	V_L
	14	15	16	17	18	19	20	21	22	23
Andhar C.	1.12	.520	.480	1.111	3.80	0.263	14.54	18.32	7.22	7.00
Juri N.	1.06	.739	.261	1.152	3.97	.252	32.31	35.14	6.65	13.00
Kanchan C.	1.22	.607	.393	1.273	4.14	.242	25.08	25.42	7.58	8.10
Puti C.	1.05	.737	.263	1.136	4.50	.222	24.92	25.00	7.95	8.70
Dhanai C.	1.38	.568	.432	1.364	4.03	.248	20.08	20.84	6.72	8.70
Tuichakma C	1.28	.349	.650	1.111	4.40	.227	14.23	19.14	6.18	7.10
Garam C.	1.12	.368	.632	1.056	3.95	.253	15.08	16.67	6.76	7.10
Gangarai C.	1.23	.395	.605	1.125	4.28	.234	16.23	21.25	7.33	8.00
Ekjan C.	1.65	.404	.596	1.263	3.51	.285	34.48	38.00	4.67	19.00
Mailak C.	1.25	.597	.403	1.300	3.18	.314	56.20	44.35	4.18	20.00
Kakri N.	1.27	.509	.491	1.214	3.68	.272	61.09	45.40	5.75	14.00
B. Gang	1.25	.204	.439	1.257	4.23	.236	60.50	44.00	5.52	17.50

TABLE – 4.14

CORRELATION MATRIX

	N_1	N_2	N_3	N_4	N_5	L_1	L_2	L_3	L_4	L_5	R_b	CI	VI	HSI	TSI	SSI	Dd	CCM	Area	P	S_F	V_L
1	1	0.97	0.89	0.83	0.77	0.97	0.94	0.76	0.82	0.75	−0.35	0.19	0.03	0.02	−0.36	0.44	−0.25	0.05	0.94	0.88	−0.40	0.66
2		1	0.95	0.87	0.75	0.96	0.94	0.70	0.77	0.73	−0.40	0.02	−0.13	−0.01	−0.38	0.30	−0.18	0.11	0.90	0.83	−0.31	0.59
3			1	0.86	0.74	0.90	0.91	0.66	0.66	0.74	−0.48	−0.06	−0.20	0.04	−0.42	0.23	−0.15	0.16	0.85	0.83	−0.33	0.63
4				1	0.90	0.78	0.84	0.47	0.63	0.58	−0.69	−0.03	−0.16	0.31	−0.56	0.20	−0.03	0.04	0.72	0.75	−0.17	0.55
5					1	0.73	0.77	0.54	0.42	0.72	−0.82	0.22	0.08	0.32	−0.48	0.41	−0.28	0.30	0.74	0.81	−0.35	0.71
6						1	0.96	0.80	0.75	0.81	−0.33	0.24	0.10	−0.17	−0.27	0.44	−0.23	0.24	0.95	0.89	−0.49	0.73
7							1	0.73	0.74	0.80	−0.43	0.25	0.11	−0.07	−0.34	0.45	−0.19	0.20	0.93	0.91	−0.52	0.75
8								1	0.46	0.89	−0.23	0.26	0.19	−0.24	−0.05	0.33	−0.65	0.66	0.91	0.88	−0.79	0.81
9									1	0.36	−0.04	0.14	0.07	−0.05	−0.20	0.25	−0.004	−0.008	0.68	0.62	−0.18	0.32
10										1	−0.44	0.30	0.15	−0.04	−0.23	0.51	−0.57	0.61	0.91	0.90	−0.75	0.89
11											1	0.08	0.09	−0.34	0.28	0.03	0.12	−0.16	−0.35	−0.49	0.18	−0.47
12												1	0.94	−0.22	0.10	0.81	−0.43	0.43	0.32	0.39	−0.60	0.55
13													1	−0.39	0.38	0.57	−0.38	0.38	0.18	0.28	−0.60	0.47
14														1	−0.77	0.11	−0.09	0.11	−0.09	−0.02	0.33	−0.10
15															1	−0.40	−0.06	0.05	−0.22	−0.23	−0.24	−0.12
16																1	−0.38	0.39	0.49	0.50	−0.45	−0.55
17																	1	−0.99	−0.47	−0.53	0.73	−0.66
18																		1	0.49	0.55	−0.76	0.68
19																			1	0.96	−0.67	0.84
20																				1	−0.73	0.92
21																					1	−0.87
22																						1

and frequency increases from South-West to the North-East.

INTERPRETATION OF CORRELATION FOR
22-SELECTED MORPHOMETRIC VARIABLES

The landscapes of our spaceship that are the outcome of fluvial erosion and these landscapes are most suitable geomorphic units which can be sub-divided for its micro-level geomorphic analysis.

The development of a landscape is equal to the sum total of the development of each individual drainage basins of which it is composed.[19] In this paper 22-morphometric variables are used to prepare the data matrix for the 12 small selected basins and tabulated in Table-4.13. The product-moment correlation coefficients are being calculated with the help of the formula,

$$r = \frac{\Sigma (x - \bar{x})\ (y - \bar{y})}{\sqrt{\Sigma (x-\bar{x})^2\ (y-\bar{y})^2}} = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \Sigma y^2}}$$

Correlation between stream Numbers(S_n) and stream Length (S_L)

Stream segments and respective stream lengths of each order of the small basins are all positively

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[19] J.C. Doornkamp, C.A.M. King, Numerical Analysis in Geomorphology, An Introduction, (1971), p.3.

correlated and their correlation value ranges from 0.63 to 0.97. The correlation between N_1 and L_1 is the highest (0.97) whereas, the correlation of N_4 and L_4 is the lowest (0.63). The correlation between N_2 and L_2 is also very high (0.94). If the correlation values are considered irrespective of stream number and stream length of all the orders then it is seen that very high correlation exists between N_1 and L_1, L_2 i.e. 0.97, 0.94, between N_2 and L_1, L_2 i.e. 0.96, 0.94; between N_3 and L_1, L_2 i.e. 0.90, 0.91. High correlation exists respectively between N_1 & N_2 to L_3, L_4 and L_5 i.e. 0.76, 0.82, 0.75, 0.70, 0.77, 0.73. Moderate correlation exists between N_5 and L_3, L_4 i.e. 0.54, 0.42, N_3 to L_3, L_4 i.e. 0.66, 0.66 and N_4 to L_3, L_4, L_5 i.e. 0.47, 0.63, 0.58.

Correlation value within the number of stream segments of various orders i.e. N_1, N_2, N_3, N_4 and N_5 are all positive and ranges from 0.74 to 0.97. The magnitude of values vary from highest to the lowest in respect to the Keenness, Similar is the case of inter-relation between the L_n Variables. All other correlations within the lengths of different orders are moderate except the value of L_4 - L_5 (0.36) and L_3-L_4(0.46).

<u>Correlation of Area and Other Variables</u>

Very high positive correlation exists between area are N_1, N_2, L_1, L_2, L_3, L_5 and perimeter. Out of all these values of correlation between area and perimeter is the highest 0.96 and N_2-L is the lowest (0.50). Correlation value between area and L_1, N_3, N_4, L_5 are moderately high i.e. 0.84, 0.74, 0.72, 0.86 respectively. There is moderate correlation between the area and BZ and CCM i.e. 0.49; 0.49. Area also maintains low positive correlation with CI, VI i.e. 0.32 and 0.18 respectively. Negative correlation of area in respect to the variables vary from moderate to low of which correlation with [illegible] is -0.47 and with S_f = -0.67 which is very high negative correlation.

Correlation of S_f and Other Variables

Only R_b, N_1 and Dd is having positive correlation to S_f of which R_b and S_f has the lowest positive correlation i.e. 0.18, with N_1 low positive correlation i.e. 0.33 and with Dd it has very high positive correlation i.e. 0.73. Stream frequency is negatively correlated with the all other variables, which ranges from -0.17 to -0.87. The correlation of S_f with R_f is highly negative. Some other high negative correlation of S_f with L_3, L_5, CA and P are respectively -0.79, -0.75, -0.76, -0.73. Moderate negative correlation of S_f is with A, CCM, CI, V.I, L_1, L_1, L_2 and N_4 i.e. respectively -0.67, -0.45, -0.50, -0.60, -0.40, -0.49, -0.51 and -0.17 respectively.

Correlation of Drainage Density and other Variables

There is positive relation between Dd and R_b, S_F which is 0.12, 0.73 respectively. The negative correlation of Dd with some other variables are given below i.e. with CCM, TSI, HSI, N_2, N_4, L_4 are respectively - 0.99, -0.06, -0.09, 0-10, -0.03 and -0.004.

Correlation Between the Sinuosity Indices

The correlation values of all the sinuosity indices range from -0.77 to 0.94 of which the correlation between C.I and V.I. is the highest i.e. 0.94 and between HSI and TSI is the lowest i.e. -0.77. High correlation exists between CI & SSI i.e. 0.81 and moderate correlation in between VI and SSI i.e. 0.57. Out of all sinuosity indices SSI is positively correlated to all other variables except TSI, D_d, and S_F i.e. -0.40, -0.38 and -0.45 respectively. Highest positive correlation is available between CI and SSI i.e. 0.81 and lowest value is between R_b and SSI i.e. 0.03, R_b HSI i.e. 0.11.

The drainage density (Dd) and constant of channel Maintenance (CCM) is inversely correlated i.e. $Dd \propto \frac{1}{CCM}$. From the column 17 and 18 Table-4.14 it is clearly and perfectly established by the fact that where with the same variable Dd has negative correlation, CCM has positive correlation of the same magnitude and vice-versa.

CHAPTER - V

SLOPE ANALYSIS

> "Slopes are the fundamental types of Land scape features. So they need careful study"
>
> \- L C King (1967)

The study of slopes is one of the most important aspects of Geomorphology. Primarily geomorphological investigations are done for its analysis aiming at the requirement for the practical use. Slope requires scientific and mathematical analysis to provide both qualitative and quantitative base for the developmental projects viz. construction of roads, bridges, dams, multipurpose projects etc.. It is the single largest determinant of landforms that affects activities of man, its socio-economic activities, culture and environment. Study of slope development provides fundamental background for multi-developmental planning. Morphometric analysis of slopes of a region is the measurement and scientific analysis of the configuration, its shape, dimensions of a region and that of its landforms.

The earliest surveys of slope profiles for geomorphological purposes were done by Lake (1928) and

Taylor (1975). Their potentialities for the study of slope evolution were first fully demonstrated by Fair (1947, 48), Strahler (1950), Savigear (1952) and many others. By 1960, Profiles have become established as a standard descriptive, quantitative and qualitative technique in Geomorphology. In India, the problems relating to slope and its development has not been intensively studied. Only few studies of Rai (1971), Pandey (1968), Subramanyam (1976), Sharma and Padmaja (1977, '78) amongst some others are worth mentioning. This branch of earth science requires detailed intensive work to achieve its due importance, direction and usefulness.

Thus this chapter on slope is an attempt to investigate, analyse and enumerate the slope form and its characteristics of Tripura with the help of available morphometric techniques and tools viz. -

i) Average slope-map

ii) Slope-frequency and slope-area histogram

iii) Slope profiles

iv) Slope diagram, and

v) descriptive, qualitative and quantitative statistics, etc.

Slope analysis is done mainly for the agricultural purpose, Civil Engineering and Soil Conservation. Landforms very rarely have uniform slope, lithology, structure and climate etc.. Complicate the interpretation of slopes and as such no particular law is applicable with certainty.

Development of basal slope may take place due to the transportation and deposition of weathered rock on bed rock. Vital factors which are responsible for the development of slopes are as follows:

a) The surface relief and the endogenic forces causing upliftment of the material either above sea level or from in-situ to higher altitude.

b) Both the weathering and transportation of materials on slopes are affected by climatic factors in this tropical region viz. south-west monsoon winds and rains.

c) The activity of the streams at the base of the slope, which erodes and transports the material brought to it from the surrounding steep slopes, and

d) Human activities viz. agricultural work, Jhum cultivation, industrial works and construction of multi-purpose projects etc.

METHODOLOGY AND PROBLEM

The method suggested by Wentworth (1930)[1] which

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[1] C.K. Wentworth (193) has suggested $\tan \alpha = \frac{N \times C.I}{3361}$
where n = number of contour crossing per mile and
CI = contour interval.

later on has been modified by Zakrzewska (1967)[2] as given below has been used for computation of average slope with the help of quarter inch toposheets.

$$\text{Slope in degree } (\tan \theta) \equiv \frac{V.\ N.}{0.6366K}$$

Where V = vertical contour interval in metre or in feet.

N = Number of contour crossing per Km or per mile and

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

Profile Curvature[3] is being calculated with the help of the method suggested by young viz.

$$Cab = \frac{\theta_a - \theta_b}{0.5(D_a + D_b)} \times 100$$

$$= 200 \times \frac{\theta_a - \theta_b}{Da + D_b} \quad 0/100m$$

where θ_a, θ_b are angles at a and b; D_a, D_b are distances from a and b of a point in between a and b.

Curvatures are obtained on the basis of the theodolite traverse survey as given in the tables and represented in the profiles. The main traverse line has

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[2]Zakrzewska (1967), had modified the formula as given above i.e. tan O = V.N / 0.6366K.

[3]Geomorphology (Text-3), Slopes by Dr. A. Young (1963), p.143.

been sub-divided into four parts in large scale map to have the actual nature of curvature. Some profiles of the important hill ranges are prepared to represent the nature of curvature and slopes along the north south trending structural hills.

Wentworth's method of calculations is good enough for the categorisation of slopes, to analyse the general slope pattern for a region as is done for the whole study region. (Fig. I). For better results large scale maps have been used. Because of the fact that addition or omission of a contour of 250 feet in 1" = 4 mile map either due to maperror or personal error effects the accuracy of the slope. Smaller be the area under the gridlines drawn at a certain interval to have the average value of number of contour crossings per mile or per km larger be the accuracy of angle.

Thus to findout the nature of slopes and their characteristics, grid lines are drawn to coverup an area of (4 sq. mile) 10.36 sq. km. area for the whole study region. For the biggest river basin it is done to cover up (1 sq. mile) 2.59 sq. km. area from the 1" - 1 mile map and for a part of the Khowai river basin in between Bara Mura and Athara Mura ranges it is done to

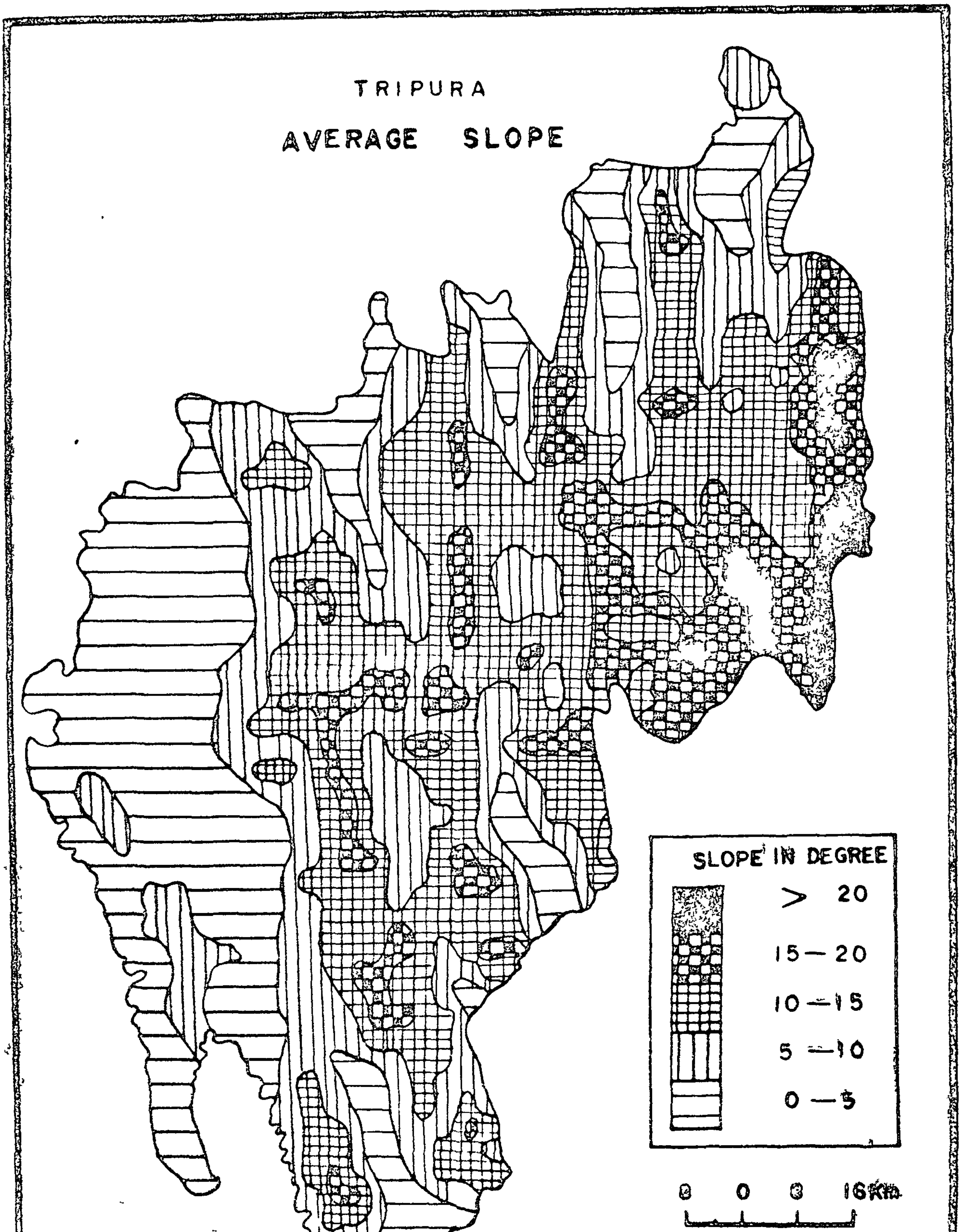
TRIPURA
AVERAGE SLOPE
SLOPE IN DEGREE
> 20
15 — 20
10 — 15
5 — 10
0 — 5
8 0 8 16 Km

FIG. 1

cover up an area of 0.65 sq. km. for one inch map.

Again slopes for the Gumti river basin has been represented in histogran to reveal the correlation of frequency and area to slopes (Fig. III).

In Fig. IV, an attempt has been made to delimit the plainlands upto 2° slopes, which constitutes the flood-zone in almost all the north-south flowing rivers. Thus its is seen that larger the scale of map and smaller be the area covered by the grid square to have the average slope and greater is the accuracy. As it is seen that in Fig. II and III 20.25° slope category occupies certain central part of the hill ridges which have been merged under the category of $15-20^{\circ}$ in case of Fig. I which has been done from the quarter inch map.

To overcome the problem theodolite traverse has been done to have the profile curvature and for general slope analysis greater-weightage has been given to Fig. II and III along with other figures and tables.

ANALYSIS OF AVERAGE SLOPE CATEGORIES
AND THEIR CHARACTERISTICS IN TRIPURA

Slopes are computed in degree for the entire State of Tripura in quarter inch map, Gumti river basin, a part of Khowai river basin and 12 small selected basins in one inch, or one centimetre to one kilometre scale, groupings have been done at five degree interval as given in the following table.

TABLE - 5.1

AREAL EXTENT OF SLOPE CATEGORIES IN TRIPURA

Sl. No.	Slope category	Slope angle in degree	Area in sq.km.	P.C. of area to total area
1.	Very gentle	0 - 5	3821	36.47
2.	Gentle	5 - 10	2611	24.92
3.	Moderate	10 - 15	2688	25.66
4.	Moderately Steep	15 - 20	1174	11.20
5.	Steep	20 - 25	157	1.50
6.	Very steep	25	26	0.25
	TOTAL		10477	100

It is observed that slope angle increases from south-west to North-east, starting from very gentle $0-5^{o}$ slope category in the extreme west and more than 25^{o} i.e. very steep slope category in the easternmost part of the State.

Analysis of Average Slope Categories

1) Very Gentle ($0-5^{o}$)

Very gentle slopes are predominent in the western part of Tripura along Bangladesh boundary and also has developed along the main streams of synclinal valleys in between the hill ridges. Aggradation of alluvium deposits from steepy hills are mainly responsible for the development of these slopes both in respect to space and time. This category occupies about 36.44 per cent of total area of the State which is about 3821.28 square kilometre. About 1200 square kilometre area lies in the extreme western part, surrounding few shallow remnants of hills viz. (i) Sona Mura (ii) Eta.

2) Gentle $(5-10^{\circ})$

Gentle slopes has developed surrounding the recent alluvium plains of very gentle slopes, in the region of old alluvium deposits. About 2610.72 square kilometre which is about 24.92 per cent of total area of the study region. Both very gentle $(0-5^{\circ})$ and gentle $(5-10^{\circ})$ slopes are best suited for agricultural purposes, settlements and construction of roads.

3) Moderate Slope $(10-15^{\circ})$

This category forms major parts of Tillas (Small round shaped hills) and foot hills of hill ranges(Muras). Characteristic angles[4] are included in this category. Slopes under this category is dominant in north-east, central and south-east parts of the State, which forms

[4]Angle classification, Slopes by Dr.A.Young(1963) p.163.

major water-sheds in between the important (river systems) river basins. These slopes are also responsible for the development of intermediate streams of higher order. Shifting cultivation is also practised in these slope regions which occupy about 25.66 per cent of total area and second in rank and the slope categories. In the east Tripura roads are being constructed along the alignment of these slopes mainly in North-South direction. Due to the inception by the higher slopes in North-South direction, the construction of roads in the East-West direction is uneconomic and risky for modern transportation.

4) Moderately Steep Slope ($15-20^{\circ}$)

These slopes occupy major parts of North-East Tripura where trallis pattern and lime-stone topography is visible. This slope group is responsible for the development of forests and occupies 11.20 per cent area without any aid of modern technique, cultivation is very difficult in these slopes. Heavy rainfall causes intensive soil erosion and the materials are carried and accumulated in the valley region of gentle slopes.

5) Steep ($20-25^{\circ}$) and Very Steep(25°)

These slope categories are visible in the higher parts of ridges and though occupies insignificant areas, but significant from the climato-genetic point of view. These slope categories are developed respectively in the Upper Bhuban and lower Bhuban formations, where this rock exposure is due to be developed.

It is seen that very gentle slopes (0-5°) has been formed by the very recent formations and respectively the oldest Bhuban formations has developed steep and very steep slopes. That is slopes are directly related to the geological formation, structure and even lineament. Generally the slope characteristics of the region are as follows:

i) over 20° slopes, very high peaks in the east Tripura;

ii) 15°-20° slopes, relatively high peaks that are available on the hill ridges and area occupied in comparison to total land surface is low;

iii) 10°-15° slopes occupies very large areas in the eastern part of Tripura.

iv) 5-10° slopes, represents convexity over low round shaped hills (mounds);

v) 2-5° slopes, mostly concave in nature and is observed in the valleys in between hill ridges.

vi) 0-2° slopes are observed in the recent alluvium (modern deposits) plains.

Slopes more than 20° forms the limiting angle for many peaks of hard sandstone, mostly of Bhuban formations. In the region scarp (free face) plays a dominant role to create gravity force for mass wasting processes like landslides. The slope on the steep sedimentary rock face is influenced by frequent action of weathering process due to heavy rainfall, high humidity and differential temperature. The impressive physiographic feature is represented by the characteristic slope angles i.e. 5-15^{o}, which forms the transitional terrain between the Alluvium plains and the structural hills.

TABLE - 5.2

SLOPE ANGLE, FREQUENCY AND AREA

Sl No	Number of CC permile	Slope in Degree	Frequency of slope unit of 1sq mile	Area in sq.km	Are in P.C to total area
1	2	3	4	5	6
1(a)	-	less than 51'08"	25	64.75	2.83
1.	1	00^{o}51'08"	12	31.08	1.36
2.	2	01 42 15	6	15.54	0.68
3.	3	02 33 19	5	12.95	0.57
4.	4	03 24 20	25	64.75	2.83
5.	5	04 15 14	27	69.93	3.05
6.	6	05 06 02	28	72.52	3.17
7.	7	05 56 42	28	72.52	3.17
8.	8	06 47 13	60	155.40	6.79

Table contd...

Table-5.2

1	2	3	4	5	6
9.	9	07 37 33	44	113.96	4.98
10.	10	08 27 42	65	168.35	7.35
11.	11	09 17 37	52	134.68	5.88
12.	12	10 07 18	77	199.43	8.71
13.	13	10 56 44	43	111.37	4.86
14.	14	11 45 53	66	170.94	7.47
15.	15	12 34 45	41	106.19	4.64
16.	16	13 23 19	50	129.50	5.66
17.	17	14 11 33	18	46.62	2.04
18.	18	14 59 26	49	126.91	5.54
19.	19	15 46 59	22	56.98	2.49
20.	20	16 34 09	37	95.83	4.19
21.	21	17 20 56	26	67.34	2.94
22.	22	18 07 20	23	59.57	2.60
23.	23	18 53 19	11	28.49	1.24
24.	24	19 38 54	14	36.26	1.58
25.	25	20 24 02	4	10. 36	0.45
26.	26	21 08 45	10	25.90	1.13
27.	27	21 53 01	6	15.54	0.68
28.	28	22 36 49	6	15.54	0.68
29.	29	23 20 10	3	7.77	0.34
30.	30	24 03 03	1	2.59	0.11
		TOTAL	884	2289.56	100.01

THE INTERPRETATION OF ANGLE FREQUENCY

The interesting feature of angle frequency distribution is that gentle slopes up to 5° are more extensive in comparison to the steep angles more than 20°(Fig.III).

This may represent the relative survival time of slopes of different angles. The steep slopes along the structural hill ranges are more rapidly changed by the weathering and the weathered materials are carried to the low lands by mainly the streams and deposits there, which is responsible for the evolution of the gentle slopes as well as moderately gentle (5-10^{o}) slopes. In Tripura gentle slopes are developing at low altitudes where the river courses are comparatively graded and this slopes survive in the landscape for longer time and increasingly occupy larger areas. This means the rate of destruction of slopes are increasing exponentially with the increase in angle from the centre of a cynclinal valley to the crest of an anticlinal hill ridge.

Though the area occupied by the gentle slope is more than that of the steep slopes, yet in Tripuraas a geomorphologically in young stage, there intermediary slopes 5-15^{o} are predominant. The morpho-climatic activities are more in the low hills where slopes from 7^{o} to 15^{o} is at random available.

In Tripura particular conditions of structure and geology produces characteristic angles. For example in alluvium formations of low altitude 3^{o}-6^{o} are the

the characteristic angles, $8^{o}-12^{o}$ are in Bokabil formations and $15-18^{o}$ are in Bhuban formations.

ANALYSIS OF SLOPE CHARACTERISTICS
IN RELATION TO GUMTI RIVER BASIN
AND A PART OF KHOWAI RIVER BASIN

About 2295 sq. km. area of the study region is being covered by the Gumti river basin. (Fig. II). This west flowing river originates from the western part of Longtari-Sardeng hill range. In between the hill ridges the important streams are flowing in the north-south, south-north direction along the steep and moderately steep slopes. This is an antecedent river and maintaining its course to the west. In the extreme western part of the state its course is controlled by the Sona Mura-Eta hills in the south and low hills of about 85 m above sea level maximum height in the north bank. The altitude of the eastern most part is about 400 m. From east to west the hill ridges crossed by the river are (i) Athara Mura, (ii) Bara Mura and (iii) Sona Mura, which are successively lower in altitude.

It is observed from the Fig.II that the crests of the Muras are of steep ($20-25^{o}$) slope category and other slope categories succeed in descending order upto very gentle slope (0-5^{o}). Out of this very gentle slopes, slopes 0-2^{o} occupy a strip of land surrounding the main channel of all the basins. About 111.37 sq. km area is lying along the main channel of the Gumti river, mostly in the western part of Bara Mura.

It is clear from Table-5.3 that gentle slope (5-10^{o}) and moderate (10-15^{o}) covers about 70.25 per cent area. While very gentle slope (0-5^{o}) covers about 11.31 per cent and steep slope (20^{o}-25^{o}) covers only 3.39 per cent. This means that the whole region is under the active process of peneplanation. Degradation of materials from the hill ranges are responsible for the evolution of steep and very steep slopes along the crests which are aggraded in the western part of the basin and that of the region along the grand base level of the Bay of Bengal, resulting the development of very gentle (0-5^{o}) slopes. Thus slopes in the eastern Tripura is steeper and in the western Tripura is gentler.

It is interesting to note that in the Fig. II it is clear that very gentle slope catagory occupies maximum area on the eastern side of sonamura-Eta hill and in the west of Bara Mura; upto the eastern most part of it, nowhere this slope (0-5^{O}) development has taken place enclosing a small area in between [illegible] and [illegible] Dura. Concerning the syncline in between [illegible] and [illegible], high slope [illegible] are occupy in larger areas (steep moderately) and in the [illegible] one smaller areas in the western part of Triqura.

The slopes and their frequencies are graphically plotted and diagrammatically represented in Fig. III, where areas occupied by a particular slope is also represented. It is seen that frequencies of slopes are higher within the slope categories of (5-10°) [illegible] and moderate (10-15°) only. From the Table-5.2 all the available slopes of the basin under reference are represented. For example, for every contour crossing per mile is one its slope in degree is 0.25° which occupies an area of 1.08 sq. km. and its number of frequency is 12. From the Fig. III and Table-5.2 it is clear that 10° 07' slope is present in an area of about 200 sq. km. with maximum frequencies of 77 and 24°03' occupied only [illegible].59 sq. km. by its low frequency. The above [illegible] table and the respective Fig. III shows the nature of slopes in the basin and their pattern of evolution, which is also a [illegible] in case of almost all the [illegible] river basins.

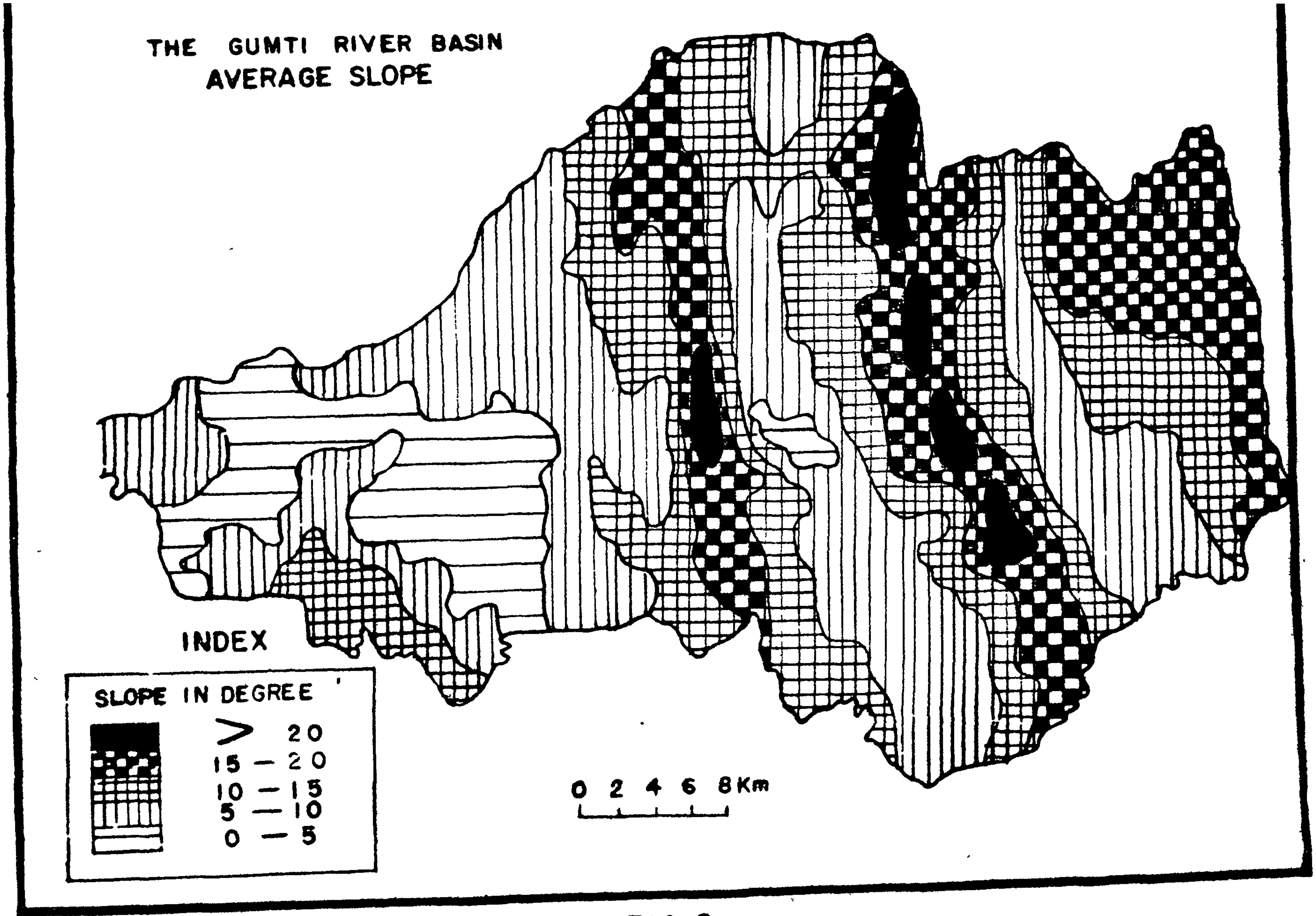
THE GUMTI RIVER BASIN
AVERAGE SLOPE
INDEX
SLOPE IN DEGREE
> 20
15 — 20
10 — 15
5 — 10
0 — 5
0 2 4 6 8 Km

FIG. 2

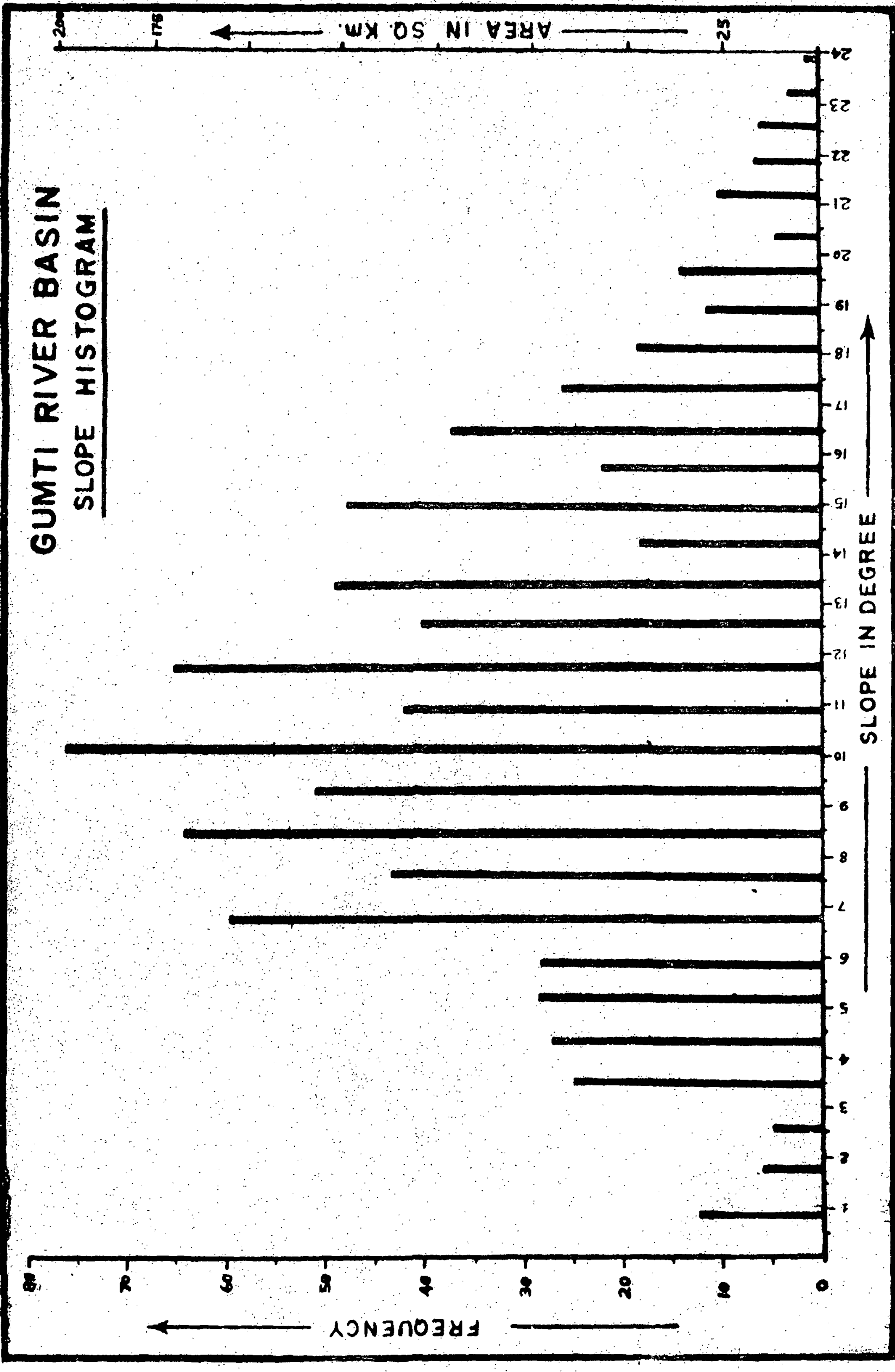
GUMTI RIVER BASIN
SLOPE HISTOGRAM
AREA IN SQ. KM.
FREQUENCY
SLOPE IN DEGREE

FIG. 3

The existence of such an equilibrium of slopes as indicated by the gentle (5-10°) and moderate (10-15°) slope categories within a small region of the Gumti river basin gives indication of uniform relief, rock-type, climate and vegetation. The same phenomena is being indicated by the profile of the river, as well as the east-west, and north-south cross-sections of the basin and of the region in general. (Fig. V cross-section).

The river has been initiated by the steep slope condition and higher rainfall in the eastern part of the state of Tripura. Great areas of low land with very gentle and gentle slope in the western part of the basin with perceptible undulations and landscape indicates maturity of the river which is heading towards peneplanation of the region. Masses of resistant hard sand stones forming the core of the north-south trending structural hills (Muras) would remain as "erosional survivals". Known as monaduock, presently occupied by very steep and steep slopes (20° and above). (Fig. II).

Gradual change in the evolution of slopes from the hill region in the east towards the Bay of Bengal in the west and south-west, gives the idea and nature of cycle development as emphasised by the Davis. (Fig.I).

In the eastern part of the state provides the initial slopes (steep and very steep) down which rivers first begin to flow are provided by the earth movements. The sea-ward and consequent slopes of the region may be termed as secondary slopes (moderate and moderately steep) down which tributaries of the rivers develops subsequentl slopes. (Fig. I). Thus an area of about 64.75 sq. km. is the most flood effected zone, surroundings which slope category 1^{o}-5^{o} covers about 200 sq. km. area of the Gumti where modern alluvium deposits are taking place in every flood season.

The Sona Mura, Eta hill, Gojalia and foot hills of Bara Mura, Athara Mura and mounds consists of 5-10^{o} slope which has been developed in the Tipam formations of plerstocene period. Out of about 2,300 sq.km. area of the Gumti river basin only about 77.70 sq. km. area has remained under the steep category (20^{o} and above) which are high altitudional hills located on the structural hill ridges. Vast area of the Gumti river basin is covered by the characteristic slope angles, which are located surrounding the resistant hill ranges in the eastern part and surrounding very gentle slope (0-5^{o}) category in the western part (shallow hills). 5-10^{o} slope category has developed mainly in Tipam formations which is of pliocene and 10-15° has developed in the Bokabil formations of Mio-pliocene period. Thus it is seen that in the Gumti river basin average slope categories of 5° interval has direct bearings to their respective geological formations. This means steeper the slope, older the geological formation.

TABLE - 5.3(a)

SLOPE CATEGORIES OF GUMTI RIVER BASIN

Sl No	Slope in degree	Category	Area in sq.km.	P.C. to total area
1.	(a) 0 - 2	Plain land	111.37	4.86
	(b) 2 - 5	Very gentle	147.63	6.45
2.	5 - 10	Gentle	717.43	31.33
3.	10 - 15	Moderate	890.96	38.92
4.	15 - 20	Moderately steep	344.47	15.05
5.	20 - 25	Steep	77.70	3.39
		TOTAL	2289.56	100.00

TABLE - 5.3(b)

ANGLE FREQUENCY AND AREA FOR A PART OF THE KHOWAI RIVER BASIN

Sl No	Slope in degree	Category	Frequency of slope unit each of 0.647 sq.km.	Area in sq. km.	Area in p.c. to total area	Land scape	Maximum altitude in m.
1.	0 - 2°	Plain land	90	58.23	10.80	Almost level surface	30
2.	2 - 5°	Very gentle	179	115.81	21.49	Minor undulations	60
3.	5 - 10°	Gentle	243	157.22	29.17	Spurs, Tillas of small hills	100
4.	10 - 15°	Moderate	249	161.10	29.89	Lower part of Muras	150
5.	15 - 20°	Moderately steep	67	43.35	8.04	In between lower part and summit	230
6.	20 and above	Steep	5	3.24	0.60	Crest (Muras)	350
		TOTAL	833	538.95	99.99		

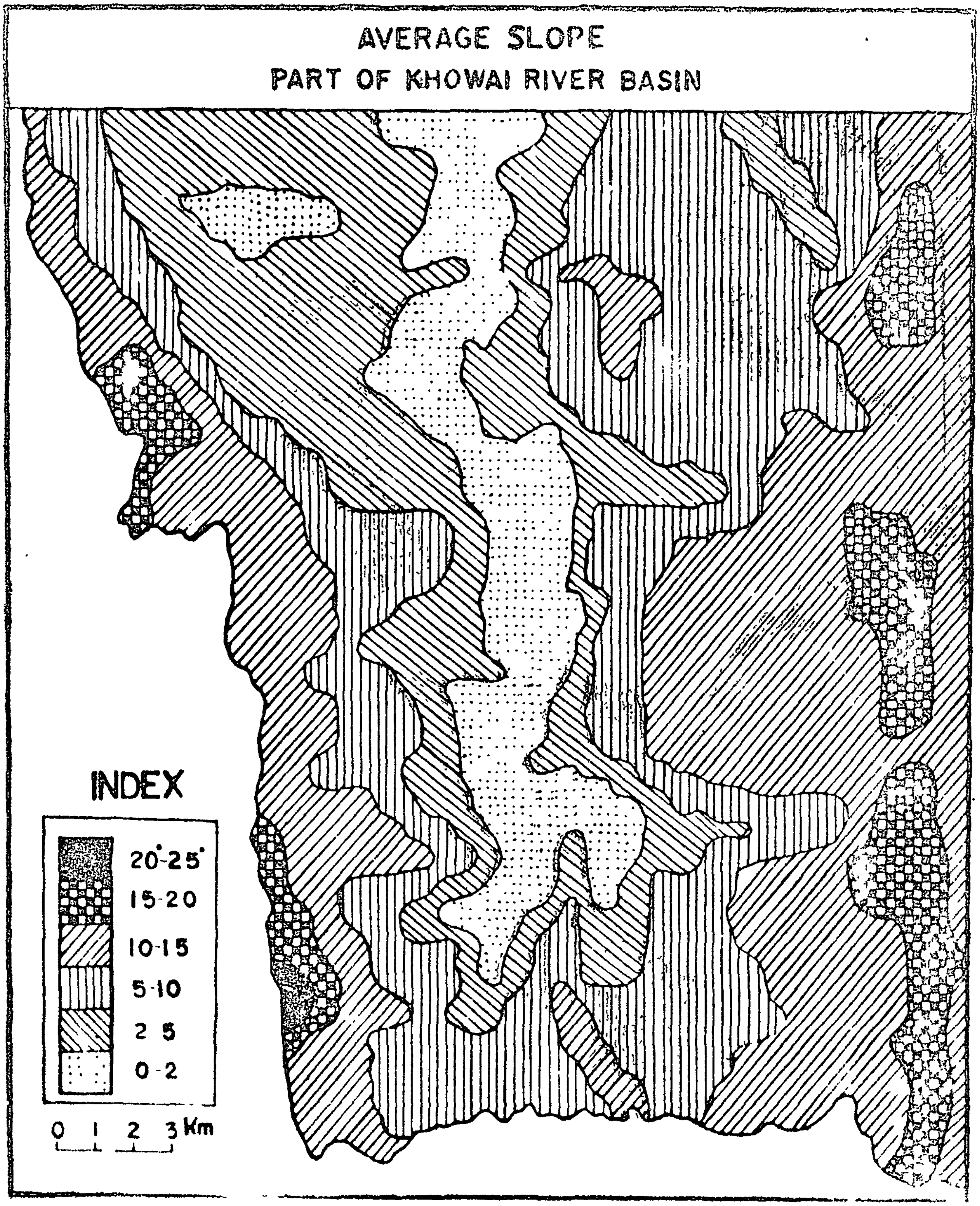
AVERAGE SLOPE
PART OF KHOWAI RIVER BASIN
INDEX
20°-25°
15-20
10-15
5-10
2 5
0-2
0 1 2 3 Km

FIG 4

A part of Khowai river lying in between Bara Mura and Athara Mura has been mapped from one inch to one mile map. It is observed that 0-2^{o} slopes had developed surrounding the main channel and occupies about 10.80 p.c. of area covered by Fig. IV which is flat and typical erosional landscapes. Slopes 2^{o}-5^{o} covers an area of about 115.81 sq. km. out of 538.95 sq. km. Slope angles 5-15^{o} covered about 59.06 per cent and forms the characteristic slopes of the basin, which includes major parts of hill ridges and spurs and high hills. Higher slope angles are available in the eastern side of the Khowai river valley along Ahtara Mura. Higher slopes occupy higher area in the eastern part of all the south-north flowing rivers, because of the fact that from west to east hill ranges are successively older and higher. Thus Fig. IV represents the nature of slope development in the catchment of each north flowing rivers. Only the difference is that altitude gradually increases due to the change in elevation of local base levels of the river basins from west to the east.

PROFILE CURVATURE[5]

Profile curvature is the rate of change of angle with distance down the true slope, expressed in degrees

[5] A Young : Slope profile analysis, the system of best units : Slope form and process. (1971), pp.1-13.

per 100 metre. Positive and negative curvature as indicated in the tables and their respective figures indicates respectively convex and concave slopes. For the purpose of this study theodolite traverse Survey method is being applied for tabulation of data and the profiles are drawn on the basis of the profile curvature method as suggested by Young as referred in methodology.

TABLE - 5.4

PROFILE - 1

Sl No	Point	Distance	h	Height	Verticle angle	Profile curva-ture
KULKULIA HILL						
1.	b	-	-	55.3	-1.20	
2.	c	287	-6.0	49.3	-0.87	C_{bd}=(-)0890
3.	d	178	-2.7	46.6	-1.49	
4.	e	1006	-26.2	20.4	-0.02	C_{df}=(-)0.220
5.	f	369	-0.1	20.3	-0.13	
6.	g	694	-1.6	18.7	-0.06	C_{fh}=(-)0.027
7.	h	716	-0.8	17.9	-0.10	
8.	i	1234	-2.1	15.8	-0.02	C_{hj}=(-)0.012
9.	j	740	-0.2	15.6	-0.17	
10.	k	735	-2.2	13.4	+0.13	C_{jl}=(-)0.005
11.	l	756	+1.7	15.1	+1.35	
12.	m	505	+11.9	27.0	-	C_{km}=(+)0.235

TABLE - 5.5

PROFILE - 2

Sl. No	Point	Distance	h	Height	Verticle angle in°	Profile curvature
1.	A_1	-	-	28.5	+0.21	
2.	B_1	193	+0.7	29.2	+0.02	C_{AF_1}=(+)0.102
3.	C_1	257	+0.1	29.3	+0.73	
4.	D_1	158	+2.0	31.3	+0.43	$C_{C_1E_1}$= 0.563
5.	E_1	254	+1.9	33.2	+0.13	
6.	F_1	174	+0.4	33.6	+0.04	$C_{E_1G_1}$=(+)0.069
7.	G_1	316	+0.2	33.8	+0.41	
8.	H_1	112	+0.8	34.6	+0.06	$C_{G_1I_1}$=(+)0.435
9.	I_1	104	+0.1	34.7	+0.09	
10	J_1	248	+0.4	35.1	-1.92	$C_{I_1K_1}$=(-)0.790
11.	K_1	215	-7.2	27.9	+0.70	
12.	L_1	114	+1.4	29.3	-1.15	$C_{K_1M_1}$=(-)0.324
13.	M_1	164	-3.3	26.0		
Total		2309m	-2.5			

TABLE - 5.6

PROFILE - 3

Sl No	Point	Dist- ance	h	Height	Verticle angle	Profile curvature
1	a_1	-	-	16.0	+0.81	
2.	b_1	156	+2.2	18.2	-0.33	$C_{a_1c_1}$=(+)0.173
3.	c_1	398	-2.3	15.9	+0.03	
4.	d_1	198	+0.1	16.0	+0.08	$C_{c_1e_1}$=(+)0.035
5.	e_1	428	+0.6	16.6	+0.06	
6.	f_1	709	+0.8	17.4	+0.93	$C_{e_1g_1}$ =(+)0.160
7.	g_1	530	+8.6	26.0	-0.72	
8.	h_1	96	-1.2	24.8	-0.89	$C_{g_1i_1}$=(-)0.653
9.	i_1	397	-6.2	18.6	+0.04	
10.	j_1	907	+0.6	19.2	+1.48	$C_{i_1k_1}$=(+)0.197
11.	k_1	633	+16.3	35.5	+1.20	
12.	l_1	191	+4.0	39.5	[illegible]	$C_{k_1m_1}$=(+)0.151
13.	m_1	219	-3.4	36.1	+1.28	
14.	n_1	152	+3.4	39.5	+0.74	$C_{m_1o_1}$= 1.287
15.	o_1	162	+2.1	41.6	+0.25	$C_{n_1p_1}$=(+)0.535
16.	p_1	208	+0.9	42.5		
TOTAL		5384m	+26.5m			

TABLE - 5.7

PROFILE - 4

Sl. No.	Point	Dist-ance	h	Height	Vertical angle in°	Profile curvature
1.	A	-	-	38.4	+1.38	
2.	B	232	+5.60	44.0	-0.07	C_{AC}=(+)0.562
3.	C	234	-0.30	43.7	-1.71	
4.	D	127	-3.80	39.9	+0.28	C_{CE}=(-)0.519
5.	E	424	+2.10	42.0	+0.71	
6.	F	73	+0.9	42.9	-2.67	C_{EG}=(-)1.600
7.	G	172	-8.0	34.9	+3.84	C_{FH}=(+) 842
8.	H	106	+7.1	42.0	+0.74	C_{GI}=(+)1.974
9.	I	358	+4.6	46.6	+0.51	
10.	J	712	+6.3	52.9	+0.56	C_{IK}=(+)0.133
11.	K	897	+8.7	61.6	-	
TOTAL		3335m	+23.2m			

TABLE - 5.8

PROFILE - 5

Sl No	Point	Dist-ance	h in m	Height in m	Vertical Angle in degree	Profile Curvature 9°/100m
1.	a	-	-	14.5	-0.09	
2.	b	398	-0.6	13.9	-0.06	C_{ac}=(-)0.027
3.	c	696	-0.7	13.2	-0.06	
4.	d	1331	-1.3	11.9	0.00	C_{ce}=(-)0.005
5.	e	1276	-0.8	11.1	-0.03	
6.	f	523	-0.3	10.8	-0.02	C_{eg}=(-)0.005
7.	g	1468	-0.6	10.2	-0.04	
8.	h	544	+0.4	10.6	+0.01	C_{gi}=(+)0.005
9.	i	1361	+0.3	10.9	+0.03	
10.	j	829	-0.4	10.5	+0.16	C_{ik}=(+)0.028
11.	k	538	+1.5	12.0	+0.05	
12.	l	492	+0.4	12.4	+0.31	C_{km}=(+)0.041
13.	m	1261	+6.7	19.1	+0.81	
14.	n	540	+7.6	26.7	-0.25	C_{mo}=(+)0.141
15.	o	256	-1.1	25.6	+0.58	
16.	p	207	+2.1	27.7	+4.96	C_{oq}=(+)1.897
17.	q	377	+32.6	60.3	+1.08	C_{pr}=(+)2.445
18.	r Morgang bari	117	+ 2.2	62.5	-	
TOTAL		12214m	+48m			

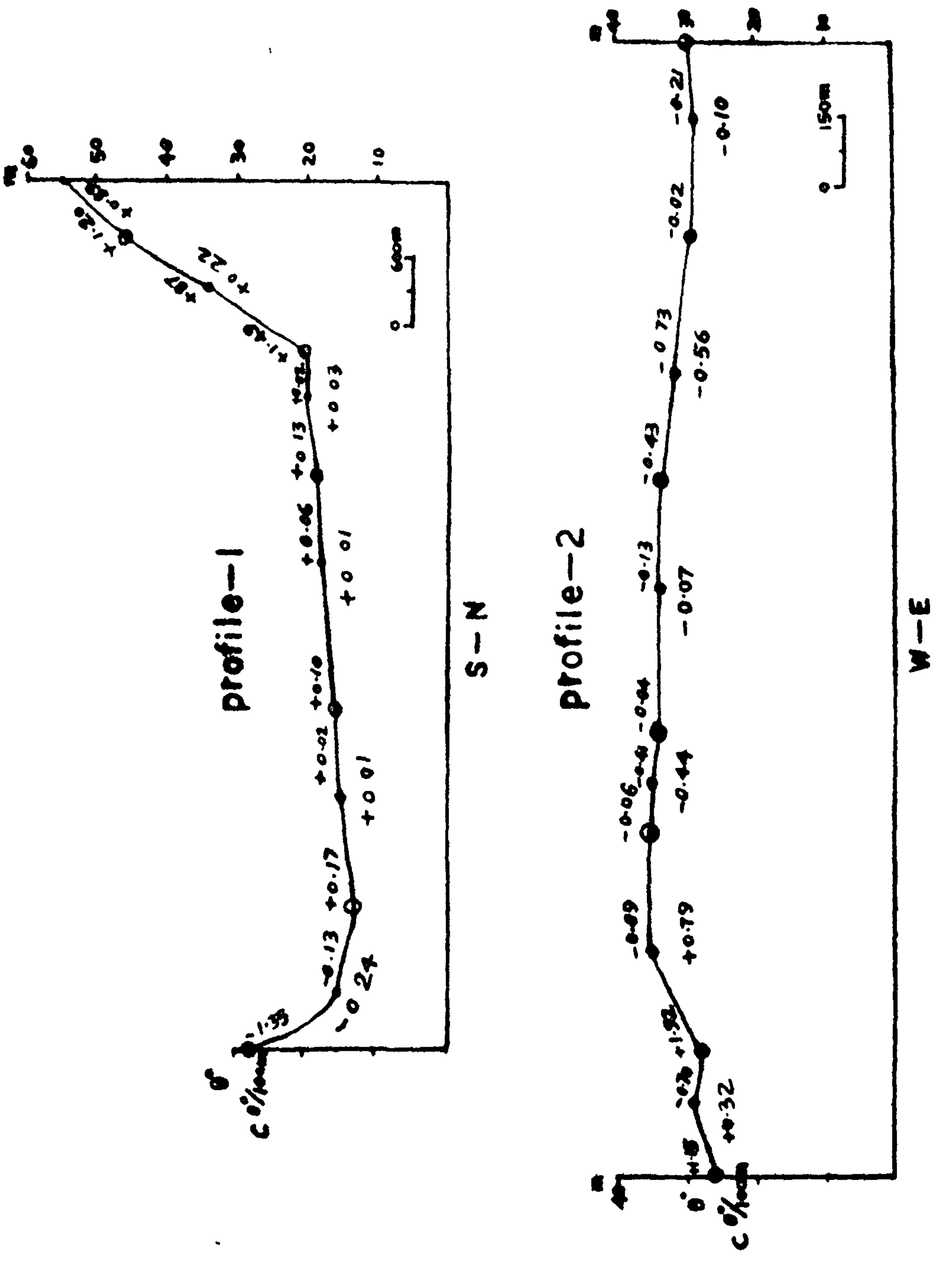

FIG.5

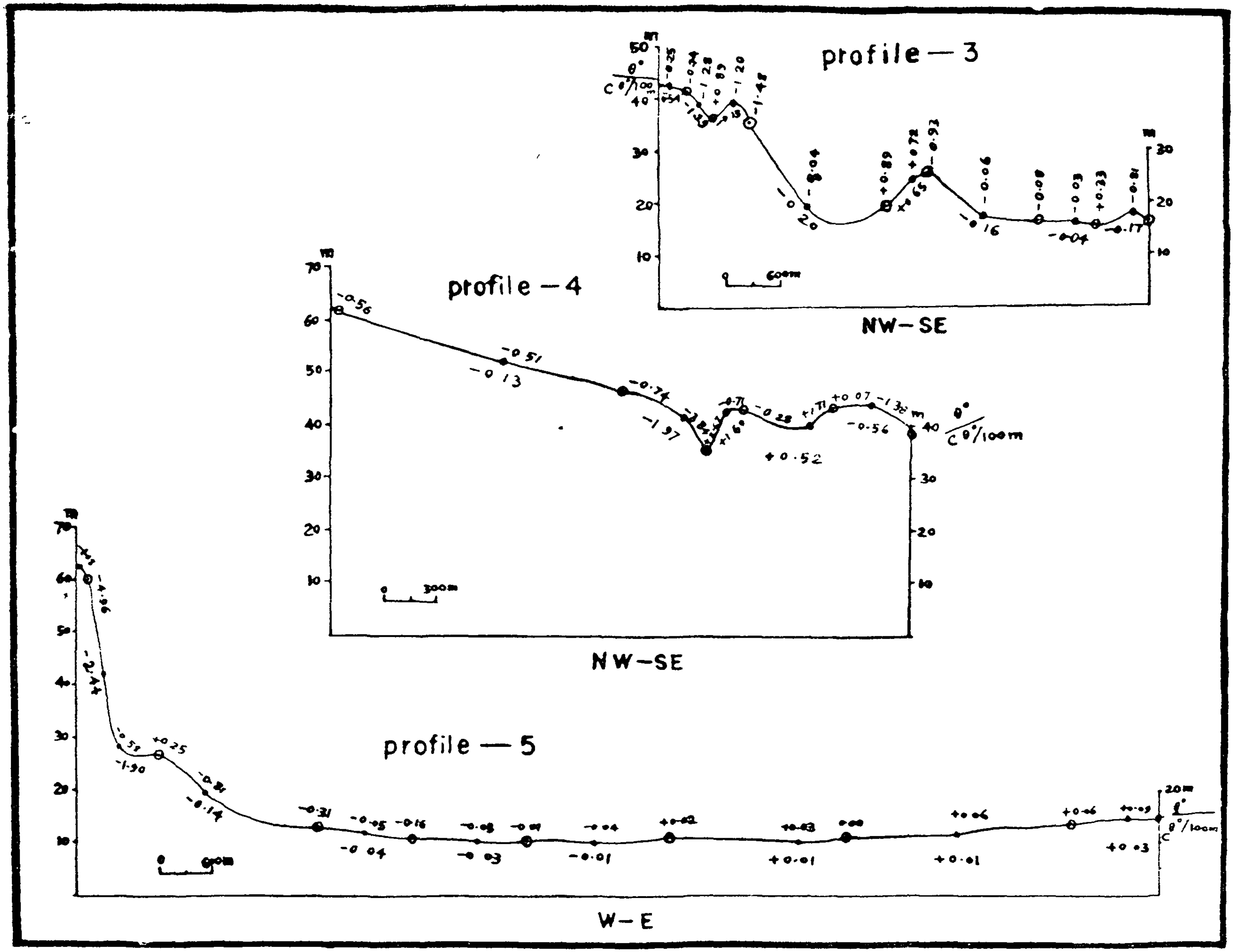

FIG. 6

The slope profiles of some of the low hills and their adjoining areas namely Morgang, Neng and Kulkulia, locating in West Tripura district as done by the thedolite traverse depicts the actual picture of the western part of Tripura, as has been categorised under 0-5^{o} average slope category (Fig. I). The thedolite traverse is done for about 30 km length and is represented in the profile (Fig. V) which represents the nature of slope. This main profile is being sub-divided into five sections for the true representation of the slope profiles in the larger scale. Mathematical tables i.e. table-4 to table-8 represents the actual observed data, out of which respective profiles (Profile 1 to 5) are constructed and represented in (Fig. V and VI). The traverse is being done mainly from east to west and as such the profiles indicate the nature of slopes practically in the east-west direction. In fact the profiles represent the nature of slopes prevailing in the isolated low hills and their surrounding regions of west Tripura. The slopes in the western Tripura are of three types viz.

i) Concave

ii) Convex and

iii) Convexo-concave.

In fact these profiles reflect the nature of slope in the entire Tripura region. In the eastern Tripura north-south trending hill ranges (anticlines) and river valleys (Synclines) are alternately arranged. If a profile in the east-west is drawn ranging in between crests of two successive hills it gives profile of a concave slope. Similarly if a profile is drawn in between two points of two successive river valleys (Synclines) it gives convest slope. The cross-section as drawn along the 23°50' represents the nature of slope in the east-west direction for the entire state of Tripura. (Fig. cross-section).

In between the hill ranges lies the river valleys and in either side of the river valleys lies (tillas) low hills of older alluvium and in between the main stream and the other alluvian lies the new alluvium of holocene period and slopes in these areas are mainly convexo-concave. In the north-south direction also the slopes are of both concave and convex along the ridges as indicated by the profiles of three important hill ridges (Muras) viz. (i) Bara Mura-Deota Mura (ii) Athara Mura-Mari Mura and (iii) Langtarai-Sardeng. The large scale slope profiles of the extreme northern and southern parts of the Muras are of gentle slope category (0-5°) as represented in the average slope map (Fig. 1). The degraded materials from the Muras are being aggraded in the (Lunga lands) flood plains. The width of the hill ranges are very narrow in comparison to their length. The eroded materials are being transported in either side of the ridges i.e. in the west and east and the slopes of the valley (Synclinal) areas are becoming gentler in comparison to the hills (anticlinal) areas. The Central Tripura forms the water-shed zone for all the rivers of the state irrespective of their direction of flow and as such the eroded materials from the high hill ridges of east Tripura are being transported to the west mainly by the west flowing rivers.

For example Gumti, Burigang, Sonai, Haora rivers are flowing from east to west of which the catchment areas of Burigang, Sonai and Haora rivers are located in the average slope category of $0-5^{o}$ and $5-10^{o}$. Out of which only a part in the source comes under the category of $5-10^{o}$ lying in the western side of Bara Mura hill range, the range which itself is representing smooth profile in comparison to the successive hill ranges lying in the eastern Tripura e.g. Athara Mura, Langtari, Sakhan and Jampui.

TABLE-5.9

NATURE OF PROFILE

Profile No	Nature of Profile	Length in metre	Range of elevation in m
1.	Concave	7220	15.1 to 55.3
2.	Convex	2309	26.0 - 35.1
3.	Convexo-Concave	5384	15.9 - 42.5
4.	Convexo-Concave	3335	34.9 - 61.6
5.	Mostly Concave	12,214	10.2 - 60.5

Out of all the profiles it is seen that only some parts of the main profile (Fig. 9) represents Convexo-Concave slope along the comparitavely high hill e.g. Kulkulia, Neng etc., otherwise the mounds (round shaped chills) represents convex slope and next to it to the lower parts lies the concave slopes. Generally convex and concave slopes are alternately visualised in the east-west direction. These profiles are available at random in the western part of Tripura, mainly in the west of Bara Mura hill range. Some other places in the extreme north and southern river valleys where average slope categories 0-5° and 5-10° are available, the nature of slopes are also similar to the slopes as in the western part of Tripura. If a continuous traverse is done along a hill range in addition to concave and convex, convexo-concave slope is also available as indicated in the profiles of the important ridges(Fig.VII). The sharpness of difference in between the slope categories and in the nature of slopes increases from west to east.

NATURE OF SLOPE AND ITS DEVELOPMENT

The State of Tripura exhibits primary endogenetic and secondary exhogenetic slopes. The endogenetic slopes that have been produced by faulting, folding and compre-ssional forces have been obliterated, altered and modified by exogenetic processes operating on them since oligocene period. Most of the slopes of the western Tripura and northern and southern margin of the state are exogenetic in origin. Whereas slopes of the eastern Tripuras is of both endogenetic and exogenetic in character and is based on complex geological formations. Coully erosion is prominent in west Tripura and in the synclinal valleys of the east, whereas during the rainy season mass movement and landslides are regular features in the eastern parts, mainly in the structural hills of steep and very steep slopes.

Element of Slope form (Fig. VII A & B)

Field observations, slope profiles, curves maps

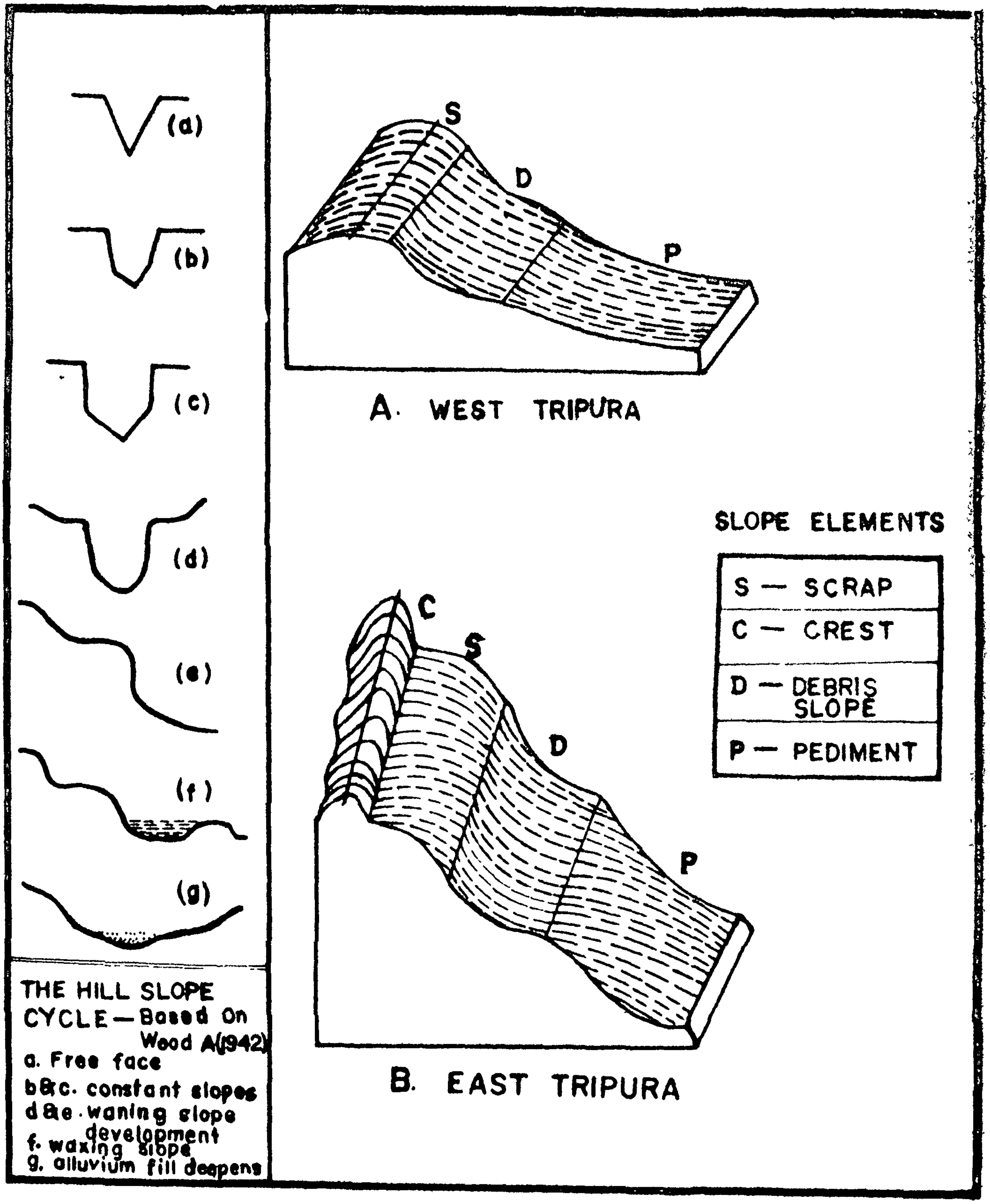
(a)
(b)
(c)
(d)
(e)
(f)
(g)
THE HILL SLOPE CYCLE—Based On Wood A(1942)
a. Free face
b&c. constant slopes
d&e. waning slope development
f. waxing slope
g. alluvium fill deepens
S
D
P
A. WEST TRIPURA
SLOPE ELEMENTS
S — SCRAP
C — CREST
D — DEBRIS SLOPE
P — PEDIMENT
C
S
D
P
B. EAST TRIPURA

FIG. 7

and lineaments reveal that in Tripura there are mainly four elements of slope viz. (i) Crest, (ii) Scarp, (iii) Debris slope and (iv) Pediment.

Crest - This element is available in the sumit area (higher parts) of the hill ridges where convex slope is on the high hill ridges. Crests are located within 15-20° slopes. There is a critical distance over which least erosion takes place during winters and less erosion takes place during monsoon showers by way of rills.

Scarp (free face) - It is the bedrock out crop on the steep slope area (20° and above) and is more active element in backwearing of the slopes as a whole. As the distance from the water parting is more only erosive power of water flowing is either in the form of rills or thin sheets, which steepens the slope profile. In steep scarps landslides occur in the higher parts of hill ranges viz. Athara Mura, Longtarai, Sakhan and Jampui.

Debris Slope (Constant slope)

It is formed by detritus taken from the scarp above. Angle of repose of the coarse sandy materials determine its angles. Weathering reduces it to finer particles, which are then removed by streams, in the form of rills. Generally 10° to 15° slope angles form this category. Due to moderately gentle slopes of free face the maximum deposition of debris has been observed in the Sadar and Udaipur sub-divisions of the State, in comparison to Dharmanagar and Kailashahar sub-divisions. The process of retreat of the debris slope keeps pace with the retreat of the scarp slope. Debris slopes are at random developing in the western, northern and southern parts of the State.

Pediment (Waning Slope)

It is the broad concavity extending from the base of the other elements to the stream or alluvial flood plains. Rock cut feature is available mainly in Ahtara Mura where Khowai river and Gumti river had crossed the range while flowing towards west from their upper reaches. Pediment zone is occupied by the plain surface in the slopes ranging mainly from 5° to 10°. The ~~infor~~ uniformitarian nature of hillslopes[6] are developing out of the main slope elements.

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[6] L.C. King, The Uniformitarian Nature of Hill Slopes, (1957), pp.81-102.

Five slope categories viz. Very Gentle, Gentle Moderate, Moderately Steep, Steep and Very Steep, respectively has developed in recent formations; old alluvium formation; unconsolidated sadimentary rocks of sand and silts; unconsolidated to consolidated sedimentary rocks and hard compact sadimentary rocks.

Straight slope angles are developed on the flood zones of modern deposits and all other higher slope angles are developed successively surrounding the areas under the flood zones of respective river basins. Slopes 10-15^{o} forms the characteristic angle with maximum area under it and forms the angle of rest of the scree debtis. Successive higher slope angles are developed on the successive higher and older rock formations leading to the development of very steep slopes along a strip of land in the southern part of the Jampui hill range, which is of sedimentary rocks of Bhuban formation.

Gnele slope (5-10^{o}) forms the characteristic angle in the western Tripura and some other pockets in the northern parts, whereas moderate slopes (10-15^{o}) forms the characteristic angle in the eastern parts and north-eastern parts. Generally 10-20^{o} slopes, where the frequency is higher, constitutes the transition zone in between the gentle and steep slopes.

Slopes are the basic forms of landscape features, which under the continuous impact of geomorphic processes tend to attain a common level which is directly or indirectly connected to the Grand Base Level of the Bay of Bengal. Initial slopes are developed along the structural hills down which streams and rivers first begin to flow towards the gentle slopes in the valley sides. The seaward and consequent slopes of the region are secondary slopes (10-29^{o}) and down which important tributaries of the rivers develope subsequent slopes (5-10^{o}) and thereafter plains lands with gentle and straight slopes.

The development of slopes in Tripura is mainly due to the fluvial action of streams and rivers under impact of high humidity, thermal condition and heavy rainfall. Average slope in Tripura ranges from 0^{o} to 30^{o} of which very gentle slope 0-5^{o}) category occupies largest area i.e. 36.47 per cent of total area of the State, which is of recent and sub-recent formation. The steep and very steep i.e. 20-25^{o} and 25-30^{o} occupies respectively 1.50 per cent and 0.25 per cent of total area which are of Bhuban Formation. These variations are influenced by the lithological, structural, topographic characteristics of the underlying rock formations, in combination with other geomorphic elements.

Important slope categories in the region are closely connected to the particular landforms at a certain altitude. The association of particular litho-stratigraphic unit with distinct slope category demarcate different zones of land formation. The linear and areal distribution of the average slope of the State of Tripura reflects the salient features of its surface in relation to lineament, dissection, structure and relief. In this State, younger the geological formation, gentler the slope, which may otherwise be stated that older the rock formation steeper the slope. Gentle slopes and even straight slopes are developing mainly in the western parts and the steep and very steep slopes are developing in the easternmost part of the state. Parallel slope retreat is taking place along the steep and very steep slopes in the high hill-ranges, which is responsible for the development of 'V' shaped narrow river valleys in between the successive hill ranges. Concave surface has developed by the recession on pediment surface, which may be attributed to the combined action of fluvial erosion and retreat of slopes. Convex surface has developed on the subdued hill crests. In Tripura slope is the single largest determinant of landforms that affects both man and environment.

3. Land slides on the steep slopes of Sedimentary rocks of Athara Mura Hill.

4. A view of the hard sedimentary Bhuban rocks exposed along a steep Slopes near Unokuti Hill.

1. A view of the vegetables grown on the flood plains of Gumti river near Udaipur.

2. A view of parallel spurs on the bank of river Khowai near Baramura.

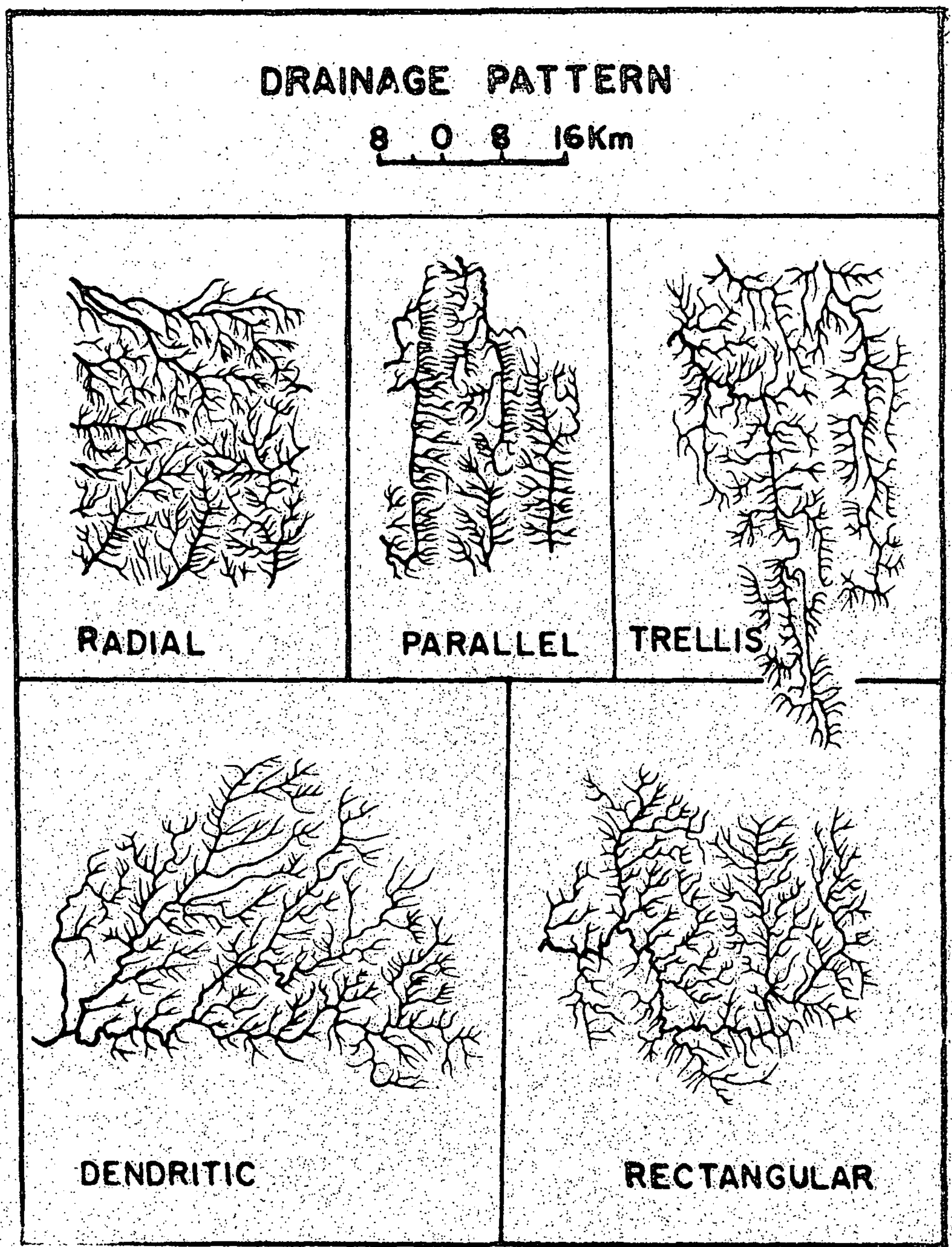

DRAINAGE PATTERN
8 0 8 16Km
RADIAL
PARALLEL
TRELLIS
DENDRITIC
RECTANGULAR

FIG I

MORPHOMETRIC ANALYSIS

> "Morphometry may be defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of the landforms. The main aspects examined here are the area, altitude, volume, slope, profile and texture of the land as well as the varied characteristics of the drainage basins."
>
> – J I CLARKE (1966)

James Hutton, as the leader of the plutonist group, had recognised the evidence for metamorphism of of rocks and founded the concept "Present is the key to the Past". Geo-Morphometry differentiates the measurement of the shape of landforms from geology. After the Second World War, the study of physical geography and its objectives have changed, thus changed are the objectives of geomorphological studies. Morphometric analysis is essentially needed for identification of geomorphic characteristics of a region like Tripura. The surface features of Tripura are the landscapes most prominent visual characteristics. Even Geologists can not ignore surface features, which draw significant inferences about internal constitution of a geomorphic region. The study of rocks and processes thereof leads to the study of landforms. Morphometric methods and techniques are applied to have a clear understanding of the geomorphic characteristics of Tripura which are responsible for the development of landforms, their interpretation in respect to both causes and nature of phenomena are also important.

The State of Tripura, though occupying a small area of the earth surface, it represents a varied topography, lithology, structure, texture, slope, drainage density, stream frequency, numerous streams and rivers, hills and hill ranges, which provide a very wide field for investigation, interpretation and analysis of various geomorphic elements to diffuse the geomorphic bondage of this small region as of a type. Morphometric methods and techniques are of great significance from the point of view of geomorphic investigation. Morphometric interpreation is necessary, for the proper evaluation of the earths surface features, their characteristic properties and process of evolution of landscapes. Even experimental laboratories have been set up in United States of America and some other developed countries for correct determination and accurate application of hydraulic laws to wave current and stream action. In fact the study of landforms can never be fully explained and be reduced to mathematical equations with laboratory experiments also.

PHYSIOGRAPHY

Physiographic features represent the major geomorphic elements as observed in Tripura, are of both structural and topographic significance; which are mostly in accordance with the normal landscape features. The whole state of Tripura is dissected into a number of narrow to broad and long river valleys. These river valleys are located mostly in the eastern part, alternately in between the north-south trending, parallel hill ranges. In the western part, there are few shallow anticlinal ridges and small hills. There are five prominent hill ranges with numerious dissected hills and spurs, which are as follows:

1. Jampui 2. Sakhan
3. Longtarai 4. Athara Mura and
5. Bara Mura

Development of alternate synclines and anticlines in the eastern part of Bara Mura is distinctly marked as an important Geomorphic feature. The important rivers

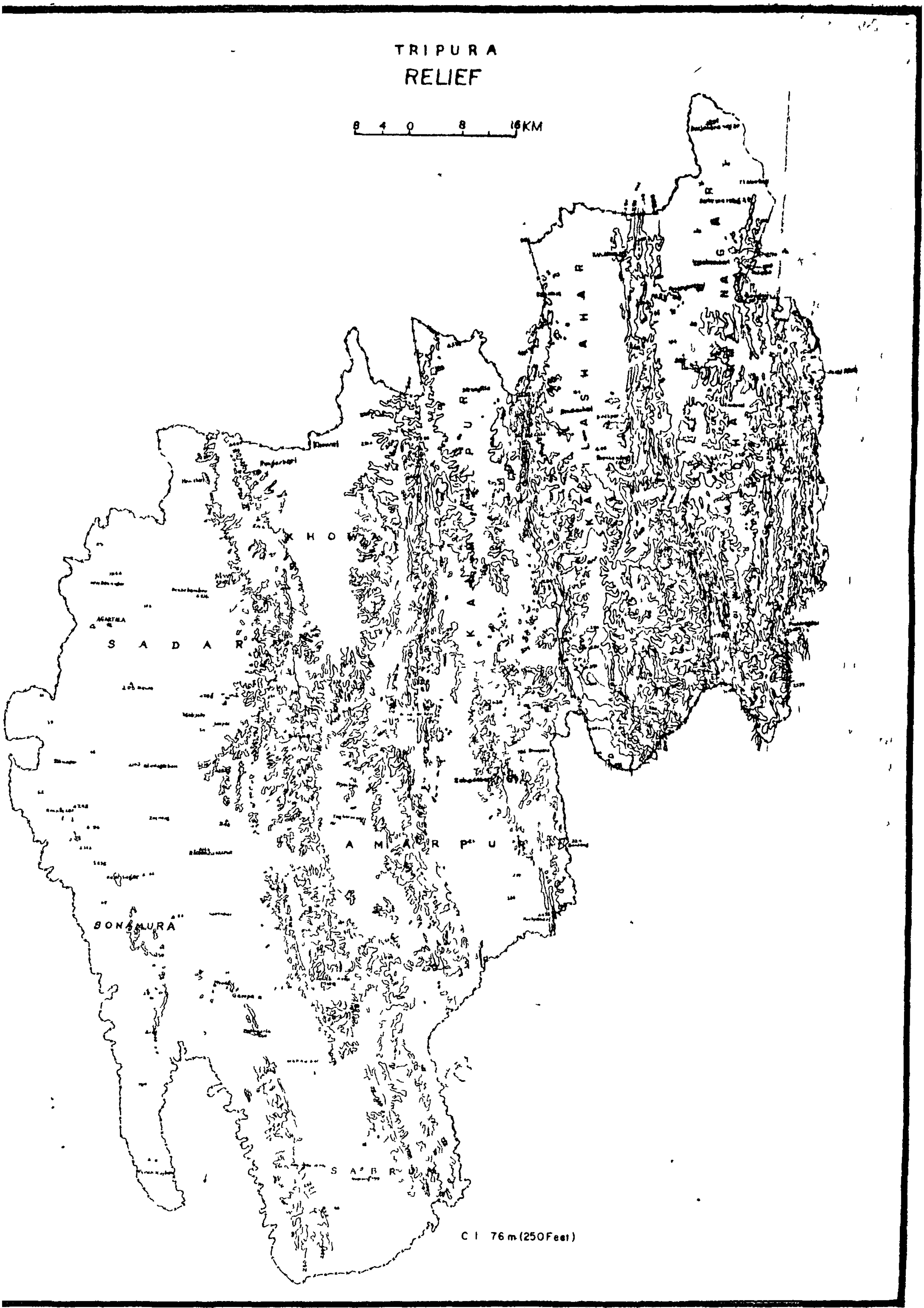

TRIPURA
RELIEF
8 4 0 8 16 KM
SADAR
KHOWAI
AMARPUR
SONAMURA
SABROOM
C I 76 m (250 Feet)

FIG. 2

and their characteristics have been referred with reference to drainage and some of the characteristics of important hill ranges.

The Jampui range is in Dharmanagar Sub-division, which is about 74 Km in length and highest peak is Betling Sib, which is about 975 m. in altitude. The Sakhan range is about 56 Km in length and forms the inter-Sub-division boundary between the Dharmanagar and Kailashahar. The northern part of Sakhan is about 20 km. in length and is known as Unokuti. The Long-tarai range forms the common boundary of Kailashahar and Kamalpur Sub-division, which is about 48 Km in length. Highest peak is the Longtarai which is about 515 m in height. Athara Mura forms common boundary at many places in between Amarpur, Khowai and Kamalpur. Highest peak of the Athara Mura range is Niungmarueta which is about 514 m in height.

A small hill range joins southern part of Athara Mura - Jari Mura with Sardeng. Bara Mura is the western most hill range and is about 47 Km in length. Its southern part is known as Debta Mura which is about 85 Km. The north-South trending hill-ranges are inter-connected by a transverse range extending from the direction of Mizo Hills to the western part of the State. The same transverse range from the major watershed zone of the region, which delimits the catchment areas of both north and south flowing rivers. Almost all the hill-ranges are thickly forested, which with the lapse of time and progressively increasing human activity has changed them into a few barren patches.

DRAINAGE

According to Doornkamp and King,[1] when air photographs of the same quality and scale are used for delimitation of river valleys, uniformity is more likely to result, than when only topographic maps are employed.

Stream frequency and drainage density respectively give a measure of number of streams per unit area and total length of streams per unit area. Variables are related to basin form and development and are the result of denudational processes. Landscapes ase observed in the region are the outcome of the fluvial processes which have been operating in the geological

[1] John C. Doornkamp and C.A.M. King, Numerical Analysis in Geomorphology (1971), p.12.

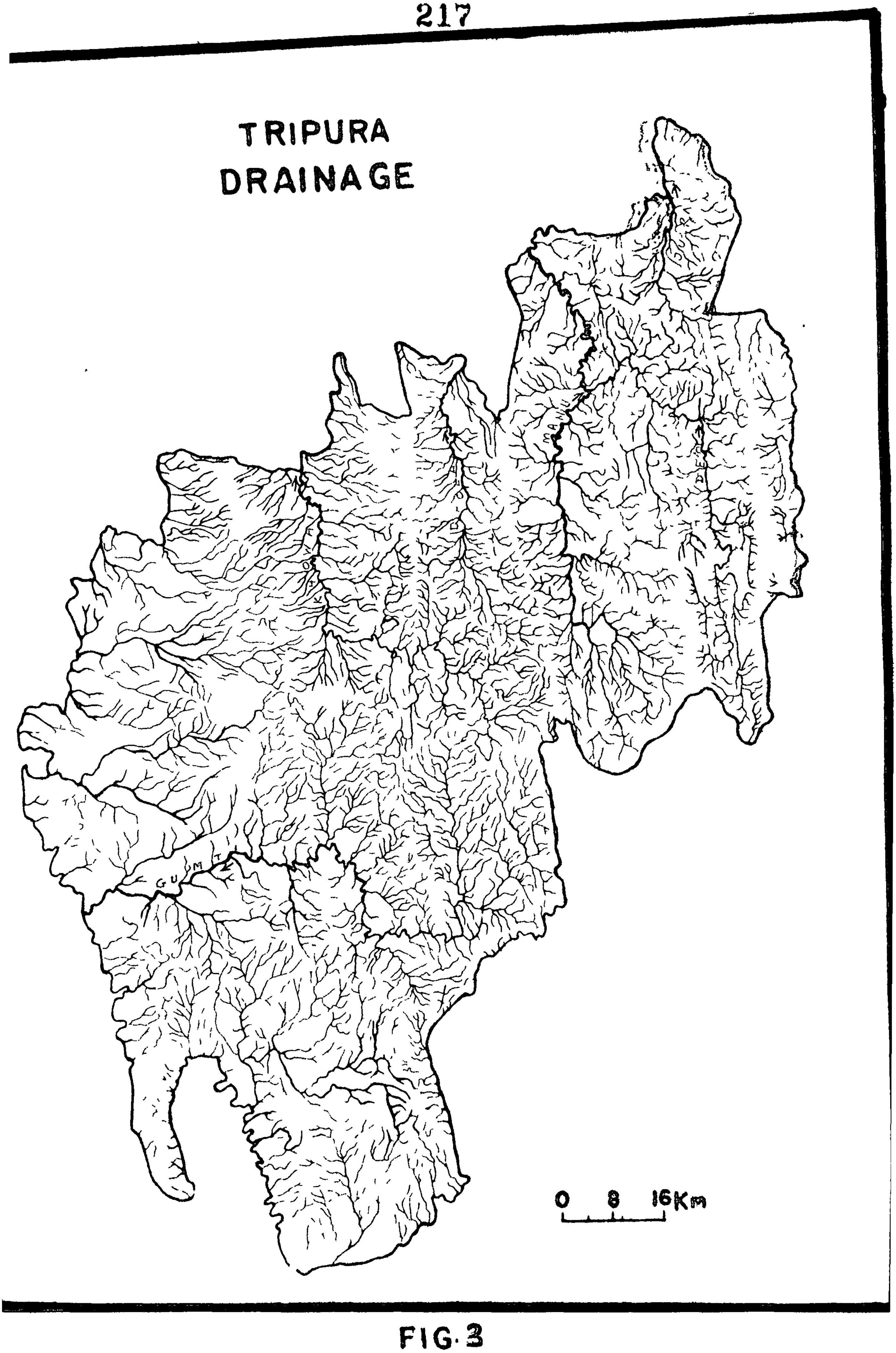


FIG. 3

past. Processes in operation at present are also moulding rise to the shape of landforms. The Present form of a drainage basin may be the result of a sequence of different morphological processes.

The processes responsible for the development of the present landforms can be reflected through present day basin characteristics. There is a dynamic equilibrium of forces. Morphometry of the drainage basins, is an approach towards the study of equilibrium between form and forces in respect to dynamism of the physical environment. The whole State is dissected by a number of north-south aligned river valleys, which are located in between successive parallel and sub-parallel anti formal ridges. The river basins consist of flood plains, lowlands and parts of watershed zones. The valleys are broken by intermittent round shaped hills. Most of the rivers rise from hill ranges which are being fed by innumerable streams. Most of the streams flow through the valleys into the mighty rivers of Bangladesh viz. Kushiara, Meghna etc.

DRAINAGE PATTERNS

Drainage patterns of the region or a river basin of it reveals the particular plan or design, which the individual river with its stream courses collectively form and represent. Drainage pattern and the litho-logical structure of Tripura represents the nature of adjustment with one another. It also reflect the influence of slopes, differences in rock composition, softness, hardness, porosity, structural controls, diastrophy and the recent geologic and geomorphic history of the area of study. The drainage map (Fig.II) reveals that there are five types of drainage patterns, as mentioned below:

(i) Dendritic pattern;
(ii) Parallel pattern;
(iii) Radial pattern;
(iv) Rectangular pattern; and
(v) Trellis pattern.

(i) Dendritic Pattern

It refers to the type of drainage as developed when a consequent river receives a number of tributaries, which in turn are fed by smaller tributaries. The whole pattern is like a tree with numerous branches (Fig. I). Small rivers in the western Tripura for example Haora river, Buri Gang, Lohar nadi belongs to this category. The rock formation formed in these areas are mainly alluvial deposits. Prominent streams of the young rivers like Khowai, Manu, Deo belong to this category. North flowing Dholai river in between Athara Mura and Longtarai hill ranges represents a typical example of this pattern. Even Raima charra and Chaima chara, two major streams of the Gumti river belong to this category.

(ii) Parallel Pattern

The ridges run in the N-S direction with alternate valleys, major faults also run in the same alignment. Most of the faults and folds are lying in the north Tripura's central part, where main channels of the rivers viz. Juri, Manu, Khowai run parallel to each other. Average slope map indicates that ridges consist of moderately steep and steep slopes. Most of the streams follow the NE-SW lineaments and as such parallel pattern have developed, within the limit of a particular lithological unit. Again prominent perennial streams of many rivers are originating from the hill ranges, runs parallely and joins the main channel almost tangentially.

(iii) Radial Pattern

In the State of Tripura there are some typical example of this pattern (Fig. II). This type is produced when streams flow outward from a central upland of domal shape. In the drainage map it is clearly seen that there are two distinct radial patterns, one in the central Tripura which includes streams of the Gumti and the Khowai river, which also includes the watershed zone in between the above mentioned rivers. The other in the left bank of the Gumti river and is formed mostly by the streams of the Gumti and Muhuri river i.e. in the South Tripura. Spot heights as observed indicate that Central Tripura is higher in comparison to its surroundings. Relief map supports the domal shape of the area with radial pattern. Only few contours are seen in the western, southern and N-E Tripura with the exception to the Tripura where the gradient is steep.

(iv) Rectangular Pattern

A system of folding and faulting gives rise to a rectangular pattern in three river's courses, which are namely Deo river an important tributary of Manu river in the N-W, Khowai river in the Central Tripura and Gumti river in north Tripura. Geology and land-form plays the most vital roles in the development of rectangular drainage pattern. It is seen that wherever the rivers are obstructed by a ridge or resistant rock structure, the rivers take a sharp change in its course at the end of the ridge or at a place of less resistant rocks.

(v) Trellis Pattern

This pattern is developed if an area is tilted and the differences in rock types which are exposed to erosion. The tributaries of Deo river and Langai river are of this pattern. This pattern is dominant in the limestone area of south-eastern part of Tripura. Average slope map shows that in the south-eastern part the dip is highest in comparison to the other parts of the area of study.

The trellis pattern has developed in the areas adjacent to western Mizoram where folded ridges of resistant rocks are prevalent, especially in between the Jampui and Sakhan hill ranges of more than 600 m in altitude. The main consequent drainage cuts across the cuestas the subsequent drainage follows the strike valleys, long tributaries to the subsequent drainage flow down the dip of slopes of the cuestas, and short, steep tributaries flow down the scarp-face. The result is the classic trellis pattern in the

N-E Tripura along western Mizoram.

STREAM FREQUENCY

Jukes (1862) had presented a classical paper on rivers of southern Ireland in which he recognised the existence of two main types of streams viz. - (i) transverse streams which flow across geologic structure and (ii) longitudinal streams which develop along belts of weaker rock parallel to the structure or strike of rock strata. He had also believed that longitudinal streams developed later than transverse streams and should be recognised as subsequent streams.

J.W. Powell (1834-1902), studied the Unita mountains and impressed by the importance of geologic structure as a basis for classification of landforms. G.K. Gilbert (1843-1918) was the first geomorphologist who recognised sub-aerial erosion and many modifications which valleys undergo as streams erode the land. He had recognised the importance of lateral planation by streams in the development of valleys. His quantitative approach was to correlate the stream load, river volume, river velocity and gradient.

Method of Study

Stream frequency is an important morphometric

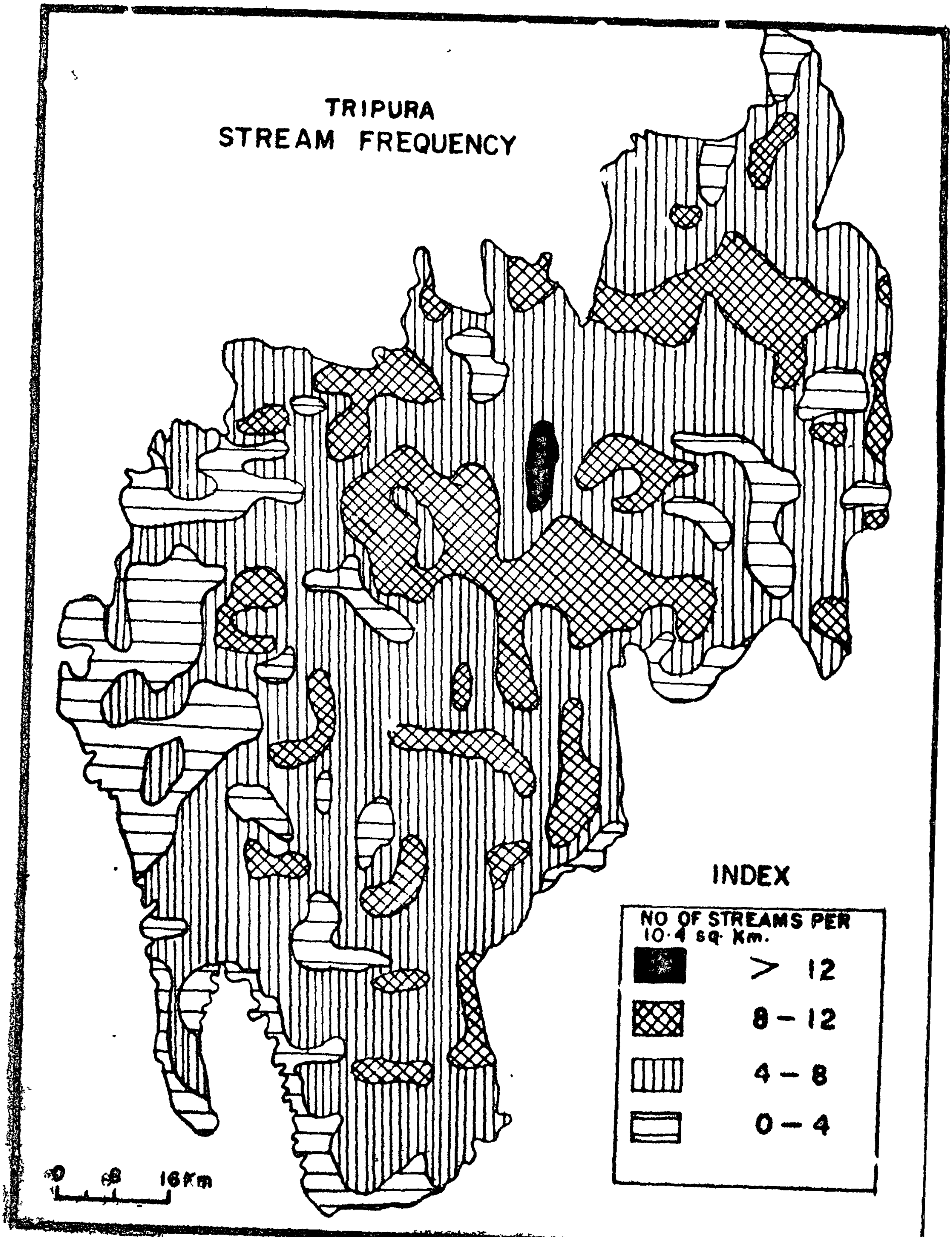

TRIPURA
STREAM FREQUENCY
INDEX
NO OF STREAMS PER 10·4 sq. Km.
> 12
8 – 12
4 – 8
0 – 4
0 8 16 Km

FIG. 4

analysis of the drainage basins, which indicate the number of streams per unit area. Computations of stream frequency has been done with the help of the following formula:

$$F_s = \frac{N}{A} \text{ where } F_s = \text{Stream frequency}$$

N = Total number of streams

A - Area (Unit Area means 10.36 sq. km.)

TABLE - 6.1

AREAL EXTENT OF STREAM FREQUENCY

Sl No	Texture	Stream category	Frequency	Area in Sq. km.	Area in % to total Area
1.	Coarse	0 - 4	Low	1300	12.41
2.	Medium	4 - 8	Moderately low	7458	71.19
3.	Fine	8 - 12	Moderate	1682	16.05
4.	Very Fine	> 12	High	37	0.35
TOTAL				10,477	100.00

The isopleth map is drawn according to above mentioned categories to study the spatial variation of stream frequency over the surface at various parts of the region. Stream frequency map (Fig.IV1) clearly indicates that most of the area of the region is covered by the category of medium frequency i.e. 4-8 streams per 10.36 sq. km., which is 71.19 per cent of total geographical area of the region, whereas very fine category i.e. more than 12 occupies only about 37 sq.km which is only 0.35 per cent of total area. Climatic factors and the intensity of rainfall in combination with other geomorphic elements viz. vegetation, ground water potential, rock structure, lithology, altitude, slope etc. play important role in the development of stream frequency.

The greater part of Tripura is densely covered with vegetation like grass, creepers, cane, bamboo and mixed forests. The common forest trees include the mythical chhattim (Alstonia scholaris), the Chamal (Artocarpus chaplasa) the fibrus Udal, the garjan, the Sal, the teak etc. Total area under forests is estimated to be 6193.21 sq. km. i.e. 59.11 per cent of total area. Vegetation cover of the hilly areas serves as a barrier between the atmosphere and the ground surface, intercepts a good percentage of total rainfall, which also diffuses radiation. Evapo-transpiration system significantly regulate the whole water regime. Vegetation narrows the temperature ranges, increases the amount of moisture in air and soil, which has immense impact on the development of streams.

ROLE OF LITHOLOGY IN THE
DEVELOPMENT OF STREAMS

Porosity of clay, unconsolidated silt, sand, sandy clay, decomposed vegetable matter is very high, this type of lithology is prevalent in the westernmost part and some valley regions in the northern and southern parts of the State. As a result low stream frequency 0-4 has developed in this alluvial soil of Recent Formation with gentle slopes (0-5°)

Old alluvium (Dupitila) of Pleistocene period, Tipam group of the Pliocene period and a part of Surma group of Mio-pliocene period consisting mainly reddish-brown to buff sandy clays, sandy loams, sandy shale, ferruginous sand stone, pockets of grey plastic clays, silt stone and sandy mud-stone, with less porosity and moderate slopes (5-10°) and altitude in comparison to the Recent Formation; it is responsible for the development of moderately low stream frequency i.e. 4-8.

Surma group of Mio-pliocene period consists of thinly bedded repetition of sandstone, siltstone, shale alterations, shales and ferruginous sandstone etc. has moderate resistance capacity, where run off makes its way along the weak rock structure with average slopes 10°-20°. As a result areas covered by the group of rocks has developed moderate stream frequency i.e. 8-12 which covers 16.05 per cent of total area of the State.

Bhuban group of rocks area of hard compact both massive and well bedded which have least porosity in comparison to the other geological formations which may be responsible for the development of highest frequency of streams. Thus the highest stream frequency, i.e. more than 12 is observed in an area of about 21 sq. km. at Ambasa area of Dholai river source region with complex lithological and geological structure. Superimposition of geology, slope and stream frequency maps in a single one reveals the inter-relationship of the lithology slope and stream frequency both in spatial and areal aspects.

TABLE - 6.2

CORRELATION OF STREAM FREQUENCY, SLOPE AND LITHOLOGY

Lithology	Average slope in degrees	Slope category	Stream frequency per 10.36 sq.km	S_F Category
Recent	0 - 5	Gentle	0 - 4	Low
Tipam	5 - 10	Moderate	4 - 8	Moderately low
Surma	Mainly 10-15, 15-20	Moderately Steep and Steep	8 - 12	Moderate
Complex	More than 20	Very Steep	$>$ 12	High

From the above analysis, tables and relevant maps it is clear that generally the slopes and lithologic characteristics have direct impact in the development of stream frequency. Indirectly the development of streams is dependent on altitude, vegetation cover and rainfall.

Rainfall is higher in the high altitudional places in the eastern Tripura which has generally higher stream frequency whereas the western Tripura includes greater part in the low stream frequency category due to low rainfall, low altitude and gentle slopes. The stream frequency increases from west to east along with the gradual increase in slope steepness, and the rock compactness with the increase in elevation.

CROSS-SECTION

West to East

The section has been prepared from quarter inch toposheets which represent the nature of topography along $23^{o}50'$ N latitude from near about Agartala to Phuldangsi, at an altitude of about 15m in the west and about 950m in the East, which has traversed a number of river valleys and hills.

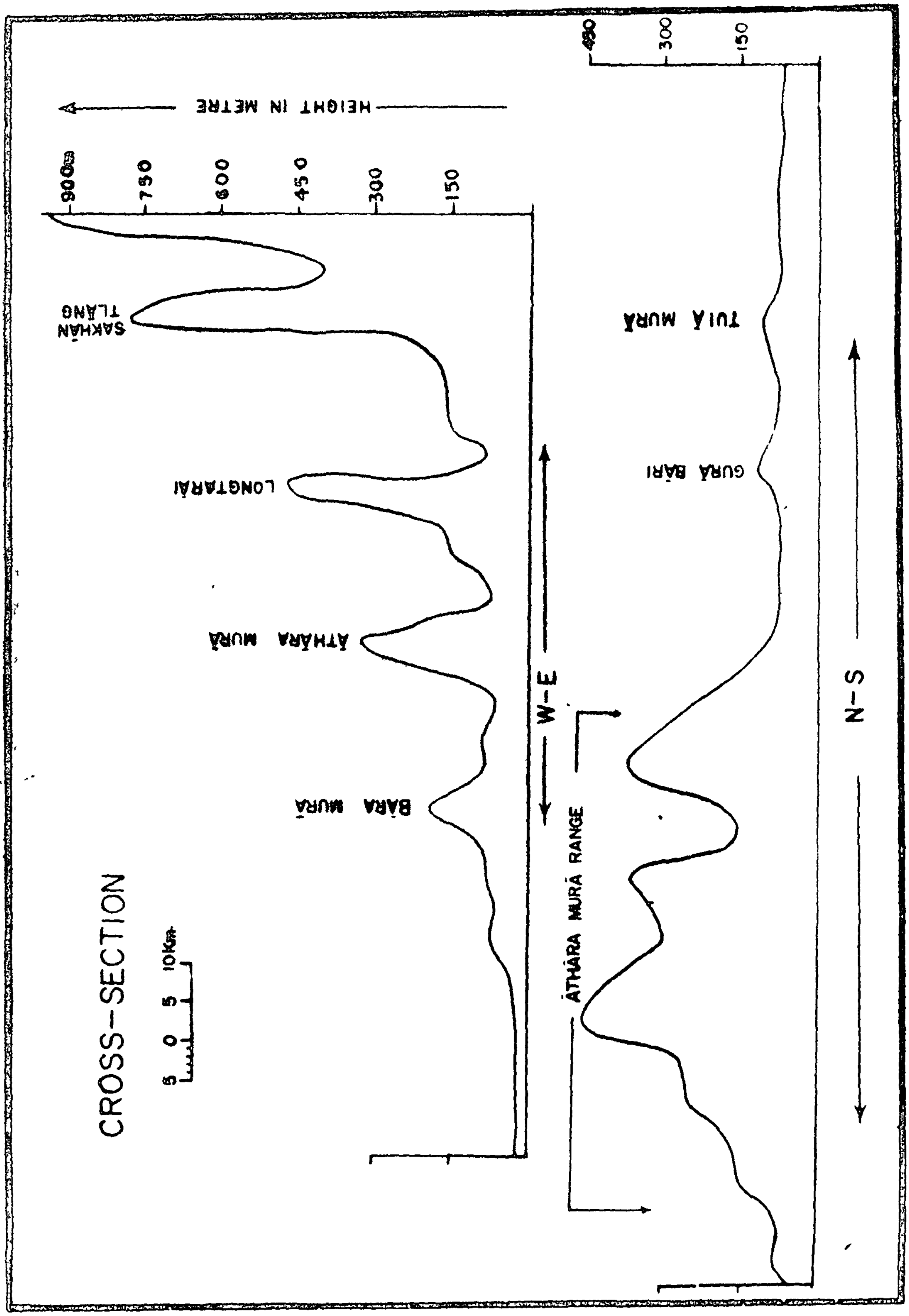

CROSS-SECTION
5 0 5 10Km
HEIGHT IN METRE
900m
750
600
450
300
150
SAKHĀN TLĀNG
LONGTARĀI
ĀTHĀRA MURĀ
BĀRA MURĀ
W-E
ĀTHĀRA MURĀ RANGE
TUIĀ MURĀ
GURĀ BĀRI
N-S

FIG.5

This profile mainly cuts the Haora Khowai, Manu and Deo rivers; Bara Mura, Athara Mura, Longtarai, Sakhan and Jampui hill ranges. The highest peak of Athara Mura and Longtari 480m, and the high altitudional places in between these two hill ranges form the major watershed zone of the important rivers viz. Khowai, Dholai, Manu and Gumti. It crosses Sakhan hill range at about 785 m and Betling Sib hill on the Jampui hill range at about 940 m. Jampui hill range lies in between Deo river in the west and Longai river in the east, whereas, the Sakhan hill range is located in between Manu river and Deo river. Longtarai hill range in between Dholai river and Manu river, Athara Mura in between Dhalai river and Khowai river Bara Mura hill range divides the west flowing rivers from the north and south flowing rivers.

This section indicates the nature of altitudinal differences of the successive hill ranges and river valleys. The general elevation increases from west to east, from about 15m in the westernmost part and to about 1,000m in the easternmost part. This also indicates that the western part of the Bara Mura hill range is smooth in comparison to the eastern parts, because of the fact that western parts are controlled by the base level of the Bay of Bengal along with the plains of Bangladesh. It is also marked that the valley bottoms of the river basins of the east Tripura are successively higher which gives indication of some local base levels. These local base levels are indirectly connected to the Grand Base Level of the Bay of Bengal. The remnants of oldest surface may be noticed in eastern part of Tripura. Whereas, the youngest surface may be seen in the western part of Tripura which is still in the developing stage.

North-South

The section is taken along 91°45' longitude line and northern part of this section crosses along the northern part of the Athara Mura hill range along high peaks of the 343m and 357m on the northern side of the Khowai river, where the river crosses the hill range as mentioned above. Other higher points along the section are 364m and 222m. This section divides Gumti river into two parts, the eastern part consists of its upper course with important streams. The section had also crossed the southern part of Bara Mura hill range at an altitude of about 113m at Gura Bari and about 231m at Taita Mura, which forms the watershed between the Fenny river and Manu Gang both flowing to the south. This section represents the region as described above and each N-S section represents different picture mainly in the eastern parts. For example, a section along the synclinal valley and a section along the anticlinal ridge is quite different and as such this section is not as significant as the W-E section which remains almost same for the major parts of the study region.

LONGITUDINAL PROFILES

Profiles of Gumti, Manu, Khowai, Buri Gang, Haora, Langai, Deo, Dholai, Mahuri, Fenny and Manu Gang have been prepared (Fig. VI-A & B). The rivers for which profiles have been prepared are flowing in north to south, south to north and east to west directions. Thus, the profiles give an idea that these rivers flow through different rock formations. From the profiles, it appears that there is no major nick point in any of the rivers. There are some breaks in the gradient which indicates that the region had uplifted in the different geological periods. The prominent breaks of the profiles are mostly in between 50m to 100m in altitude. In the lower reaches almost all the major rivers have attained graded profiles.

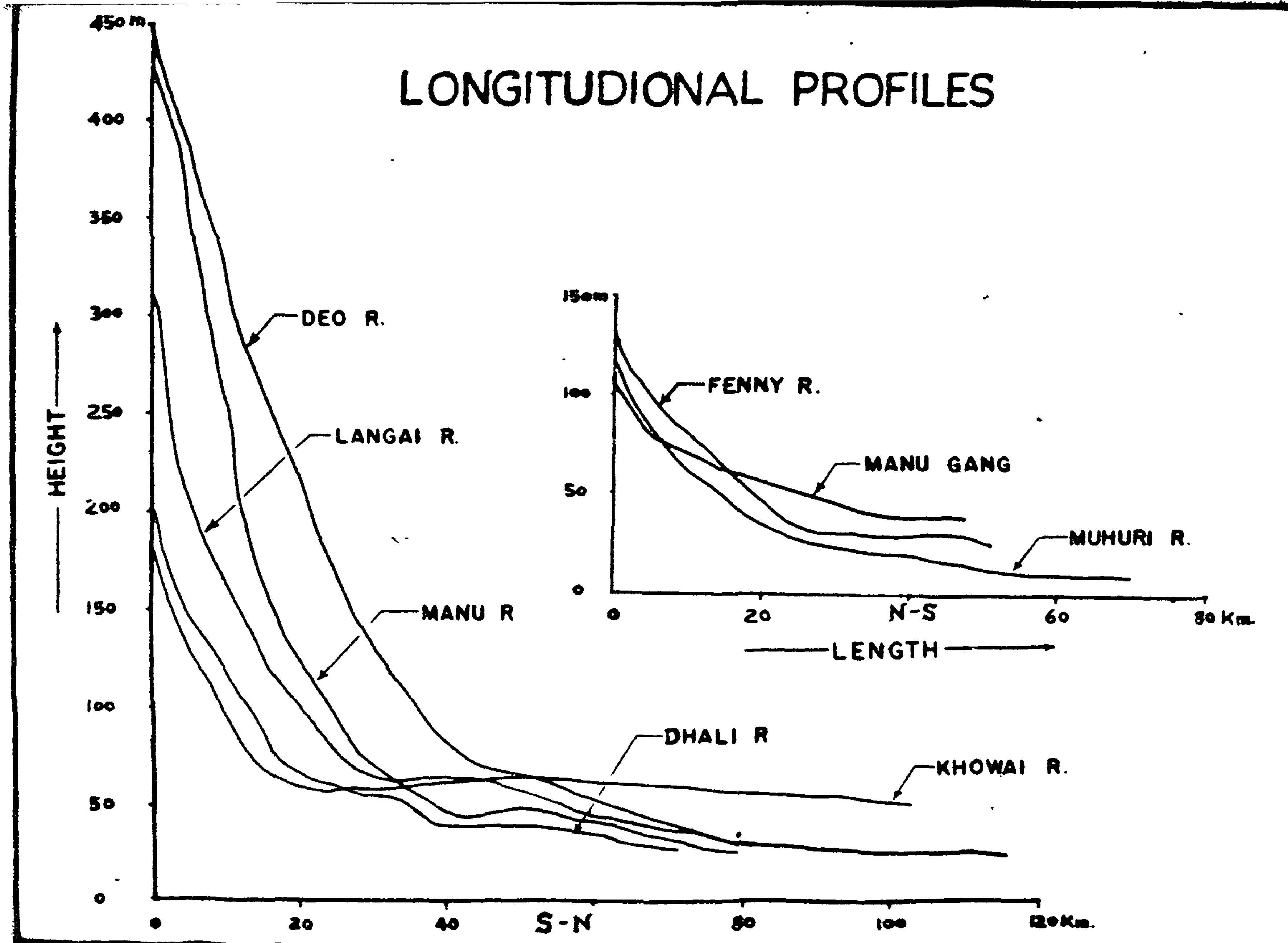
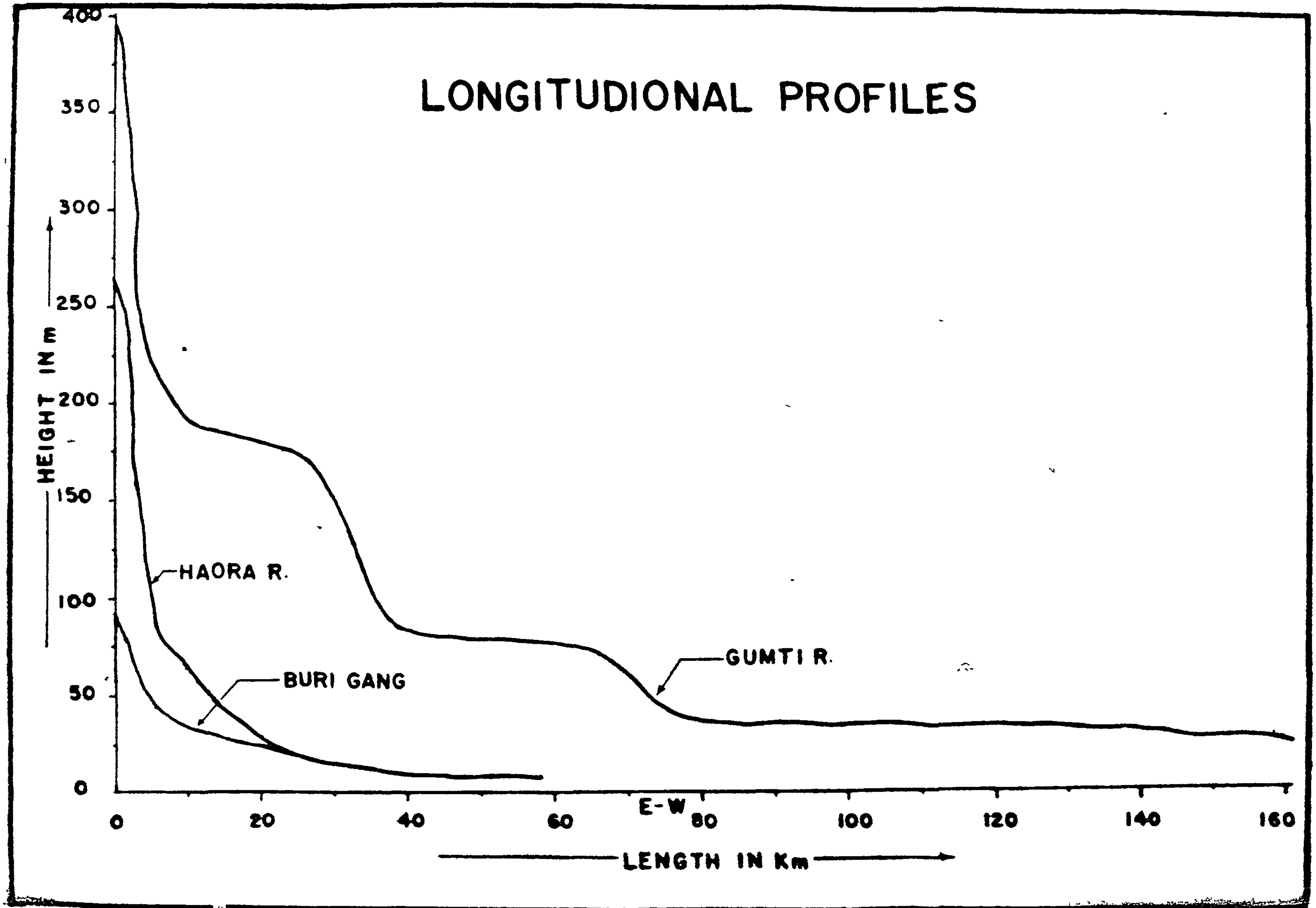

LONGITUDIONAL PROFILES
450 m.
400
350
300
250
200
150
100
50
0
HEIGHT
DEO R.
LANGAI R.
MANU R
DHALI R
KHOWAI R.
0
20
40
S-N
80
100
120 Km.
150m
100
50
0
FENNY R.
MANU GANG
MUHURI R.
20
N-S
60
80 Km.
LENGTH

FIG.6-A



LONGITUDIONAL PROFILES
400
350
300
250
200
150
100
50
0
HEIGHT IN m
HAORA R.
BURI GANG
GUMTI R.
0
20
40
60
E-W
80
100
120
140
160
LENGTH IN Km

FIG.6-B

It is generally observed that the older rivers have smooth profiles in comparison to the young north flowing rivers. Sudden changes in the profiles of Gumti and Khowai rivers give clue to the tectonic activities. Most of the rivers originate in the high hill ranges and ultimately flows towards Bangladesh plains, as such the upper courses of all the north flowing rivers are steep.

Longest profile of the oldest and biggest Gumti river of the region has a sharp break in the gradient on the eastern side of the Athara Mura hill range where the Dumbur waterfall is located. The main stream of the river turminates almost at about 90^{o} while crossing structural sedimentary hills viz: the Athara Mura, Bara Mura and Sona Mura and had maintained its course generally towards west, which gives the character of an antecedent river. The west flowing other rivers viz. - Buri gang, Haora have attained almost graded course. Similarly the Khowai though initially has flown to the west just after crossing Athara Mura range has turned to the north almost at 90^{o} angle.

In comparison to the north-south profiles, west-east profiles reflect the better picture in respect to the nature of topography with alternate valleys and the nature of erosion that has been taking place.

North-south profiles are smoother because they follow mostly the lineaments and trend lines, along the hills and valleys and represent the slopes with systematic variation. Whereas, the west-east profiles represent the differential picture of hills, valleys, slopes, altitude and nature of local base levels.

SUPERIMPOSED PROFILES

Superimposed profiles of the region represent the nature of differential erosion. A number of profiles have been drawn at an interval of five centimetre with a vertical scale of 2 cm to 150m. The profiles are drawn both in the west-east and north-south direction (Fig. VII). The profiles indicate the nature of flat alluvial plains in the west Tripura and the rugged topography in the east Tripura. Two levels of erosional surfaces can distinctly be identified from the intersection of the profiles at a certain height. The youngest surface may be seen in the western part of the Tripura at height of 50m is very close to base-level of the Bay of Bengal. The remnants of low isolated Hill tops may be seen in between the alluvial plains of western Tripura.

Superimposed profiles reveal that the western Tripura has maximum deposits and thick soil profile(Fig-VII)

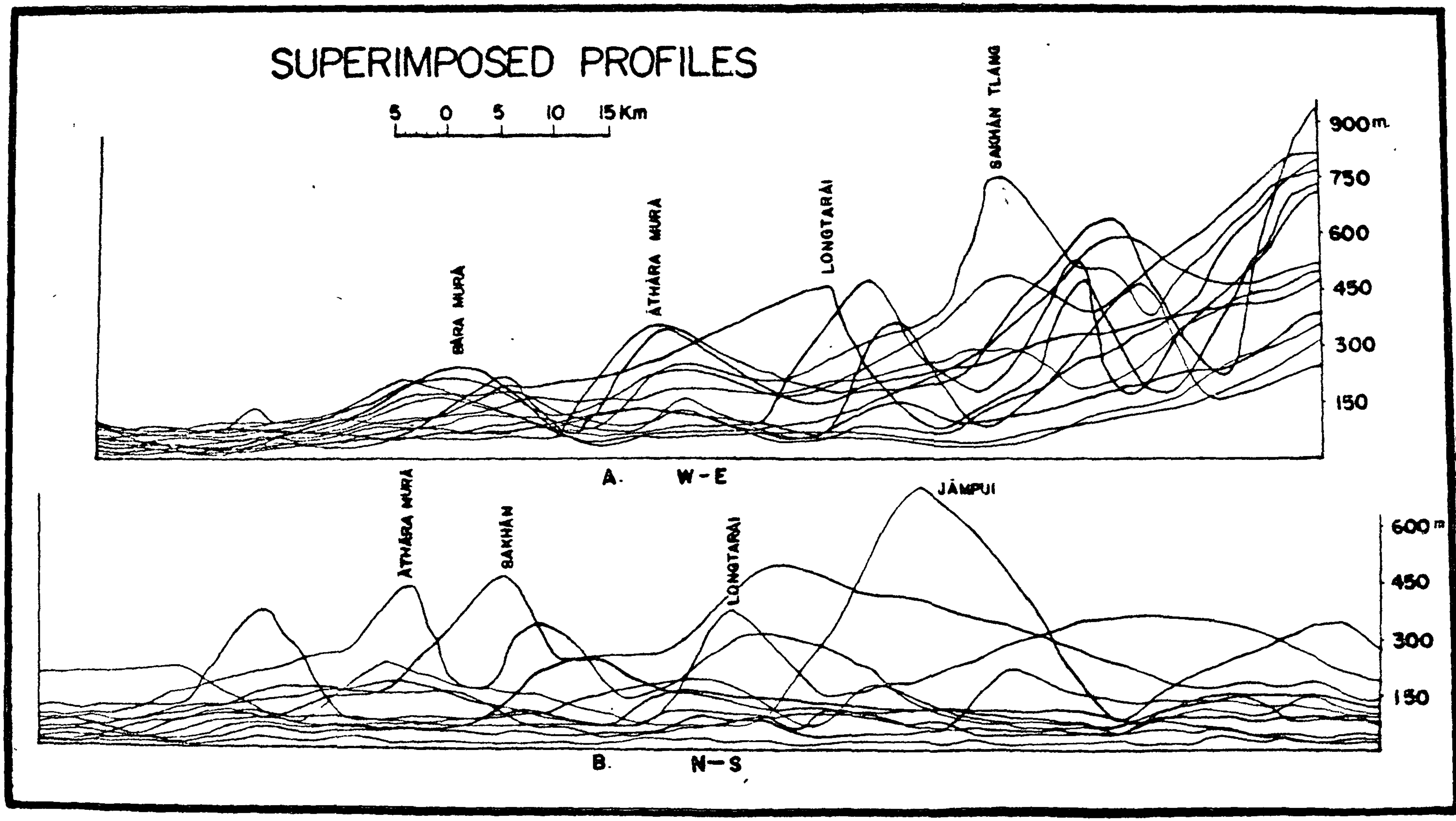

SUPERIMPOSED PROFILES
5 0 5 10 15 Km
BĀRA MURĀ
ĀTHĀRA MURĀ
LONGTARĀI
SAKHĀN TLANG
900 m.
750
600
450
300
150
A. W-E
ĀTHĀRA MURĀ
SAKHĀN
LONGTARĀI
JĀMPUI
600 m
450
300
150
B. N-S

FIG. 7

The north-south superimposed profiles indicate that the northern and southern parts are low in altitude and has thick soil profile in comparison to the central Tripura. This is due to the fact that from the Mizoram side in the east to the western side of the Tripura state there is a transversial range which is also responsible for the development watershed in between both north and south flowing rivers of the State.

The soil profiles i.e. thickness of erosional deposits are in the descending order with the increase in altitude. Enormous degraded materials are being deposited mainly in the western part of Bara Mura from the higher hills and hill ranges viz. Athara Mura, Longtarai, Sakham and Jampui. The base level of the Bay of Bengal is very closely related to this part which is responsible for the development of vast alluvial plains with minor undulations. Even the hill ranges lying in the western part has been eroded, mostly subsided and lastly only higher parts are visible above the local base level in the form of shallow hill ranges viz. Sona Mura, Gojalia etc.

ALTIMETRIC FREQUENCY CURVE

Bauling believes that "The pattern of highest points would define an upper enveloping surface which

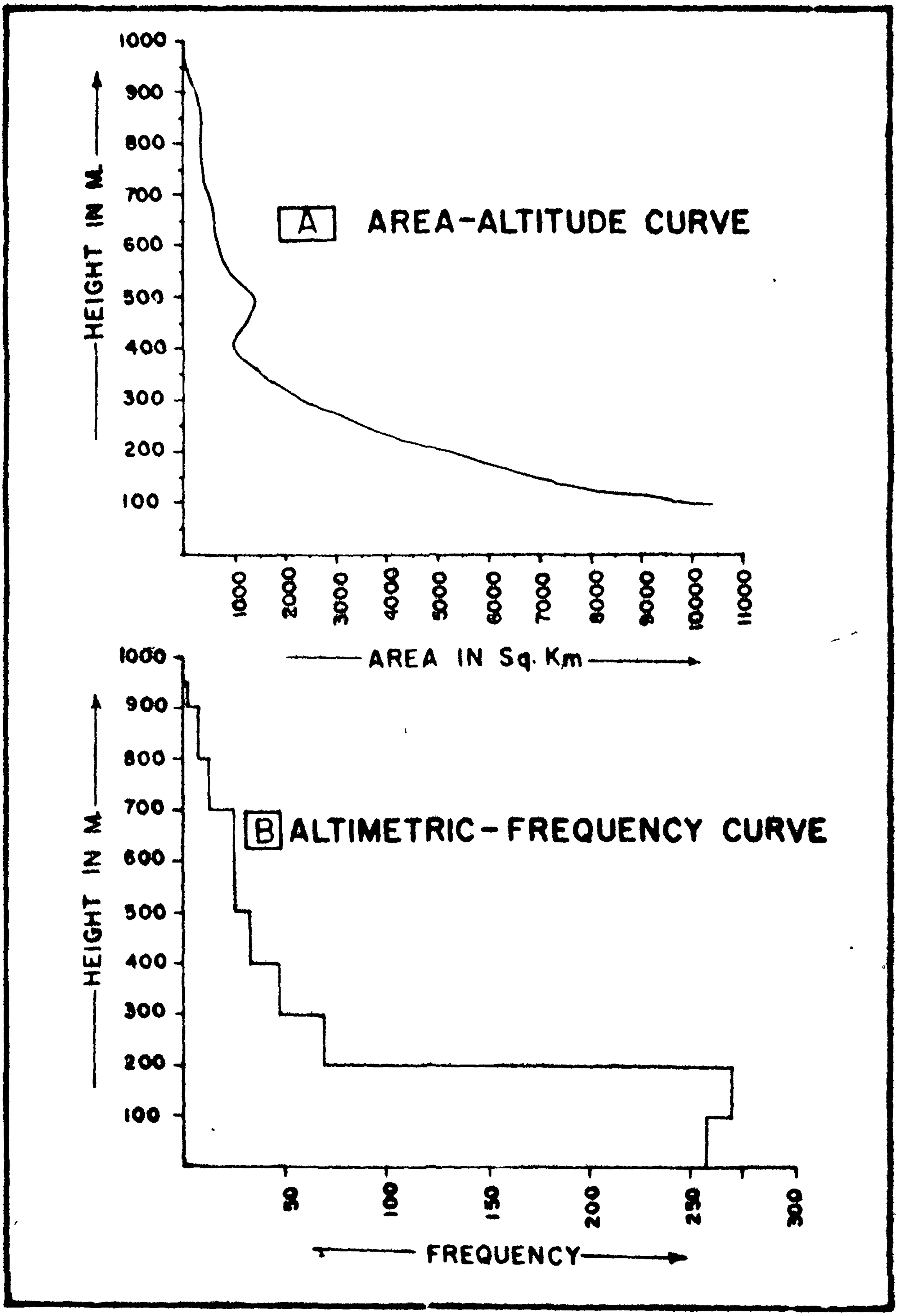

A AREA-ALTITUDE CURVE
HEIGHT IN M.
1000
900
800
700
600
500
400
300
200
100
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
AREA IN Sq. Km
B ALTIMETRIC-FREQUENCY CURVE
HEIGHT IN M.
1000
900
800
700
600
500
400
300
200
100
50
100
150
200
250
300
FREQUENCY

FIG. 8

becomes closer to the real surface as the local relief becomes more gentle."[2]

Remnants of the former erosion surface are the highest part of the landscape, because the normal headward erosion takes enough time to dissect this part. The altimetric frequency graph (Fig. VIII) reveals the nature of topography in Tripura. Maximum frequency occurs in between the height 100 m to 200 m, while heights within 750m to 1000m is limited to the Sampui hill region, adjacent to Mizoram. In the western part of Tripura isolated hills of about 50 m to 70 m in altitude is of pleistocene deposits. The streams had attained graded course in this part, whereas in the eastern part, valley cutting is still going on. Areal extent of high altitudinal places has been decreasing mainly due to the degradation of the weathered, materials from the uplands and hills. Thus the altimetric frequency curve indicates the presence of at least two erosion surface. The oldest surface is noticed at the height of about 900 m and the youngest surface is noticed at the height of about 50 m.

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[2] J.I. Clarke, Op.cit., p.20.

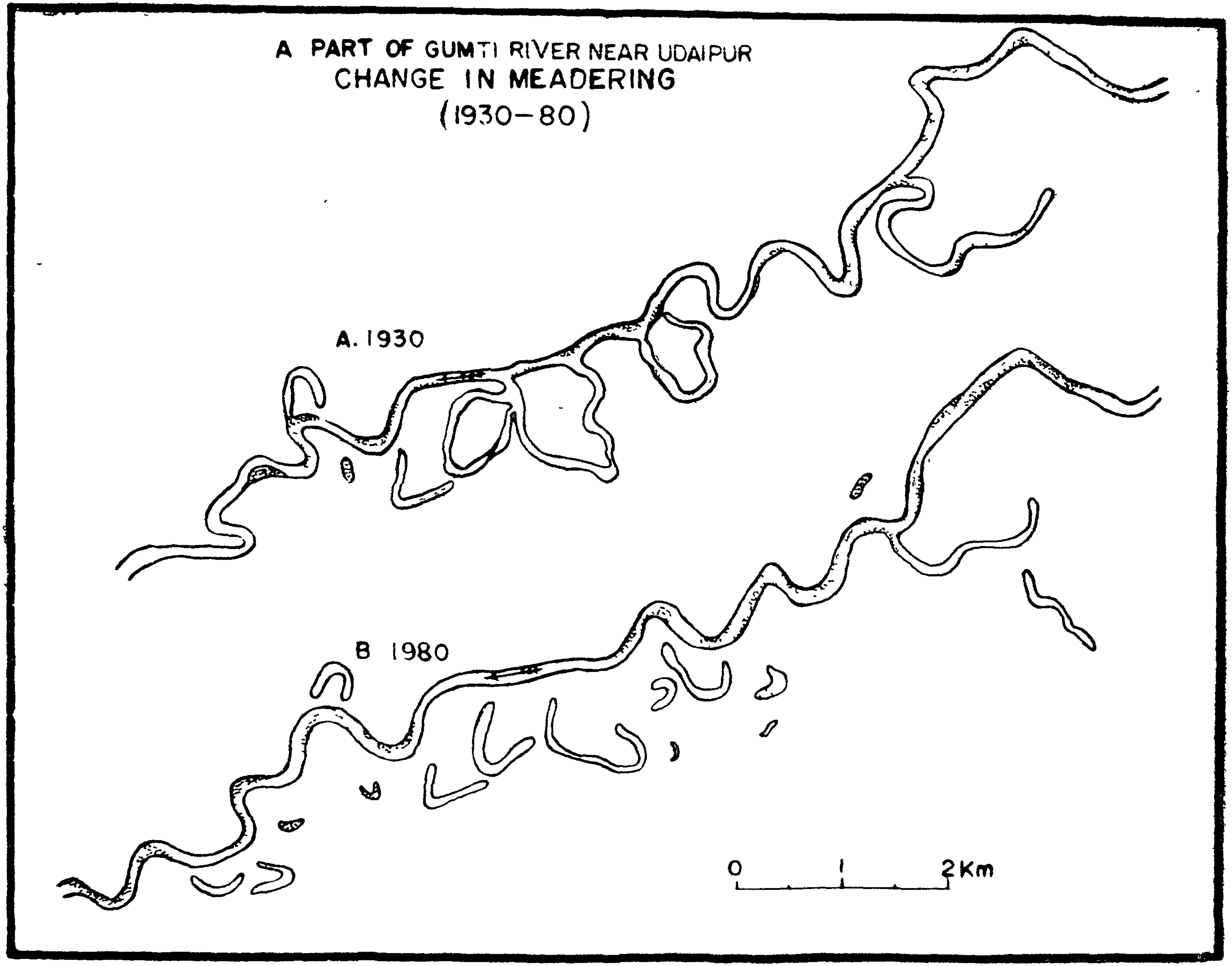

A PART OF GUMTI RIVER NEAR UDAIPUR
CHANGE IN MEADERING
(1930-80)
A. 1930
B 1980
0
1
2Km

FIG.9

Identification of Erosional Deposits

There are different litho stratigraphic successions which had developed due to the differential erosion that had been taking place during the past geological periods. Climato-genetic developments are mainly responsible for the evolution of various stratigraphic successions, which are also differentiated by unconformities viz. (i) Alluviam formation, (ii) Tipam formation, (iii) Boka Bil formation, and (iv) Bhuban formation, etc.

Change in Meandering

A section of the Gumti river in its lower course near Udaipur has been presented as an evidence, that it has been attaining its maturity during the recent past. The meanders that were connected with the main channel during 1930's had been disconnected within a period of about 50 years. Some of which, as observed in the field, had already been dried up after detachment from the original channel (Fig.IX-B). Moreover, the main river course had been considerably straightened. The river courses in the west of the Bara Mura hill range which are all flowing to the west are attaining their graded course viz. Buri Gang, Haora river, Gumti river, Sonai Nadi etc. whereas the rivers of the eastern part can be termed as in young stage, and the Khowai river in between the Bara Mura and Athara Mura flowing to the north is passing through an early mature stage.

Most of the important streams and rivers of the eastern parts are maintaining their sinuous courses and just some of their lower courses viz. Manu, Dholai, Deo and Juri river are proceeding from early young stage to late young stage.

THE EROSION SURFACES

Geological and geomorphic history of a region is marked by a series of sequential events heading to an ultimate phase of peneplains. Landscapes are thus envisaged as products of an orderly evolutionary course. In the evolutionary scheme of essential sculpturing of landscapes, Tripura represents youthful topography. Geological structure controls the first order hills and valleys. Vigorous erosion is taking place resulting in sculpturing of anticlinal ridges and formation of alluvial flats in synclinal valleys. Fluvial process is by the most active geomorphic process in the region. Erosion begins with the first appearance of a land above the sea level and continues throughout the time of 'Growing up' the time of intermittent uplifts culminating in the upland surface. The whole cycle includes everything from plain to the upland and hills. For the recognition of the erosion surfaces in the region, different morphometric techniques have been applied, as discussed earlier. Extensive field work has been undertaken to collect the field evidences. Longitudinal profiles of rivers, cross-sections, superimposed profiles, altimetric frequency curve etc. suggest intermittent upliftments. There are some breaks-in-slope which indicate either folding, faulting or rejuvenation due to diastrophism.

Superimposed profiles indicate that the old cycle of erosion is over and the new cycle is still active, specifically in the eastern parts, where the rivers are still deepening their valleys (Fig. VII). Old erosion surfaces are prominent in the eastern surfaces are prominent in the eastern part and the new erosion surface is extensively developing in the western part of the State. Sediment deposits on the top layer of the lithological units are mostly Quaternary age. These occur on and around the shallow remnant hills in the low-lying areas of dissected hills and in extensive river valleys.

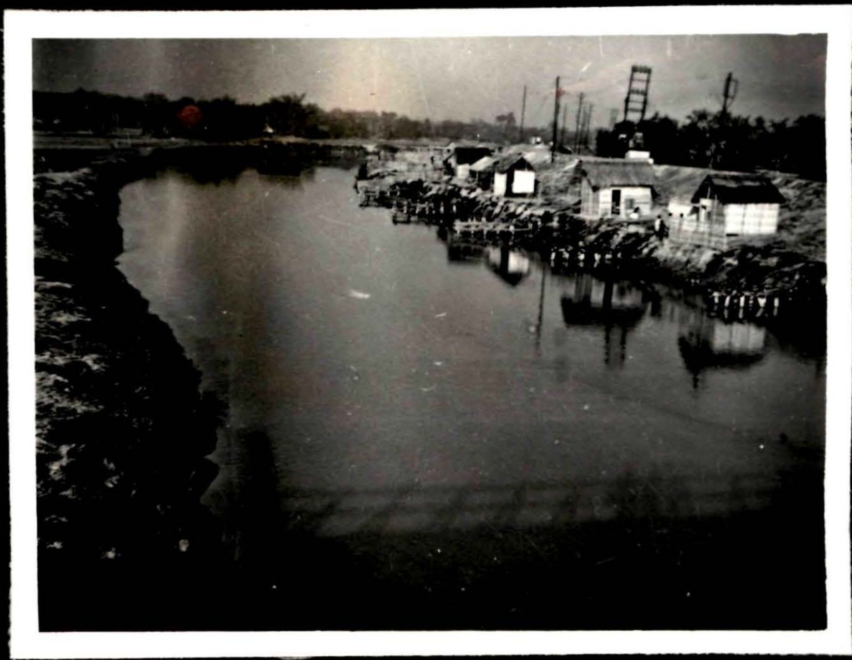
Identification of the Erosion Surfaces

Due to the complex interplay of geological structure, lithology, neo-tectonics and differential fluvial erosion, the recognition and correlation of erosion surface is rather difficult. In fact large scale differential erosion of the region and the presence of subdued residual hills at different heights, may be attributed to the effect of upliftment and rejuvenation of the region in different geological periods leading to the development of unconformities in between various geological formations.

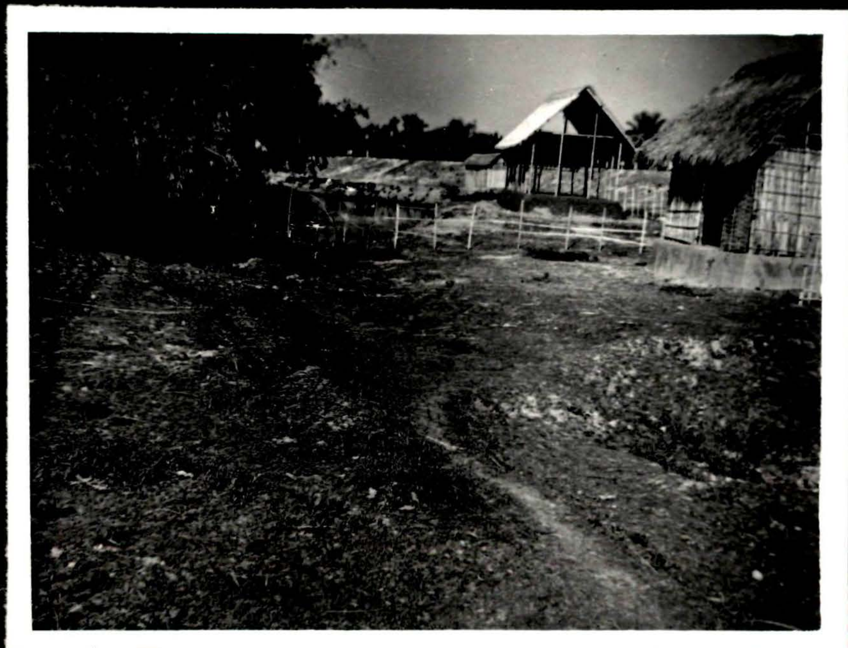
Though within Tripura, there exist only one significant waterfall i.e. Dumbur, yet there are numerous waterfalls in the adjoining eastern parts of the region namely, Chittagong hill tracts of Bangladesh. The presence of nick-points and break in gradient in the longitudinal profiles of rivers also suggest the rejuvenation of the old erosion surface. (Fig. VI-A & B).

It is observed that the highest parts of the hill ranges would be the last to lose remnants of the former erosion surface, because the dissection spreads through the mouth of the river valleys. Thus, two notable geomorphic surfaces viz. (i) alluvial plains and (ii) structural hills and uplands in between the valleys are recognised as the old surface of the region. Narrow and high intervalley lands of hard sedimentary rocks are the remnants of old erosion surface where few rock exposures are noticed. There is a transverse cross-fold extending from Mizo hills to the western side which divides the north and south flowing rivers also belong to the Pre-Pleistocene surface. The old unconsolidated sediments have mostly been worn away but some of the lowlying hills, specially in the west Tripura indicate their former positions and comparative altitudes. The whole region has not been peneplained due to insufficiency of time, from geological point of view.

The earlier erosion cycle might have been over by the end of pliocene period. From the area-altitude and altimetric frequency curve it is observed that maximum area of the region is below 200 m which means that new cycle of erosion is more actively developing both in space and time. The cross-section indicates that the old erosion surface of the region is locating in the eastern part along the Mizo hills and occupy very insignificant area, which is also decreasing under the impact of weathering and erosional processes. The erosion surfaces are (i) Pre-Pleistocene (generally 200m and above) and (ii) Pleistocene or Post-Pliocene (generally below 200m). All alluvial plains belong to the Pleistocene cycle and the remnant hills and hill ranges of consolidated to compact sedimentary rocks belong to the old one i.e. Pre-Pleistocene. The upland surface remains with rounded crests that are gradually losing height indicates old erosion surface. Highly dissected uplands and hills with numerous initial streams and senile streams of higher order, with moderately steep slopes indicate the Pleistocene surface.



1. A view of the embankments of Haora river near Agartala.



2. New settlements on river terraces of Haora river near Pratapgar.

3. The burntout slopes of Unokuti Hills preparing for Jhumming.

CHAPTER-VII

PHYSIOGRAPHIC AND GEOMORPHIC REGIONALISATION

> "The most common form of spatial analogue model is that in which adjacent contiguous areas are grouped together on the assumption that each unit can be better understood in forms of generalizations about some larger region of which it forms a part."
>
> — R J CHORLEY (1967)

Regionalisation is one of the fundamental procedures in any scientific discipline. The first stage in a geomorphic investigation involves the grouping of facts according to common characteristics. Geographers have traditionally been concerned with the description of the earth's surface. Even areal studies have not been prominent in Post Davisian geomorphology in the European countries.

MODERN TREND OF REGIONALISATION

Regionalisation of the earth's surface was primarily concern of the discipline of physical geography. Recently, many have been undertaken by social sciences. However, the largest contribution to development of concepts, methods and techniques in regional studies have come from Soviet Economic Geographers over the past three decades or so. In India regionalization as a substantive methodology of geographical research in physical geography or in geomorphology is still in the rudimentary stage, except studies done in climatology.

Within geomorphology, the regionalisation of the landform facies is a complex issue, because of the fact that process of evolution of landforms differs from place to place. As such no particular methodology is uniformly applicable for the purpose of regionalisation. Regional concept from the view point of geomorphology includes geological structures, physical features and climatio-geomorphic developments, in addition to some other morphometric parameters. In 1905 Herbertson sub-divided the whole world into natural regions on the basis of climate, configuration and vegetation. He was followed by Dokuchaiev, who had suggested a soil scheme for the whole world, based on climato-vegetational zones. Single feature regions are simple geomorphic units. Notable are those of de Candolle (1856) and Schimper (1903) for plants; Whittlesey (1936) for agriculture, W. Koppen (1937) for climate and so on.

For the purpose of geomorphic regionalisation there is no scope of assumptions, the landforming processes, geomorphic features as developed out of the processes operating in a region in combination with other geo-morphometric parameters are required to be grouped and classified into natural geomorphic units. Thus from geomorphic point of view it is a difficult task and is a relatively new approach. The purpose of regionalisation is to classify the surface of the earth with respect to the properties of interest. So that the processes responsible for variation and co-variation in the properties can be isolated and examined. The establishment of a regional classification is thus seem to be a means to identify the causes of the observed relationship between a set of areal units.

IMPORTANCE OF GEOMORPHIC REGIONALISATION

Geomorphic regionalisation is necessary for multi-dimensional purposes, viz:

(i) Identification of land facies needed for the purpose of land classification and landuse planning;

(ii) maintenance, preservation and improvement of natural environment and geomorphic elements, and

(iii) agro-economic planning

Geomorphic regions are helpful for the prevention and curative measures of the continuously degraded natural environment, viz. forests, soil structure etc. Some regions of young topographic elements of the tertiary morphological evolution may require special attention for its maintenance, both within the region and its adjoining areas.

For example, the brittle nature of the less consolidated surface formations of rocks in tertiary folded mountains as in Tripura is highly prone to erosion under high rainfall conditions. If, the vegetation cover, however is preserved, the rate of erosion can be significantly reduced. A consequence of such erosion of the exposed surfaces would result in carrying down of the debris into otherwise fertile recent alluvial valleys rendering them useless for the purposes of agriculture. Thus an attempt has been made to differentiate and identify different micro-geomorphic regions of the state. This may help in explaining the problems related to the agricultural and regional development planning at various geomorphic units.

The task of marshalling the production of renewable natural resources of the State, in respect to the agro-economy and natural environment, is dependent on appropriate maintenance and utilisation of the micro-geomorphic units.

Man's life is intricately woven into the whole web of life in any part on this earth surface, which is so organised that it satisfies his mental and biological requirements. With the increase of population thrust on this study region, human interference in the landshaping geomorphic processes is steadily increasing, which requires appropriate adoptation in the natural landscapes. Though man cannot control the geomorphic processes operating in the region in a categorical sense, yet, he can take some curative and preventive steps, by way of proper management, destruction of forests of the region for firewood, timber, housing, by way of jhuming and cultivation along hill slopes without soil protective measure accelerates the erosional processes and in turn retardates the eco-system.

Thus in contrast to the single feature natural regions, geomorphological regions are multipurpose ones. The idea of evolving such units for the organisation of planning, so that the relationships between the natural resources and the people exploiting them, will secure the maximum returns with least friction, not only administrative friction but as it were, the friction of man with his environment. According to P. Sengupta, Planning regions for resource development in India is essentially needed. Withour proper assessment of the natural resources, their characteristics, quality and quantity in relation to the environment no planning for the development of the resources can be done.

No significant physiographic regionalisation have so far been undertaken for the study region. In the United States, the challenge of rapid expansion and newly developing land created an interest and stimulated activities in geographical studies and methods in the late nineteenth and early twentieth centuries, (Joerg, 1914). Bowman (1914) had sub-divided the country (USA) into physiographic types, which he related to land use. Presently it is recognised that the relationship between physical elements, human activities, and economic values, and that man's use of land in each locality was controlled by the dominant recurrent physical elements, notably topographic configuration, water supply and climate. The researcher had used slope, lithological and altitude alongwith topographic configuration for physiographic regionalisation.

Whatever the criteria and view taken of regions, delimitation of landscapes always remain difficult, because of the fact that the core area of a particular type of landform is surrounded by transitional zones of different types. Moreover natural landscape regions are studied at a point of time, which are undergoing continuous changes.

PHYSIOGRAPHIC REGIONS

Physiographically the State can broadly be divided into three broad divisions as detailed in the previous chapter :

1) Alluvial plains,
2) Low lands with mild undulations and round shaped intermittent hills,
3) Uplands with hilly terrain and all hill ranges.

Alluvial plains of recent origin consists of average slope mainly 0-5^{o} and partly 5-10^{o}, low lands with intermittent hills of unconsolidated sediments mostly of 5-10^{o} and partly 10-15^{o} slopes. Uplands and hill ranges are of sedimentary rocks of 10-15^{o} slopes and generally 15-20^{o} and above.

The relief map[1] represents that contour density

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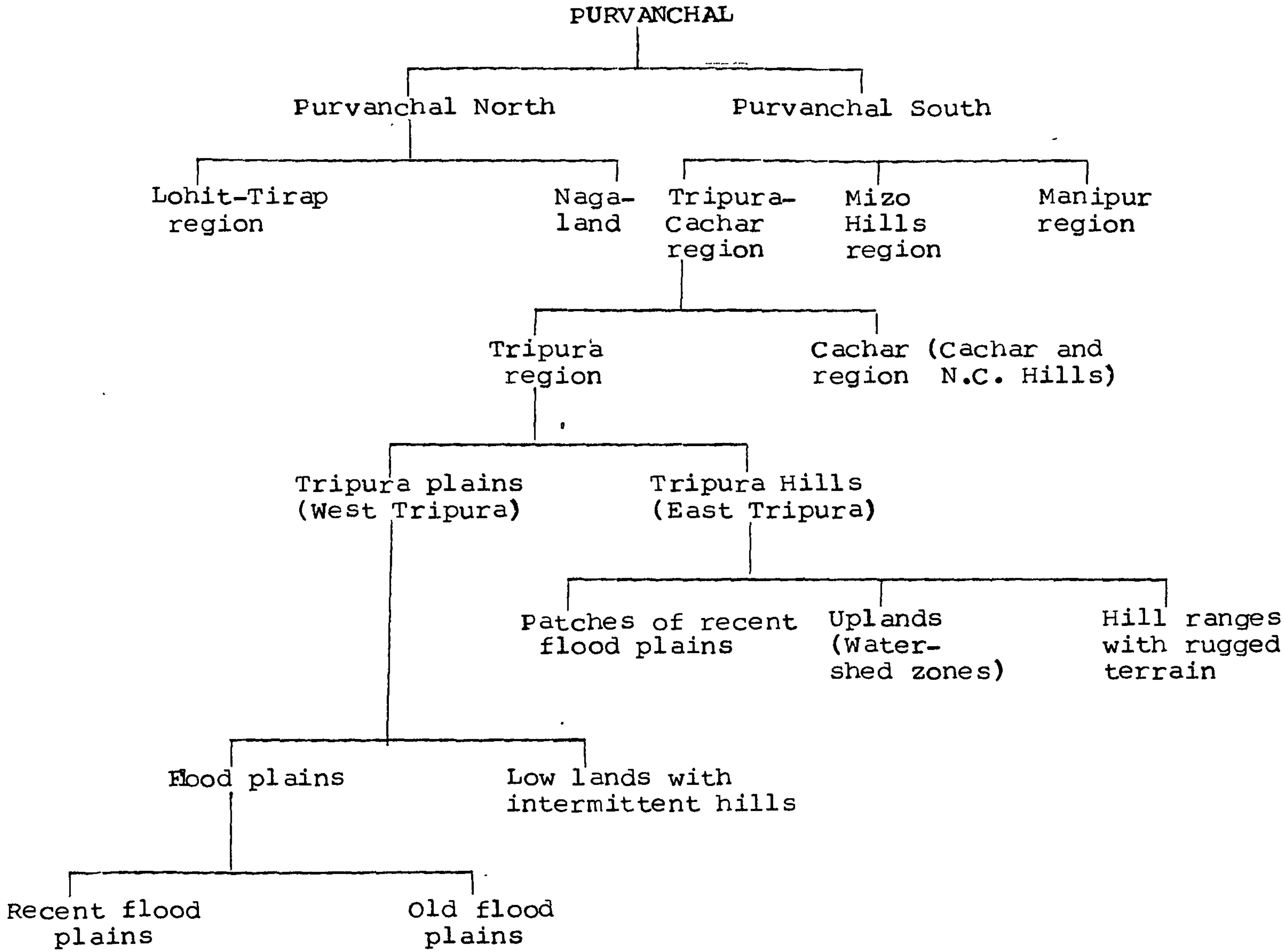
[1]Chapter-VI; Fig. II. , p. 214

increases from west to east. The compactness of contours are very high in and around the structural hill ranges, whereas in the river valleys it is very sparse. Few scattered contours in the Western part of Bara Mura represent lowlying eroded hills and shallow remnant hill ranges. Areas with no contours includes places below 76 metre in height and occupies about half of the total geographical area.

Schematically the physiographic regions are given below in hierarchical order.

METHODS AND PRINCIPLES OF GEOMORPHIC REGIONALISATION

Landform classifications are done mainly on the basis of the geomorphic facies as developed under the impact of the geomorphic processes as operating in a region as revealed by the geo-morphometric analysis, quantitative analysis, nature of fluvial erosion and climate. Whereas, the basis of delimitation may be the superimposition of morphometric maps viz. relief, slope, drainage system, stream frequency, geology, rock structure, lineament and tectonics in combination with relevant profiles, figures and field investigation. Quantitative analysis may be supported by the qualitative


PURVANCHAL
Purvanchal North
Purvanchal South
Lohit-Tirap region
Naga-land
Tripura-Cachar region
Mizo Hills region
Manipur region
Tripura region
Cachar region (Cachar and N.C. Hills)
Tripura plains (West Tripura)
Tripura Hills (East Tripura)
Patches of recent flood plains
Uplands (Water-shed zones)
Hill ranges with rugged terrain
Flood plains
Low lands with intermittent hills
Recent flood plains
Old flood plains

descriptions to give them a more realistic framework on the basis of parametric system of terrain evaluation.[2]

Composite parametric map represents various attributes of the subject on a single sheet. Thus in the state of Tripura a landscape classification naturally separates areas with different seasonal and other temporal changes in addition to the present rock structure, landforms and vegetation. G.D. Weaver (1965)[3] has divided the study of landforms into following types:

(i) Formulating the basic criteria to analyse quantitatively the surface features rather than studying the genetic implications of various morphometric techniques.

(ii) Changing the scale of observation under which we may consider characteristics of the area from macro to micro scale.

(iii) Dismantling the landforms, and

(iv) Reassembling the landforms.

D.R. Lueder, is worthy of special reference, and his concept of 'unit landform' and component classes of drainage pattern can hardly be overlooked. In addition, Lester King, R.J. Chorely; Arthur Holmes, C.R. Longwell,

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[2] J.A. Mabbutt; Review of Concepts of Land Classification, (1968), pp. 11-28.

[3] D.G. Weaver; "What Is Landform?", Prof. Geog. Vol. XXII, No.1 (1965), pp.11-15.

A. Knoff, R.F. Flint, Schumm and many others have made valuable contribution in the study of landforms.

Grigg (1967) in his principles of regionalisation[4] had discussed two methods for solving the problem of delimitation.

(i) Maull's Girdle Method - The superimposition of maps of each land property in question on a single map where delimitation is done on the basis of coincidence of of maximum number of boundaries. This method is similar to the terrain classification by physiographic approach.

(ii) Statistical Principal Components Method - Direct analysis of factors and correlation between a large number of properties as measured and the significant criteria is being extracted from the initial properties. This method may be termed as parametric approach.

For the purpose of the present study mainly the first method has been applied. It can rightly be pointed out that starting from the common place every country may be sub-divided into finite number of physical regions, each with a characteristic landscape viz. Jura in France and Piedmont in USA.

Increasing human activity on the natural landforms and land forming processes is also responsible for

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[4] D. Grigg; Regions, Models and Classes in Chorley and Haggett, Models in Geography,(1967), pp.461-509.

the modification of the natural landscape. In the present study the researcher has used both quantitative techniques and qualitative methods to define, describe, analyse and lastly to regionalise the landforms in respect to their developments in space and time, which reflects the spatial pattern of landforms in Tripura.

DISTRIBUTION OF GEOMORPHIC ELEMENTS IN THE EAST AND WEST OF BARA MURA HILL RANGE

General geomorphic elements as observed in the Western part of Bara Mura and in the eastern part of Bara Mura are indicated in the Table 7.1. In general major plain lands of the State which is about one third of the total geographical area lies in the Western part, whereas most of the rugged hilly terrain is located in the eastern part.

TABLE 7.1

DISTRIBUTION OF GEOMORPHIC ELEMENTS IN THE EAST AND WEST TRIPURA

Geomorphic Elements	Western Part	Eastern Part
1	2	3
Hill ranges and hills	Parts of Bara Mura Hill Range, Sona Mura, Gojalia and Chikania (etc.) shallow hill ranges and remnant hills of about 60 m maximum height.	Athara Mura, Longtarai Sakhan and their sub-ranges viz. Debta Mura Unokati Kalajhari, Takka Tulsi Sardeng etc. and parts of Bara Mura.

Contd...

1	2	3
Rivers and their valleys	West Flowing Lower course of Gumti river; Buri Gang, Haora, Sonai, Kakri, Rangapani and some other streams i.e. all west flowing rivers and a part of west flowing Gumti is located in this part	All north and south flowing rivers and Upper and middle course of the Gumti lies in this part. (a) North flowing (i) Khowai, (ii) Dholai (iii) Mani (iv) Deo (v) Juri and (vi) Parts of Longai river. (b) South flowing (i) Muhuri (ii) Manu Gang (nala) (iii) Parts of Fenny river.
Lithology	Alluvium (recent), unconsolidated pale to dirty grey silt, sand, clay, greyish brown to redish brown sand plastic clay. i.e. Miocene to Recent formations.	Alluviums in the lower course of the north flowing rivers bordering Bangladesh. The rest thinly laminated sandstones, siltstones, micaceous sandstones with mudstones and their repetations at places. The core of the ridges are of hard, compact sandstone of pliocene and Oligocene formations.
Average slope	Mostly very gentle (0-5°) Gentle(0-10°) and Moderate (10-15°), partly moderately steep (15-20°)	Most moderate (10-15°), moderately steep (15-20°) in the northern part and southern part very gentle (0-5°) and gentle (5-10°) and along Jampui 20° and above slopes.
Stream frequency	Mostly 0-4, 4-8 per 10-36 sq.km. and patches of 0-4 and above 12	Mostly 4-8, 8-12 per 10.36 sq.km. and patches of 0-4 and 12

contd...

1	2	3
Average annual rainfall	234.62 cm	234.73 cm (North Tripura District 247.76 cm) and (South Tripura District 228.62 cm).
Dams and Hydel Projects	NIL	Dam on Khowai river and Manu river for both flood control and irrigation. Gumti Hydro Electric Project on Dumbur Waterfalls.
Forests	About 15% of total forests	About 85%
Altitude	Mostly between 15m to 200 m	Mostly between 100 m to 750 m.
Geology	General Pleistocene to Holocene	Generally Oligocene to Pleistocene.
Bills and Waterfalls	NIL	Three important bills in the Khowai river basin and one water-falls across Gumti river.
Area	About 3510 sq. km.	About 6,967 sq. km.

Crestline through Bara Mura hill range is considered to divide the States of Tripura into two parts.

Sources: (i) Some basic statistics of Tripura (1981), pp. 1-14.
(ii) Statistical abstract of Tripura, Directorate of Statistics and Evaluation (1978), pp. 43-44, 54, 62-66.
(iii) Department of Agriculture, Govt.of Tripura.
(iv) Geological Survey of India Publications and memoiers.

IMPORTANT GEOMORPHIC FEATURES

Important geomorphic features of the State of Tripura are resistant high altitudinal structural hill ranges with alternate low river valleys, plain lands, hills, slopes varying from gentle (0-5^{o}) to very steep (25^{o}), Nine important rivers and numerous perennial streams, tropical vegetation and climate, high rainfall under the impact of South-West monsoon, folds and faults, lineaments, high humidity and high temperature fluctuation. Under the heavy rainfall during the monsoon mainly in the months of May to July the rivers, even the dry streams swell up with enormous volume of water, which is mainly responsible for sculpturing of the topographic features both in a linear and areal fashion. The geomorphic evolution of the natural landscape in the State of Tripura is the resultant product of the interaction between the different elements as mentioned above which are moulded by both endogenic and exogenic forces operating in the region. The inter-relationship of average slope, stream frequency, lithology and relief of various hill ranges in order from west to the east is represented in Table 7.2.

The whole region is dissected by a number of long and narrow valleys -

(i) Agartala-Udaipur-Sabrum,
(ii) Khowai-Teliamura-Amarpur-Silachari,
(iii) Kamalpur-Ambash-Chandachara,
(iv) Kailashahar - Kumarghat
(v) Dharmanagar-Panisagar etc.

These valleys are located in between almost north-south parallel hill ranges, viz. -

(i) Sona Mura, Mamun Bhagna - Gojalia
(ii) Bara Mura - Deota Mura
(iii) Athara Mura - Jari Mura.
(iv) Langtarai-Sardeng
(v) Sakhan, and
(vi) Jampui hill ranges, respectively from west to east.

Small scale geomorphic elements are river terraces, spurs, lunga lands, bills (shallow water bodies), some moderate gorges, springs, rapids and waterfalls etc.

TABLE 7.2

INTERRELATIONSHIP OF AVERAGE SLOPE, STREAM FREQUENCY, LITHOLOGY OF HILL RANGES IN ORDER FROM THE WEST TO EAST

Hill Range	Average Slope	Stream frequency per 10.36 sq.km.	Lithology	Max. height
1	2	3	4	5
Sona-Mura	$0-5^{o}$	4-8	Mostly thick pile of grey shale, siltstone, mudstone and at some places sandstone	110 m
Gojalia	$5-10^{o}$ & $10-15^{o}$	4-8	Mottled clay, mostly unconsolidated sand and silt of ferruginus nodules	150 m
Bara-Mura	$5-10^{o}$& $10-15^{o}$	4-8 & 8-12	Northern part similar to the Sona Mura hill. Southern part medium to coarse grained sandstone with fossilwood alternating at places with siltstone and shale bands	275 m

Contd..

1	2	3	4	5
Athara-Mura	5-10°	4-8	Grey siltstone, soft sandstone often micaceous of Upper Bhuban formation.	450 m
	10-15°	8-12	Predominently thick pile of thin bedded grey shale, mudstone and certain places with sandstone bands	
Long-tari	10-15°	4-8 & 8-12	As in northern part of Athara Mura	500 m
Sar-deng	5-10°	8-12	As in northern part of Athara Mura	500 m
Sakhan	10-15°	4-8	As in Southern part of Athara Mura	800 m
Jampui	10-15° 15-20° 20 and above	8-12 4-8 0-4 & 4-8	Well bedded hard grey sandstone at places alternating with siltstone of Bhuban formation	975 m

The rock formations mainly vary in age from Oligocene to Holocene. The base of the sediments (Barails) are not exposed. Bhuban formation consists of hard sedimentary rocks which are believed to be the oldest are mainly of indurated sandstone with about 50 per cent grey and olive clay rocks, generally earthy grey to light dark in colour.[5]

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[5] Miscellaneous publication No.30, Part-IV, G.S.I. Publication (1970), p.118.

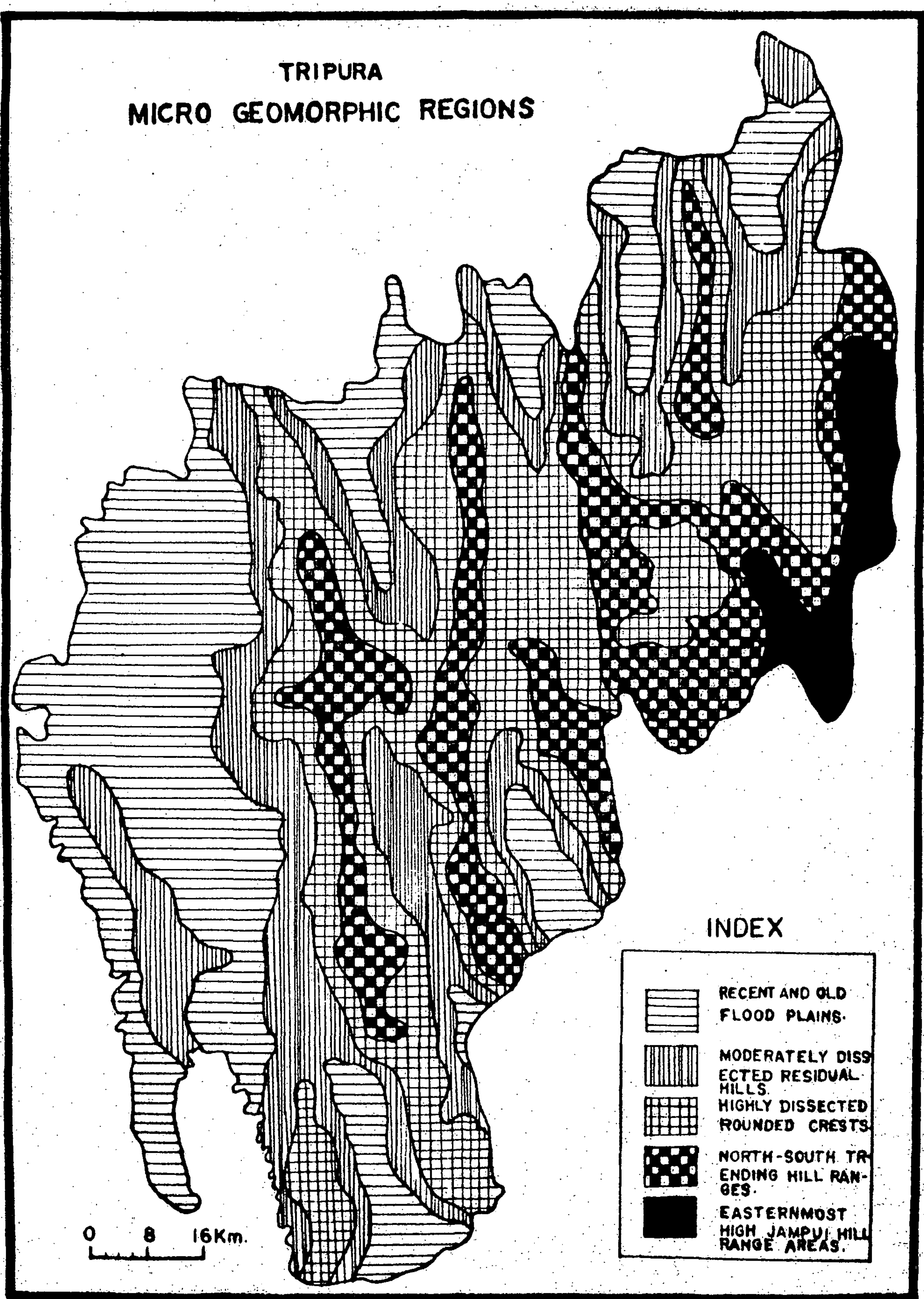
TRIPURA
MICRO GEOMORPHIC REGIONS
INDEX
RECENT AND OLD FLOOD PLAINS.
MODERATELY DISSECTED RESIDUAL HILLS.
HIGHLY DISSECTED ROUNDED CRESTS.
NORTH-SOUTH TRENDING HILL RANGES.
EASTERNMOST HIGH JAMPUI HILL RANGE AREAS.
0 8 16Km.

FIG. I

Geomorphologically the land forms are attaining their differential character and the terrain is passing its transitional period from young stage to the mature stage. The eastern part of Tripura is mainly young to early mature stage, whereas the western part is mainly early mature to mature stages. Landscapes in the western part are distinctly pronounced. Mainly the sequence of landforms are flood plains, Lunga lands, small tills and hill ranges.

MICRO-GEOMORPHIC REGIONS

For the purpose of the regionalisation of the study region into 5 micro-geomorphic regions, geological maps of G.S.I., landsat imagery, field observations, instrumental observations of slope, average slope, drainage pattern, stream frequency, general elevation, dissection pattern, nature of erosion, neo-tectonics climatic factors, drainage density and some other physiographic and topographic features like vegetation, jhum cultivation, human activities etc. had been considered and examined.

The micro-geomorphic units are as in the Table-7.3 which also represents some important regional characteristics of the State.

TABLE - 7.3

MICRO-GEOMORPHIC REGIONS AND THEIR CHARACTERISTICS

Micro-geomorphic Units	Geology	Area in sq.km	% to total geog. area	Average slope in degree	Stream fre-quency*
1. Recent and old flood plains with intermittent flatish hills having high groundwater potential, at places mound-shaped hills	Modern alluvium deposits, valley fill, sand, silt, clay and ferruginous modules of recent to Pleistocene formation	2756.31	26.31	Mostly 0-5° & in patches 5-10°	Mostly 0-4° & partly 4-8°
2. Moderately dissected lowlying residual hills, partly recharge and partly run off zone	Mostly unconsolidated to consolidated sands, silts, ferruginous modules and sandstone of Pliocene	2455.94	23.44	5.10°	Mostly 4-8° & partly 8-12° & more than 12
3. Highly dissected almost round crest denudational hills of run off zone. Only at few places sedimentary rocks are exposed	Mainly semi-consolidated current bedded sandstone, siltstone, and fossilwood and shale bands of Mio-Pliocene	2931.42	27.98	Partly 5-10° and mostly 10-15°	Mostly 8-12° & partly 4-8°
4. North-south trending parallel hill ranges which forms structural resistant rocks of moderate dissection at places. Mostly runoff zone with many springs.	This bedded grey shale siltstone, sandstone of Boka Bill and Bhuvan formation(Miocene)	1870.63	17.85	15-20°	Mainly 4-8°
5. Hard sedimentary rocks of Jampui hill range areas in the eastern most part which forms run off watershed zone in between important rivers	Hard grey sand stone, siltstone of Bhuvan formation of Oligo-miocene period	462.70	4.72	Mostly 20-25° & partly more than 25°	4-8° and 0-4°
	TOTAL	10,477	100.00		

*Number of streams per 10.36 sq. km.

RECENT AND OLD FLOOD PLAINS WITH INTERMITTENT MOUND SHAPED HILLS (Tilas)

Most of the rivers of the study region have their respective flood plains, both of Holocene and Pleistocene deposits. Size of the geographical area under this category vary from 1708.9 sq. km. to 36.0 sq.km. The Gumti river lower course, Haora river, Sonai, Rangapani, Kakrinadi, Burigang i.e. all west flowing rivers with their delimiting low lying watershed zone forms the biggest unit in the western part of the State. While Khowai river valley has the second highest area of 1235.85 sq. km. under this region and lowest is of Fenny river basin. The other units of this micro region are located in the Dholai R, Manu R, Juri R, Muhuri R and Manu Gang basins. Modern flood deposits are taking place on the both sides of the main channel of all the rivers in their lower courses and lies within the average slope catdgory 0-2^{o}. River terraces at low levels of all the important rivers viz. Gumti, Khowai, Dholai, Manu, Deo, Haora, Buri Gang has been observed, which are developed mostly on the opposite side of the meandering course with obviously less water flow and less river energy. Because of the fact channel water hits the meandering course with comparatively high energy in a tangential direction.

As a result deposition of enormous sand takes place in the opposite bank.

Abandoned channels viz. ox-bow-lake both perennial and dry are associated with this unit. Many other flood plain features like levee, point bar, back swamp are also visible. Under the impact of monsoon enormous sheet erosion takes place in this unit. This unit is very fertile from the point of soil, ground water, which includes all the culturable land of the State. Most of the settlements and urban centres viz. market, sub-divisional headquarter etc. are located in this unit.

Only the sub-unit localized in the westernmost part includes some undulating lands mainly of low mounds which has slopes 2-5^{o} in average on the lower portions and 5-10^{o} in the upper portion just below the flatish top. These mounds are made up by unconsolidated to less consolidated sands. Average height of the mounds lying in this unit vary mainly from 35 m. to 50 m. The valley fills, flood deposits of Holocene is closely associated with these sandy mounds. This indicates that the mounds are formed during the late Pleistocene period which has later on uplifted due to the upward thrust followed by neo-tectonic activities.

It can rightly be stated that each valley has cut by its river, and the size of the valley and flood zone is directly related to the litho-stratigraphy and the hydraulic action of the streams.

MODERATELY DISSECTED LOW LYING RESIDUAL HILLS

Synclinal valley areas are developing due to the aggradation of the eroded materials from the higher micro-regions viz. structural hill and denudational hills. Mostly of Tipam formation of Pliocene and partly of Pleistocene which mainly consists of coarse grained sandstone, medium grained sandstones with silt bands at places and comparatively compact. These units have developed along the flood zones of the rivers and are located in between the alluvial plains and denudational hills. These units occupy about 2455.94 sq. km. area with 0-4 and 4-8 stream frequency per 10.4 sq. km. Average slope ranges from 5-10^{o} and includes most of the areas of this gentle slope category. Most of the hills are separated from each other due to the valley hills and this detachment can be marked through the areal view of the crests ranging from semi-round to flatish tops. Dissection is clearly visible through which flows the [illegible] surface rain water to the lower places, causing gully erosion at random. Drainage is mostly dandritic with medium density of 0.25 - 0.50 km. per sq. km.

Due to comparative and continuous process of denudation which is active in this region is responsible for the differential topography. This micro-unit occupies about 23.44 per cent of total area of the State whereas, average gentle slope category occupies about 24.92 per cent of total geographical area which are almost overlapping. Most of the streams of higher order remain perennial throughout the year. The slopes are becoming gentler continuously due to aggradation of the eroded materials, where main channels of the main rivers are almost graded in their lower courses.

Pulses, orchards, cillies, and Kharib cultivations are done at low places. Recently tea plantations are undertaken on the flatish tops of the hills. There are 47 tea plantations in the state, some of which are located in this region and the rest in the small hills located in the undulating plains,[6] and area under plantation increased from 4930.6 hectare (1974) to 5225.3 hectare (1978) whereas total are under plantations in

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[6]Bulletin of Tea Statistics, published by the Directorate of Statistics and Evaluation, Govt. of Tripura, Agartala, 1978, pp.7-11.

in 1978 was 12,999.20 hectare. Recharge areas of high yielding deep acquifers. Total area under this region is due to increase with the lapse of time.

HIGHLY DISSECTED ALMOST ROUND CRESTED DENUDATIONAL HILLS OF RUN OFF ZONE

All the sub-units of this micro-region are located in the eastern part of Tripura, except, only one unit covering shallow gozalia hill range on the southern side of Bara Mura. This region occupies about 2931.42 sq. km. area which is about 27.98 per cent of total study area. This region has developed just surrounding the high hill ranges and has continuity through a narrow strip either through the northern or southernmost part of the hill ranges. This region forms major watershed zone of all the important rivers which flows to the north, south and west and includes characteristic slopes (10-15^{o}). Most of the areas are located in between Bara Mura and Jampui hill ranges. This region occupies about 40 per cent of East Tripura. Due to fluvial erosion the hills are highly dissected and very much susceptible to weathering and erosion. Headward erosion and gully erosion both are active in this region.

The crest lines are of occasionally flat topped, rounded and generally moderately round. Drainage density range from 0.25 to 0.50 per sq. km. only the Dholai river basin has more than 0.5 km. per sq. km. Soil profile is fairly thick throughout this region. Most of the regions lie in between 200 to 500 m in altitude. Stream frequency ranges from 4 and above per 10.4 sq.km.

NORTH-SOUTH TRENDING
PARALLEL HILL RANGES

This region has been identified along anticlinal axis of the Bara Mura, Athara Mura, Longtari and Sakhan hill ranges. Some of the geomorphic elements and their correlation has been represented in the Table 7-3. Total area under the five sub-units of this region is about 1870.63 sq. km. of which the north-easternmost sub-unit occupies about 835.60 sq. km. It consists of about 17.85 per cent of total study area. This micro-region represents the relief of high ridges upto the height of about 200 m to 800 m above base level. Most of the forests of economic importance are located in this region. Structural features and geomorphic elements are quite prominent in this region. Average slopes are mostly 15-20° and in patches 20-25°, which are actually as high as three times along the crest line at certain places. Thus slope ranges from steep to very steep. Crests are ranging from sharp to very sharp, which has developed on and along the ridges of hard sandstone. Hogback forms are prominent at many places within the structural hill ranges. These ridges are quite resistant to erosion, Sandy soil of thin layer has been developed. It constitutes run off zone with high annual rainfall responsible for the initiation of numerous minor streams.

OLDEST AND HARDEST SEDIMENTARY
ROCKS OF JAMPUI HILL RANGE

This micro-region is most closely related to the fourth micro region in many respects. The main differences are this region is located in the highest portion of the study area which is lying mostly in between 750 m to 975 m. Oldest and is of hardest sedimentary rocks of the State. The slopes are very steep even average slopes are ranging in between 20-25^{o} and above 25^{o}. In fact at some places slopes are ranging from 60 to 80^{o} along the high altitudinal ridges. Vegetation of this unit is very dense in comparison to other units. This region consists of well bedded hard grey sandstone at places alternating with siltstone. This micro region is not scattered occupies and occupies about 462.70 sq. km. which is only 4.42 per cent of total area. In fact the erosional agencies start their work in this region with due acceleration towards north, south and west, which ultimately ends at the main basement in the Bay of Bengal.

Similar geomorphological and geological conditions in different river basins is responsible for the development of similar landscapes, under the impact of humid tropical climate. Landscape system in Tripura helps in explaining the fundamental causes of landscape differentiation in respect to origin, process and form that has been developing under the impact of south-west monsoon. It is seen that most of the sub-micro regions as classified in some unit are located at various river basins and are very closely related to one another geographically.

The study area constitutes only one broad geomorphic region with alternate river valley and hill ranges. Other micro regional units are based on the genetic landscape developments. In reality these sub-regions are important for many practical advantageous purposes, viz:

(i) They provide a co-ordinating frame work for bigger units.

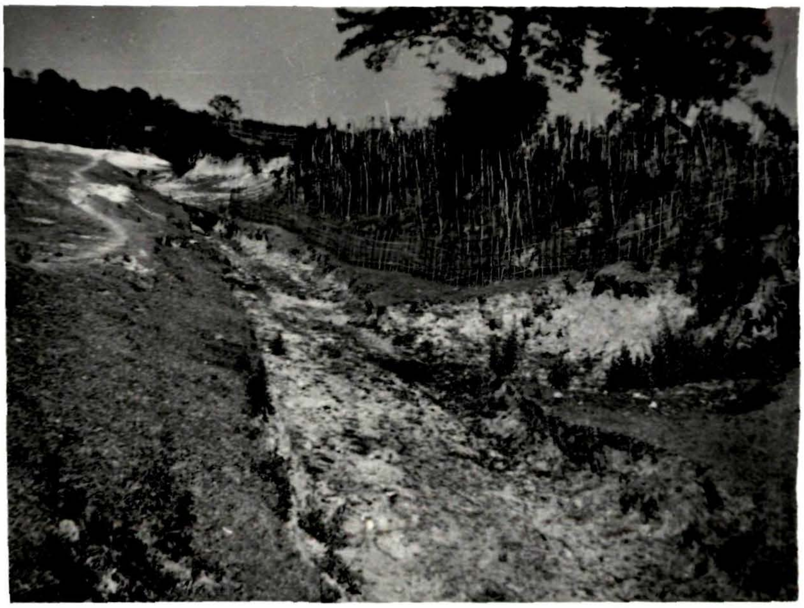
(ii) They aid in the reconnaissance of larger areas by providing an overall view of genetic relations.

(iii) They help in explaining the patterns of landscape evolution.

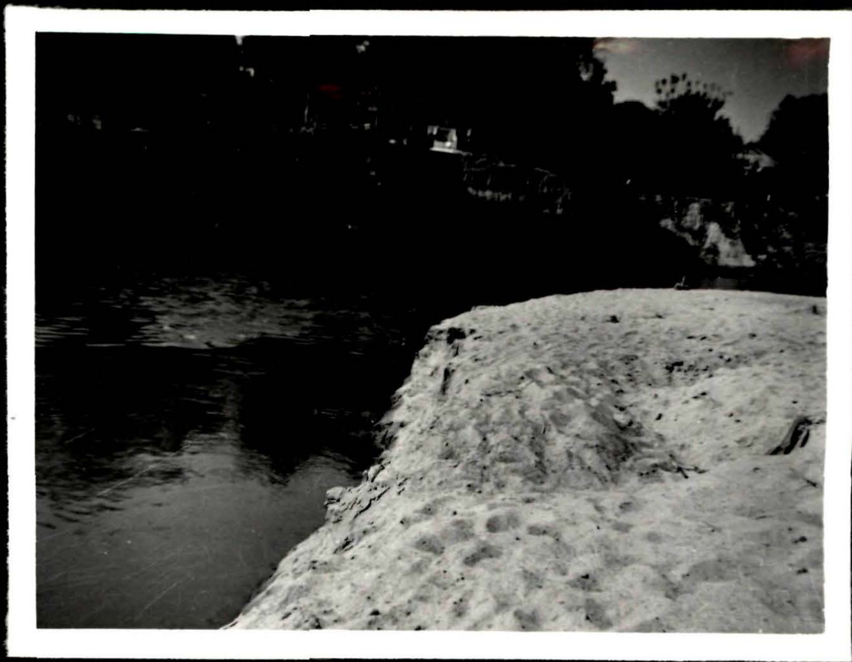
1. A view of development of flood plains on the left bank of Haora river.

2. Rice cultivation on recent flood plains of Haora river near Pratapgar.

3. A view of narrow strips of fertile valleys as has developed in between small hills.



4. A view of a dry nalla or charra which flows through the old Alluvium and joins a tributary of Khowai river near Telia Mura.



5. Recent sand deposits on the right bank and the older sedimentary rocks on the left bank, continuously eroded by the Khowai river near Telia Mura.

6. Recent Alluvial deposits on the left bank of Manu river and the rocky right bank.

7. A view of the dissected hills at Sadhur Tilla.

8. A view of the hard sedimentary rocks of the exposed Bhuban formation.

CHAPTER - VIII

SUMMARY AND CONCLUSION

The State of Tripura forms a part of the Indo-Burman orogenic belt. It was initially raised from the sea bed towards the end of the tertiary period. The Quatenary record indicates undulated continental environment. The elevation of the study area at present ranges from 15 metre in the west to 1000 metre in the east, while the average elevation varies from about 50 metre to 650 metre above the sea level. Each successive hill ranges and the intervening river valleys are progressively higher to the east. Older geological formations are also exposed in the same order. Again the hill ranges are generally higher in the central part due to a transverse cross-fold extending from the Mizo Hills to west-Tripura. The hill ranges of Tripura fade under the plains of Bangladesh in the north, west and south.

The stratigraphic record of Tripura is sub-divided into five main geological sub-groups as follows:

(i)	Recent Alluvium	) Quaternary
(ii)	Older Alluvium (Dupi Tila)	)
(iii)	Tipam	)
(iv)	Boka Bil, and	) Neogene
(v)	Bhuban	)

The north-south trending structural hill ranges are mainly formed by Boka Bil and Bhuban formations, the synclinal valleys in between the anticlinal hill ranges are filled up by the Tipam Formation and younger formations.

Western part of the Bara Mura hill range along with some other isolated patches in the northern and southern parts of the river valleys are underlain by alluvial formations of both Holocene and Pleistocene period. Alluvial plains surrounding the lower reaches of the major rivers are of Holocene age, whereas, the lowlying bad lands fringing the valley flats are of Pleistocene age. Sedimentation during the Cainozoic era was a discontinuous process, punctuated by breaks due to tectonic events.

The intensity of fold movement is higher in the eastern part. The domal shaped folds of the western part belong to later generation of earth movements.

The Bhuban Formation consists of grey siltstone, well-bedded hard grey sandstone and siltstone of Miocene age. It forms the core of the resistant anticlinal hill ranges.

The Boka Bil Formation is conformable with, and gradational to both the underlying Bhubans and the overlying Tipams. This formation consists of shales, claystones and mudstones, and is of Mio-Pliocene.

The Tipam Formation comprises medium yellow to light buff and brownish yellow sand rock. This is mainly a sand body with minor shale and siltstone interlayers.

The Older Alluvium Formation (Dupi Tila) is of Pleistocene age. It consists of mottled clay, sand and silt of fluviatile origin. Ferruginous nodules in it are pedogenic.

The youngest geological formation of the State is Recent Alluvium. It consists of unconsolidated silt, sand, clay and peat layers and occurs in all the flood plains in the inter-montane river valleys.

The important tectonic and geomorphic features in the region are :

(i) Lineaments,
(ii) Trend lines,
(iii) Regional fold structures,
(iv) Ridge forming resistant litho-stratigraphic units,
(v) Hill ranges and river valleys.

The lineaments and other tectonic elements record the imprints of crustal forces which have deformed the sedimentary pile in successive phases.

Few long lineaments and trend lines are mostly in the NE-SW direction at about 45° angle with the synclinal and anticlinal axes. The important sets of lineaments in the region are NE-SW, WSW-ENE and NW-SE of which NE-SW trending lineaments are very prominent. A transverse cross-fold forms the watershed of important north and south flowing rivers.

The State constitutes one broad physiographic region with alternate north-south aligned hill ranges and river valleys.

Important hill ranges from west to east are:-

(i) Bara Mura
(ii) Athara Mura
(iii) Longtarai,
(iv) Sakhan, and
(v) Jampui

Important rivers of the State are :-

(i) Gumti
(ii) Khowai
(iii) Manu
(iv) Deo
(v) Dholai
(vi) Haora
(vii) Buri Gang, and
(viii) Juri

Most of the forests are located in the hills of east Tripura. There are some bills (shallow water-body) in the west Tripura, four important bills are located in the Khowai river basin which are namely :

(i) Malakachi Bill
(ii) Champlal Bill
(iii) Sarlu Bill, and
(iv) Brahma Bill.

Most of the springs of the region are warm springs. The water temperature slightly exceeds that of normal ground water temperature, Garam Charra near the Athara Mura is a good example.

Structural hill ranges of sedimentary rocks have been cut across by three important rivers, viz.,

(i) the Gumti, (ii) the Khowai and (iii) the Deo. The west flowing Gumti river has crossed three important hill ranges viz., the Athara Mura, the Bara Mura and the Sona Mura and is an antecedent river. The Khowai also has some antecedent characteristics.

Under the impact of south-west monsoon, Tripura receives an average annual rainfall of about 234.67 cms. The amount of annual rainfall increases from SW to NE, highest being in the easternmost Dharmanagar Sub-division i.e. 267.05 cm.

The temperature is moderate, the mean for the year is about 25°C. Average temperature in the summer months of May-June is 35°C and minimum average is about 10°C in the winter months of December-January.

There is a great variation in relative humidity from season to season, but throughout the year remains above 60 per cent. Due to the high rainfall, moderate to high temperature and vegetation cover etc., humidity is generally very high.

The minor streams flow mostly at right angles to the direction of main streams. Drainage density and frequency of streams in the region depends mainly upon the following factors :

(i) Climate,
(ii) Lithological and structural characteristics of rocks,
(iii) Relief,
(iv) Infiltration capacity,
(v) Vegetation, and
(vi) Stage of development.

During the monsoon period frequent cyclones, hailstorms and flash floods eause damage to crops, vegetation and settlement with their maximum impact on erosional processes.

The existing landuse pattern like jhuming and agriculture on hill slopes are accelerating soil erosion.

Headward erosion is very prominent and active in the Pleistocene formations, and the gullies are actively heading towards the ridges formed by the Tipam and Surma formations having moderately steep (10^{o} - 15^{o}) slopes. Here the streams are of higher order with comparatively higher hydraulic energy.

Fluvial erosion implies consecutively the disintegration and fragmentation of rocks and setting in motion of the weathered materials through the streams into the channels to the base levels (Grand Base Level of the Bay of Bengal or local), operations which result in the form of the valleys, the slopes and the hill crests. Physical and chemical weathering is predominant in the region.

Numerous meanders are developing in the lower reaches of the north flowing rivers, whereas there are dry abandoned meanders and ox-bow lakes in the lower reaches of the Gumti river. The western part of Bara Mura i.e. Gumti river basin is most probably in mature stage, the eastern part of Longtarai is in young stage and in between the landscape is proceeding from young to early mature stage.

The rivers of the region are neither broad nor deep enough for navigation, though some of them are wider. All the rivers traverse through Bangladesh before they fall into the Bay of Bengal.

Present day sedimentation is taking place in the lower reaches of the important rivers where channel bars and extensive flood plains are developing. The sediments comprise sands, silts and clays. Development of flood plains is taking place in the river valleys where the valley bottom is 'U' shaped. In the upper reaches of almost all the rivers both headward erosion and valley deepening is active. It is observed that slope, lithology, pedology, vegetation cover and mean annual run-off determine the rate of active erosion.

The processes of weathering, mass wasting, sheet wash and landslides are significant in the eastern parts. Fluvial deposition is responsible for the development of alluvial plains in the low lying lower reaches of the rivers. The package of processes are not only lowering the elevations of the ridges, but also developing and shaping the landforms on the existing topography in between the interfluves.

Erosion capacity under the fluvial action increases with the increase of the hydraulic energy of streams and rivers in the rainy season. Even dry streams swell dangerously with the rise of water level to more than 4/5 metres during rainy season, which actively discharge waters of their catchments to the major streams.

The landscape of Tripura is far from static.

It is changing fast under the combined impact of natural and human activity.

Climatic, geological and geomorphic factors of nature play the dominant role in changing the scenery.

Point bar deposition is taking place in all young and gentle rivers of the eastern parts whereas channel bar deposits are prominent in case of late young or early mature river channels of the western parts.

Due to the relative absence of hard rocks, stones and pebbles are not common; hence the rate of mechanical abrasion of the river-bed is comparatively low.

Destructive forces have crossed the threshold of resistance of the structural sedimentary high hill ranges, and as a result recent dissections are taking place mostly along the crests.

The quantitative analysis of twelve selected sample basins of the region reveal that :

(i) There is a close relationship between area of the small basins and number of stream segments.

(ii) There is a linear relationship between the stream segments and orders. Mean stream length of any basin increases with the increase in order of the basin.

(iii) Cumulative mean stream lengths of first, second and third order segments are having regular relationship.

(iv) Topographic sinuosity indices of the basins indicate that the topography of the western Tripura is well developed in comparison to the eastern parts.

(v) Bifurcation ratio of 11 basins out of the 12 selected basins vary from 3.58 to 4.50 which indicates the mountainous topography and dissected basins.

(vi) It can be postulated for the State of Tripura that bifurcation ratio is inversely related to the relief, its dissection and structure.

(vii) Most of the basins are in sinuous course (SSI = 1.00 to 1.50), with only exception to the Garam Charra where few hot springs are located (SSI = 1.06).

(viii) Impermeable sub-surface materials, sparse vegetation and rugged topography, is responsible for the high drainage density of 6 basins out of 12 small basins i.e. 3.18 to 4.50 km per Km^2.

(ix) Stream segment and stream length of respective order of all the basins are having high positive correlation i.e. 0.63 to 0.87. This relationship decreases with the increase in order of the basin.

(x) Highest range of correlation have been observed between the sinuosity indices i.e. - 0.77 to 0.94, of which correlation between channel index and valley index is highest, between hydrological sinuosity index and topographical sinuosity index is lowest. Moderate positive correlation exists between valley index and standard sinuosity index i.e. 0.57.

(xi) Standard sinuosity index is positively correlated to all other variables except topographical sinuosity index, drainage density and stream frequency i.e. -0.40, -0.38 and -0.45 respectively.

(xii) Constant of channel maintenance ranges from 0.22 to 0.31.

In Tripura slope is the single largest determinant of landforms that affects man and physical environment. There are five slope categories within the State which are :

(i) gentle ($0-5^{o}$)
(ii) moderate ($5-10^{o}$)
(iii) moderately steep ($10-15^{o}$)
(iv) steep ($15-20^{o}$) and
(v) very steep ($> 20^{o}$)

For the purpose of micro level analysis gentle slope category have been divided into two sub-units viz., (a) very gentle ($0-2^{o}$) and (b) gentle ($2-5^{o}$). Areas with very gentle and gentle slopes are having highest population density. All towns, educational institutions, settlements and all sorts of organised human activities are confined to these areas in sharp contrast to the uplands and hills with rugged topography, steep slopes having scattered huts and small villages. Debris slopes consist of weathered clay and coarse eroded materials which cascade down from the crests and scarp faces and rest at the lower parts. Debris slopes are dominant in the western and northern parts of Tripura. The slope of this distinct geomorphic unit varies from 10° to 15°.

The system of slopes includes free face, constant slope, waning slope and waxing slope respectively from the crest to the alluvial plains.

Parallel slope retreat is visible along the steep and very steep slopes in the high hills of eastern Tripura which is responsible for the development of narrow, steep, high hill ranges with narrow to wide smooth surface along river valleys in between the successive hill ranges.

River profiles are closely related to the rock type, structures, geomorphic processes and stages. Every resistant layer of the sandstones cropping out in the course of the important rivers, has caused rapids or waterfalls. A landscape of intense dissection with moderately steep slopes (15°-20°) has evolved as a result of sculpturing of the hills by running water.

Co-existence of steep slope and deep narrow valleys is very much prominent in east Tripura where ridges and faults run parallel, and the topography is highly dissected. In west Tripura, the slopes are gentle, the hills are subdued and the inter-montane valleys are wide.

The linear and areal distribution pattern of the average slopes in the region reflects the salient features of the topography in relation to geological structure, rock formations, dissections, relief, lineaments and altitude.

In general, slope profiles are convexo-concave, whereas, hills represent convex and river valleys represent concave profiles.

The break-in-slopes between different levels of the undulating terrain, unconformities in between the lithological formations, presence of rapids and waterfalls define neotectonic activity and phased differential erosion and sedimentation during different geological periods.

In western Tripura, valleys dominate the landscape, whereas in the east, hills are prominent.

Lithologic differences, as reflected in the slopes, are very less in the west Tripura, whereas, it is very prominent in the eastern parts. The amplitudes and altitudes of the anticlines are higher in eastern Tripura where shapes of the valleys are primarily 'V' shaped.

There is a close association of particular slope category with particular lithology, structure and drainage pattern; and this factor may be taken as one of the parameters for scientific landuse planning.

Drainage density (Km. per sq. km) have been divided into four categories which are -

(i) Coarse (0-2)
(ii) Medium (2-4)
(iii) High (4-6)
(iv) Very high (>6)

Very few basins has only less than 10 per cent of their total area under the coarse category which indicates youthful topography is dominant. Generally high percentage of area is covered by the medium category.

Drainage density is inversely related to the landslopes which may mathematically be represented as :-

$$D_d \propto \frac{1}{A_s}$$

Where D_d = drainage density, and

A_s = average slope in degree

Stream frequency (Km. per Sq. km.) have been divided into four categories which are :

(i) Coarse (0-4)
(ii) medium (4-8)
(iii)high (8-12) and
(iv) very high ($>$ 12)

In most of the basins, stream frequency per sq. km. is either medium (4-8) or high (8-12). Only streams of the low lying alluvial plains has coarse (0-4) and medium (4-8) stream frequencies, and generally frequency increases with the increase of altitude towards the east.

Alluvial plains of west Tripura have coarse stream frequency and medium drainage density. East Tripura has higher stream frequency and high drainage density. This may be attributed to the presence of trellis pattern of drainage system. Characteristically slopes 10° to 15° have developed medium drainage density and medium stream frequency.

There are five drainage patterns of which radial, dendritic and trellis are prominent. The central and southern parts where radial pattern is most dominant, indicates the domal character of the recent landforms.

In general drainage patterns reflect the influence of initial slopes, inequalities in litho-logic composition, structural control of folds, faults, lineaments, recent diastrophism and geomorphic history of the region.

The rectangular pattern as reflected by the main channels of the Gumti river and of the Khowai river which have cut across the structural hill ranges bears the evidence of upliftment and subsidence due to major tectonic disturbances in the geological past.

The Trellis pattern has developed in the areas of lime-stone and along Sakhan and Jampui folded ridges of resistant rocks.

The frequency of landslides and intensity of mass wasting is very high. It appears to be increasing due to human interference.

Morphometric analysis helps in identifying various geomorphic parameters, which in turn helps in identifying various erosion surfaces. The characteristic properties provide sufficient clues to visualise and reconstruct the geomorphic history of the State.

In the State of Tripura there are two distinct erosion surfaces viz :

(i) Pre-Pleistocene (generally above 200 metre)
(ii) Pleistocene-Recent (generally below 200 metre) or Quaternary.

Quaternary surface includes all alluvial fertile land of the state, whereas Pre-Pleistocene surface occupies insignificant space along the structural resistant hill ranges and hills of the eastern Tripura.

Pre-Pleistocene being the older one includes higher and older remnant surfaces mostly in the east Tripura. The geomorphic features and their pattern of landscape modifications in the State reflect that it has witnessed a number of earth movements. Its tectonic history can be traced through the lineaments, trend lines, folds, faults and fractures in the geological substrata.

Sharp change in relief is marked by break-in-slope on the margin of the anticlinal hills and hill ranges of east Tripura. These resistant structural hill ranges are passing through a phase of vigorous gully erosion. However, no inversion of topography has taken place yet, pointing to youthful stage of geomorphic evolution of the landscapes.

The present stage of evolution is characterised by active sculpturing of the hills, and transfer of mass from the hills and uplands to the intermontane river valleys.

Jhum cultivation on the hills and other unplanned agricultural activities on the hill slopes are mainly responsible for the deforestation and aggravating the soil erosion.

Human inter-action is bringing about rapid changes in the alluvial fertile landscape of Tripura. It is also accelerating rate of mass wasting on the hill slopes.

Physiographically, the state may be divided into three distinct categories, which are :

(i) Alluvial plains,
(ii) Uplands and Hills, and
(iii) High hill ranges.

The land form facies of the State has been classified into 5 micro-geomorphic regions viz:

(i) Recent and old flood plains,
(ii) Moderately dissected residual hills,
(iii) Highly dissected rounded crests,
(iv) North-South trending hill ranges, and
(v) Eastern most high Jampui hill range.

Differential landforms can be traced surrounding the resistant structural hill ranges i.e. from anti-clinal axis to the synclinal axis, which also indicate the development of differential erosion, that had taken place during various geological periods. Major erosional and depositional landforms of the region are of the Pleistocene period.

Fertile alluvial plains should be used for multiple cropping, inspite of settlements. The settlements should be done on the less fertile round shaped small hills (tilas) of Pleistocene deposits, as these are also safe from flood destruction. For the maintenance and development of natural environment, the uplands and hills should be utilised for plantations and forest developments, which is also a potent soil conservation measure.

Jhum cultivation on the hills and other unplanned agricultural activities on the hill slopes are mainly responsible for the deforestation, which may be replaced by cultivation under the terracing system. Bench terracing is best suited in Tripura, it is also a run-off and erosion control measure.

If the geomorphic features and elements are properly interpreted, analysed, integrated and utilised, this region with vast fertile alluvial plains, forests, ground and surface water potential and manpower can easily be developed, suitable multiple cropping system may be designed, to boost up its agricultural production.

This study shows that scientific landuse planning taking into consideration the geomorphological realities holds the key to the economic prosperity of Tripura.

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