N. R. Kar *
Calcutta

INVESTIGATIONS ON A PIEDMONT DRIFT DEPOSIT IN THE FOOT-HILLS OF THE EASTERN HIMALAYAS AND ITS GLACIAL AND PERIGLACIAL SIGNIFICANCE

Abstract

The paper embodies the important results of investigations carried on by the author on a piedmont drift deposit extending for about 40 miles from east to west and for about 10—12 miles from the Sub-Himalayan zone (Siwaliks) in the north to the North Bengal Plains in the south.

The drift beds more or less overlie the northward dipping, partly denuded strata of Siwaliks (Pliocene -Pleistocene), and attain a maximum vertical thickness of 400—500 ft. at the outlet of the Himalayan river Jaldhaka, having its origin in the glaciated tracts of south-eastern Sikkim. The thickness of the deposits decreases towards the plain to which it merges, though at one place it forms an abrupt cliff of about 250 ft. The surface of the drift bed is hummocky, and shows a chain of hillocks of drumlinoid form and arranged in an arcuate fashion. In all its surface expression it gives a picture of pseudomoraine or bouldery topography typical of gravel fans at the base of the high Himalayas. From a series of geomorphic investigations the author has come to the conclusion that the drift beds owe their origin neither to marine action on a slowly rising land as conceived by Godwin-Austen in 1866 nor to subaerial recent deposition beloging to the Siwaliks group as hinted by Mallet (1874). It has been concluded by the author that the enormous depositions filling up the Jaldhaka and other Himalayan valleys represent a vigorous glacio-fluvial filling aided by solifluction etc. during the Pleistocene glaciation. They are cut by 3 systems of terraces corresponding to 3 glacial periods and that the extensive pseudomorainic deposits in the foot-hills and at the outlet of rivers belong to the „Boulder Conglomerate" group of the deposits in Western Himalayas. The very characteristic facetted, faintly striated and a high proportion of „flat-iron shaped" boulders traced by the author testify to the origin of the „Boulder Conglomerates" as a glacio-fluvial outwash. All these corroborate the findings and conclusions of De Terra in the Kashmir Himalayas in 1936. The present work traces for the first time the effect of Pleistocene glaciation on the lower hills and of the glacigenic character of „Boulder Conglomerate" beds 4 in the Eastern Himalayas.

INTRODUCTION

The present paper embodies some of the interesting results of investigations carried on by the author intermittently during the last decade at the foot-hills of a part of the Eastern Himalayas, India, many of which have not yet been published fully. The considerations which have led the author to put some of the important results of this investigation before the Symposium on „High Mountain Region, Glacial Morphology and Periglacial Process" in Abisko, Sweden, may be stated as follows:

(a) Firstly, the area belongs to a part of the mighty Himalayan moun-

* Presidency College (Calcutta University), Calcutta, India.

tain system which extends for about two thousand miles from west to east and with a width of about 200 miles in subtropical latitude offers a magnificent store-house of glacial and periglacial features, which have not yet been studied fully. If they had been studied in detail, they could have extended our present-day knowledge of glacial and periglacial processes, which have been mainly developed from meticulous studies from the European region.

(b) Secondly, the present work investigates for the first time in this part of the Himalayas the effect of Pleistocene glaciation on the pro-glacial region. By the deliberate use of the word *pro-glacial region* it meant the foot-hills and plains at the base of the Himalayas which have recorded in its massive deposits some of the evidences of glaciation which normally affected the higher mountains and hills of the Himalayan chain during the Pleistocene period.

(c) The features traced by the author and the results attained after investigations on the piedmont drift deposits far away from the so-called lowest limit of glaciation in this part of the Himalayas go to prove in an inductive way the existence and the nature of the Pleistocene glaciation in the Eastern Himalayas, which have not been studied systematically.

(d) The results also corroborate for the first time the findings and conclusion on the Pleistocene glaciation and its effects on the lower piedmont region in the Western Himalayas (Kashmir Himalayas) so wonderfully traced by Prof. De Terra and Paterson more than 20 years ago. It is also believed by the author that other parts of the Himalayan foot-hills may also reveal similar features, if work is carried out in a systematic way.

AREAL EXTENT AND LOCATION

The area of investigations lies at the foot-hills of a part of the Eastern Himalayas (locally known as Kalimpong and Bhutan hills) and is located near the junction of the boundaries of India (West Bengal), Bhutan and Sikkim State. The entire area under study could be conveniently sub--divided into (a) a lower zone and (b) an upper zone. The lower zone comprises low foot-hills up to 2 500—3 000 ft. and plains above 300 ft. at the base of the hills running for about 40 miles from west to east (88°37′ E—89°5′E) and about 15 miles from the North Bengal plains in the south to the Himalayan foot-hills in the north (26°45′N—27°N). The upper zone lies to the north of the first zone and comprises the higher hills of Kalimpong, Bhutan and southeast Sikkim. It extends for about another 30 miles upto the high ridge at an altitude of about 15 000 ft. separating Sikkim from the Tibet and Bhutan hills. It was in the lower zone of piedmont drift that intensive study and investigations were carried out by the author and which provided a key to the glaciation phenomena in the higher hills. Only cursory observations were carried out in the higher zone of the Sikkim Himalayas in order to find corroboration of the findings in the lower piedmont zone (fig. 1).

PHYSIOGRAPHIC SETTINGS

The physiographic setting is characterized by the fact that in the lower zone the Himalayan foot-hills rise to an altitude of about 3 000 ft. overlooking the Drift Beds and the North Bengal Plains to the south. A number of Himalayan rivers such as Gish, Chel, Neora, Murti, Jaldhaka and others having their origin in the higher hills flow more or less from the north to south cutting across the foot-hills and piedmont drift beds to join ultimately the river Tista, the main stream of North Bengal (fig. 1).

The innumerable hill streams and a number of major rivers which have cut down gorges in the hills have also given rise to terraces across the undulating and low plateau-like drift deposits thereby forming a typical piedmont landscape overlooking and often merging to the sandy plains to the south. To the north tiers of hills and mountains rise one after another terminating in a few peaks at about 8 000—10 000 ft. from which region most of the rivers mentioned above have their origin. Further north the Dongkya range rising upto 13 000—16 000 ft. forms a dominating back-bone of the region and forms the watershed and boundary line between South-East Sikkim, Tibet and Bhutan. The southern flank of this ridge is drained by the mighty river Jaldhaka, having its origin in the once heavily glaciated region (12 000—14 000 ft.) and this mighty Jaldhaka valley with its enormous gorge, high terraces and expansive thalweg form conspicuous physiographic features in the entire landscape of the area. We shall see later how this Jaldhaka valley provides many geomorphic and sedimentologic features of great interest and thereby becomes a key-area of the entire region under investigation.

SOLID GEOLOGY OF THE AREA

The solid geology of the area is interesting in as much as it gives a clue to the geology of the drift beds at the base of the hills (fig. 2).

The rock types met with in the area can be conveniently grouped into (a) the Metamorphics of the higher hills in the north and (b) Sedimentaries of the foot-hills in the south. The entire geological succession in the area can be described as follows:

SOUTH

(a) Sedimentaries:	Recent Alluvia
Pleistocene	Older Alluwium Boulder Bed (drift formation)
	unconformity
Pliocene	Upper Tertiary sandstone, shales & conglomerate in patches (Siwaliks)
	fault contact
Upper Paleozoic	Gondwana sandstone & shale as a narrow belt
	thrust fault
(b) Metamorphics:	Buxa series of slates, quarzites and dolomites as a narrow band
Paleozoic (Pre-Cambrian ?)	thrust fault
	Daling Beds of phyllites, schists & quarzites Darjeeling gneiss and schists including foliated granites

NORTH

It will be apparent from the accompanying geological map (fig. 2) that the Darjeeling gneisses cover an extensive area of the higher hills and ranges in the north of 27°3′. The typical rocks are pelitic schists and gneisses together with patches of foliated granite. The characteristic index minerals of higher grade metamorphism, such as garnet, kyanite and sillimanite occur in these rocks, the sillimanite bearing gneiss occurring over more extensive area.

This is followed by the Daling rocks as a broad belt where slates, phyllites and some mica-schist give evidence of their origin under low-grade metamorphism. Further south, the Buxa and Gondwana are two very narrow belts, not exceeding a mile in width, where the slates, and quarzites of the Buxa are followed in the south by the predominantly sandstones, shales and lenticules of coal in the Gondwana beds. Both of these beds show persistently high dip about 40°—50° towards the north with some degree of metamorphism.

The next important formation is the Upper Tertiary rocks occurring at the foot-hills of the Himalayas (Siwalik formation) but it is conspicuously absent, except for one single patch in the area under our study. This massive sandstone with small bands of pebble conglomerate near

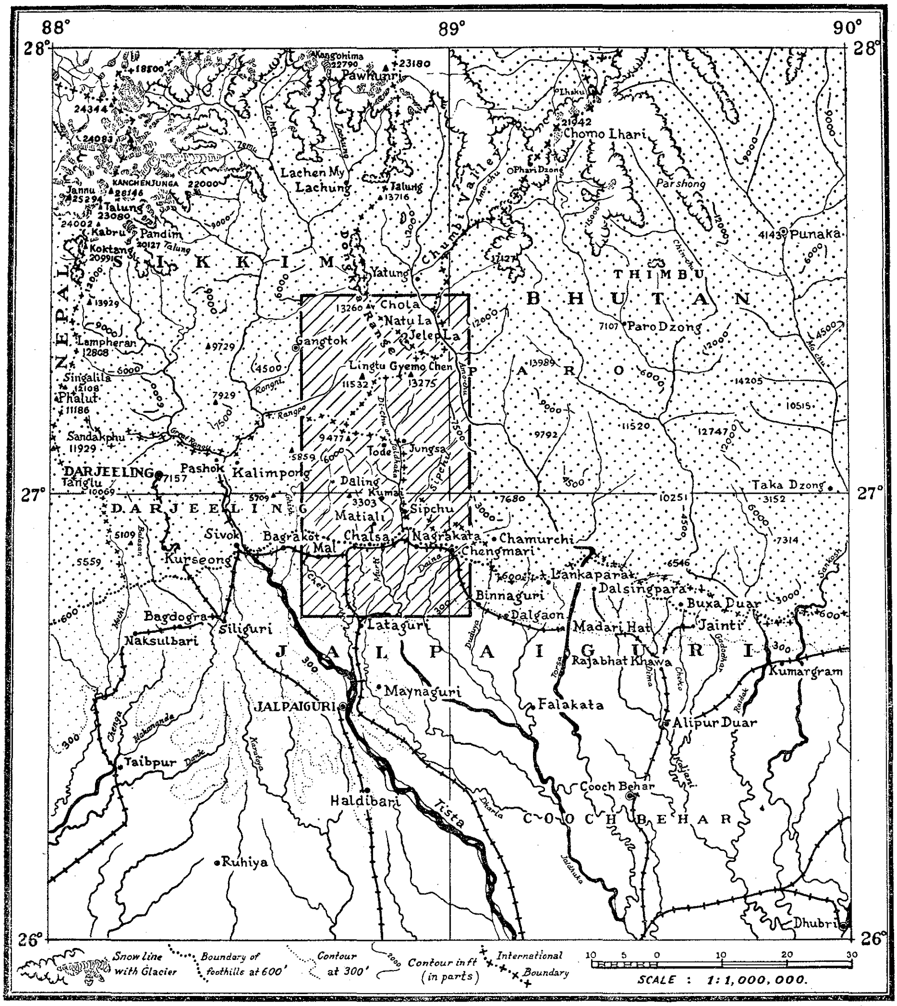

Fig. 1. Map of a portion of Eastern Himalayas showing major physiographic features

Stipled areas indicate the mountain mass, the lighter stiples denoting the undulating piedmont plains. The area demarcated by an inset and hachures indicate the area under present investigations at the border of Sikkim, Bhutan and West Bengal, India (N. B. Sikkim and Bhutan are attached to India by special treaties)

the bottom has a low dip towards the north but has a steep contact with the Gondwana beds.

The next important formation of the area and with which we are concerned is the *Boulder bed* spreading from the foot-hills as extensive drift beds between the river Chel and Daina. Between the rivers Neora and Jaldhaka, the boulder beds overlie the patch of Upper Tertiary beds while in the areas where the Tertiary rocks have been presumably eroded away the boulder drifts have been found to overlie directly over the low-grade metamorphics of Dalings. The accompanying geological sections will clarify the stratigraphic relation of the drift beds with the other rock types of the area (fig. 4).

BACKGROUND OF THE INVESTIGATION

It may be of interest to note the background of the present investigation which dates back to about 1947/48, when the author came to study the origin and development of a peculiar *Red Soil* at the foot-hills of the Eastern Himalayas. This brick-red coloured clayey-loam soil, which had attracted attention of many Soil-Scientists of the Indian Tea Association for many years as being the best tea growing soil, is conspicuously developed on the surface of this piedmont drift formation. The study of this soil led the author to investigate the nature and origin of the beds on which this soil is conspicuously developed as a surface phenomenon and it was found that the beds on which this soil occurs is nothing but a series of drift beds at the base of the Himalayan foot-hills. A prolonged study of these drift beds in the field led to the finding of forms and features of topography of unusual geomorphic interest. So the interest in the origin and development of the soil was turned on to the origin and development of this huge drift formation, which in fact proved to be of rather unusual character. The present work arose out of this interest and is based on field work carried out intermittently during the period 1946/47 to 1954.

GEOMORPHIC CHARACTER OF THE AREA

The unusual interest in the geomorphic character of these drift formations lies on the following facts:

(a) In the Chel-Neora Sector, as also in other areas, the drift beds extending for about 7—8 miles away from the hills have a gentle inclination of 3—4 degrees increasing gradually towards the north and finally abutting on the Himalayan foot-hills. The foot-hills themselves rise only to an altitude of about 2 500—3 000 ft. facing the plains. The low heights of the foot-hills overlooking the plains, the gentle slope of the drift surface extending for a considerable distance from the hills and the absence of a cone-like pattern of deposition of these beds raise doubts as to the origin of these beds due to a simple piedmont gravel drift, or alluvial-colluvial fanning process.

(b) The detailed geomorphic character of the land between the river Neora and Murti gives additional evidence of unusual character of the drift beds. Here the southern margin of the drift formation does not merge gradually to the plains in the south but forms a steep cliff-like rampart overlooking the plains by about 250 ft. This terminal cliff has a number of conical and knoblike pinnacles being rounded and of subdued height of 50—75 ft. About 4 miles further north, another line of ridge with isolated domes and conical peaks and a smooth outline of camel-back ridge makes its appearance. This ridge has an average height of 250—300 ft. and runs for about 6—7 miles in an arcuate alignment overlooking steeply the boulder plateau to the south, while northwards its rises gradually to about 1 750 ft. where they rest against the Siwalik front-ranges. In all its topographic expression, the boulder formation in the present area has a pseudo-morainic topographic character rather than a fanglomeratic character. The huge boulder bed formation lying to the east of the Jaldhaka river and extending for about 5—6 miles away from the front ranges also show a prominent outline of an asymmetrical camelback-like ridge near Hope and a conspicuously inverted boat-like low hillock of "drumlinoid" form near it. All these again add credence to pseudo-morainic features rather than to ordinary gravel drifts or alluvial fans.

(c) Even if these drift formation originated under some sort of fanning process, the very extensive area of the drift formation (40 ml. × 8 ml. approx.) in the present area, the considerable thickness of the drift beds, up to a visible thickness of over 500 ft. near the outlets of rivers and the occurrence of very many boulders of large dimension found lying in river beds and in narrow hill streams themselves suggest some sort of extra vigorous activity of the fluvial channels beyond their normal process of alluvial fan formation.

(d) Nowhere in the entire drift beds any stratified pebbly layer or any form of size-assortment was found, except just near the flank of present-day rivers. The entire drift formation was found to be composed of boulders — large and small, pebbles, rock fragments, sands, silts etc. without any sort of homogenity, stratification or assortment whatsoever. Added to this fact the sudden occurrence of large boulders even at the terminal zone of the boulder bed and occurrence of giganticsized boulders in the bed of narrow streams and even in high banks of river beds add further credence to the fact that the beds were formed by a process far more vigorous and stronger than ordinary process of gravity slip, gravel drift, or simple fluvial deposition.

(e) The lithologic character of the debris material and their possible source region, as investigated by the author reveals interesting features worthy of consideration. It was found that an overwhelming majority of rock fragments, boulders etc. constituting the drift beds are gneissic rocks (mainly sillimanite bearing) having their origin in the extensive high-grade metamorphic zone (Darjeeling gneiss area) of the higher hills beyond the Daling front-ranges of slates, phyllites etc. The proportion of gneissic rocks in the boulder beds as sampled by the author in the different parts of the drift formation rises to 75—80 p. c. with the sillimanite-bearing high-grade metamorphic gneiss itself having a proportion of 50—70 p.c. Thus the boulder bed does not seem to be derived from the denudation of the Himalayan front-ranges as suggested by the absence of a close petrographical affinity of the drift beds to the Dalings and Tertiary foot-hills overlooking them. This raises a prima facie doubts as to the origin of these beds as a huge piedmont fan under normal condition. Some sort of active scouring or mechanical denudation of the higher mountainous areas, supply of huge load of rock debris from these areas and a vigorous transportation of these materials from areas beyond the present front-ranges seem to be suggested.

Thus it becomes evident that although the position and alignment of the drift formation at the base of the Himalayan foot-hills and the character and topography of the deposits may at first sight give the impression of a piedmont gravel drift of sub-aerial origin or of alluvial fan formation of fluvial origin, the geomorphic character of the drift beds exhibits certain features which defy ordinary trend of explanations. At least many of the features traced by the author and mentioned above cannot be adequately explained by simply taking resort to sub-aerial process of gravel formation or alluvial-colluvial process of fan formation.

EARLIER CONCEPTIONS REGARDING THE ORIGIN OF THE BOULDER BEDS

It will be of real interest to note here that these conspicuous boulder beds had attracted attention of passing geologists since about hundred years back and have given rise to different speculations regarding their possible origin. They may be briefly summarised as follows:

(a) As early as 1868 Major Godwin-Austin during his travels along the foot-hills zone of the Eastern Himalayas noticed the "much larger accumulation of clays and conglomerates" (also described by him as "terraces of clays and gravels", "mass of gravels and clays") deposited at the base of the hills, especially near the outlets of major rivers or occurring as terrace remnants overlooking the stream beds. Considering the vast

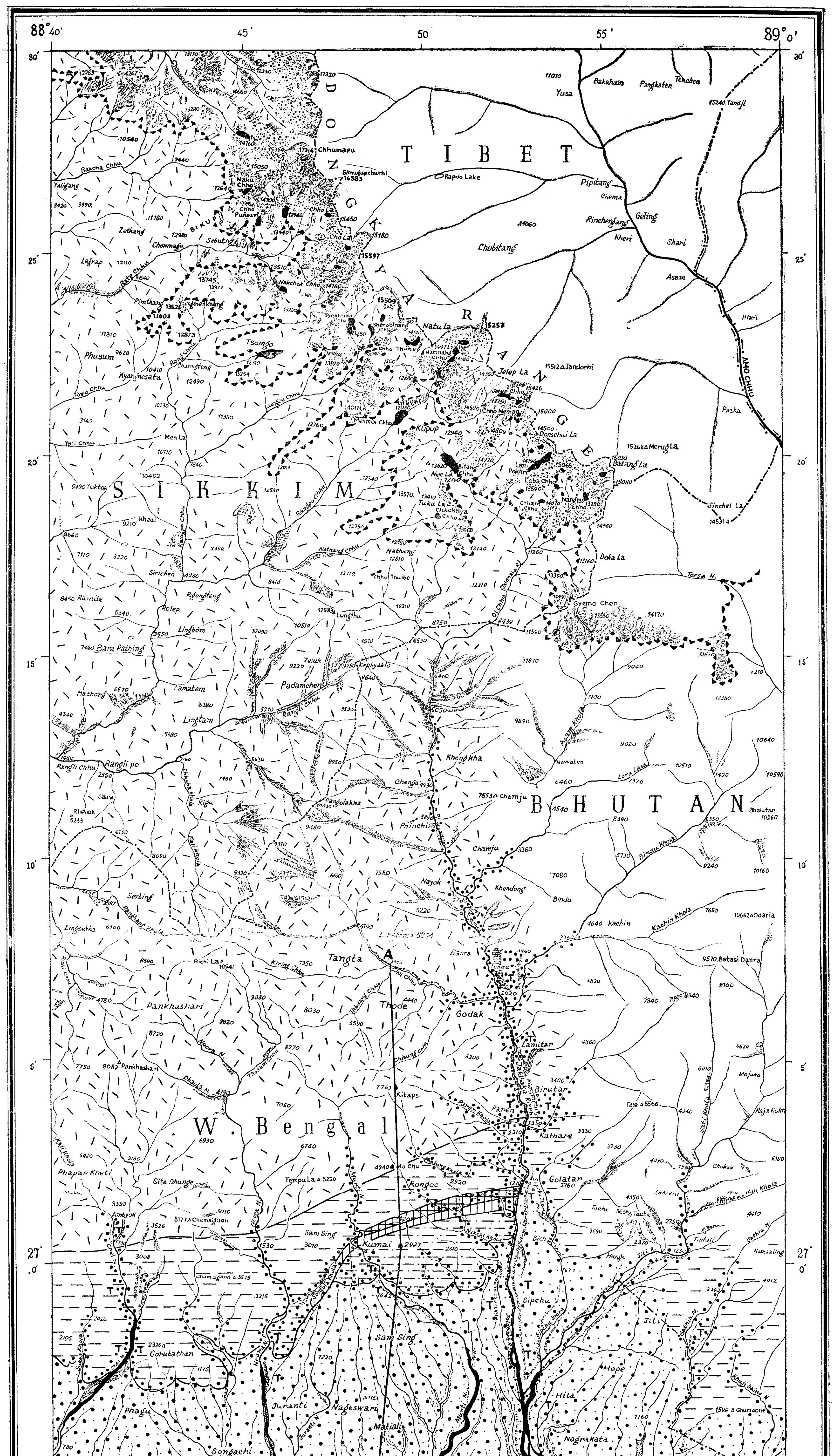

Fig. 2. Geological/geomorphological map.

1. glacial lakes, old corrie basins, and sources of rivers
2. screes, blockstreams and frost shattered deposits
3. Darjeeling gneiss, foliated granites and schistose gneiss } (Pre–cambrian?) Paleozoic
4. Daling schists, phyllites and quartzites
5a. Buxa slates an quartzites
5b. Gondwana sandstone and shales — Upper Paleozoic
6. Siwalik sandstone and shales — Upper Tertiary
7. gneissic boulder conglomerates and valley fillings } Pleistocene
8. older alluvium (sands and silts)
9. Newer alluvia — Holocene and recent
10. treeline and limit of periglacial phenomena; T — denotes major Boulder Terraces; dash and dotted line indicates international boundaries

extent of these gravel beds far away from the hills, the occurrence of large granite and gneissic boulders in the stream beds, Godwin Austin remarked that "their size and position so far from the hills required the existence of more than the ordinary transporting power of moving water". But he interpreted these gravel beds and the terrace-like features developed on them as due to "action of the sea" on a "slow but intermittent rise of the land".

(b) In 1874, F. R. Mallet of the Geological Survey of India mapped the area geologically for the first time and noticed these huge boulder formations which he called "enormous recent boulder deposits". But unfortunately he did not map these boulder beds, nor did he show them in his geological map. But he remarked that the deposits in question "might represent Siwalik group" of sedimentary deposits (Upper Tertiary) normally found along the base of the Himalayan hills. He did not at all attach much importance to the question of the origin of these boulder beds.

(c) The next reference to these boulder bed formations is contained in the interesting theory of "Siwalik River" propounded by G. E. Pilgrim of the Geological Survey of India in 1919, while explaining the history of the drainage-system of Northern India. He had noted the huge accumulation of Upper Siwalik boulder Conglomerate, of which the boulder beds under review presumably form a part, all along the Himalayan hills and bordering the Gangetic plain and attaining a maximum thickness of 5000 ft. with a width of 60 miles in the Western Himalayas but decreasing in volume towards the east until near Bhutan they occur as small patches. They persistently overlie the Upper Siwalik (Pliocene-Pleistocene) sandstone rocks, are mainly composed of well-rounded boulders of average 4 ft. in diameter and were found by him to be developed conspicuously near the outlets of mountain streams and rivers. Considering the vast extent of these boulders beds, their conspicuous thickness and stratigraphic position on the top of the Upper Siwalik beds, Pilgrim termed this formation as *Boulder Conglomerate* assigning it a definite stratigraphic horizon. He ascribed its possible origin to the voluminous accumulation of detrital matter, boulders, pebbles etc. brought by Himalayan streams into the bed of a single major river ("Siwalik River" of Pilgrim or "Indobrahm" of Pascoe, 1919) occupying a continuous depression of furrow at the flank of the Himalayan foot-hills. The dismemberments and diversion of this Siwalik River due to various tectonic causes gave rise to these huge boulder formations in its bed. Pilgrim discounted the possibility of deposition of these beds under any glacial agency during the Pleistocene glacial age and dismissed the possiblility of increased supply of erosional and detrital matter by the Himalayan rivers and streams due to excessive rainfall during the pluvial age corresponding to the Pleistocene glacial age. Though based on observations on boulder conglomerates in the Western Himalayas, Pilgrim's studies bear ample relevance to the boulder bed formation under our present study though his conclusions may be subjected to serious objections.

(d) The next reference to the boulder beds in our present area comes from Dr. Heim of Zürich (1939), who visited the area for a very short while in 1936 and was profoundly impressed by the geomorphic features of the area which left "one of the greatest geological impressions on his journeys round the world". Though he considered this area as an "El Dorado" of Pleistocene geomorphic features, he could only study the area for a very short time and traced a 3-level terrace system and some evidence of warping and folding in these Pleistocene boulder beds. It is interesting to note that besides these terrace remnants he had noticed gigantic sized boulders upto the dimension of 100 cubic metres in the narrow river beds but he ascribed their origin to the very high amount of rainfall in the Eastern Himalayas and to nothing else (Heim & Gansser 1939).

THE ORIGIN OF THE BOULDER BEDS AS CONCEIVED BY THE AUTHOR

Based on observations and investigations in the field for several years the author has come to a conclusion as regards the origin of these boulder beds. Full details of the investigations carried on by the author on geomorphic character, textural characteristics, fabric-pattern of the boulder beds and shape and form of the boulders are awaiting publication separately. In the meantime important observations and findings as to the origin of these beds are being submitted herewith for the interested readers:

(1) It has already been mentioned that the boulder formations in our area by their vast extent and thickness signify a process far more vigorous than normal fluvial process of fan formation. The author has further found that not only the thickness and extent of boulder beds but also the occurrence of huge amount of bouldery materials chocking almost every hill stream and narrow gorge in the area point towards some form of solifluidal process operating along the hill slopes at the time of deposition of these major boulder beds (fig. 2).

(2) The compact mass of heterogenous and non-sorted boulder materials in a matrix of silt and sand as mentioned before seem to indicate a fluvio-glacial origin rather than purely fluvial one. The "provenance" or zone of origin of the majority of gneissic boulder frag-

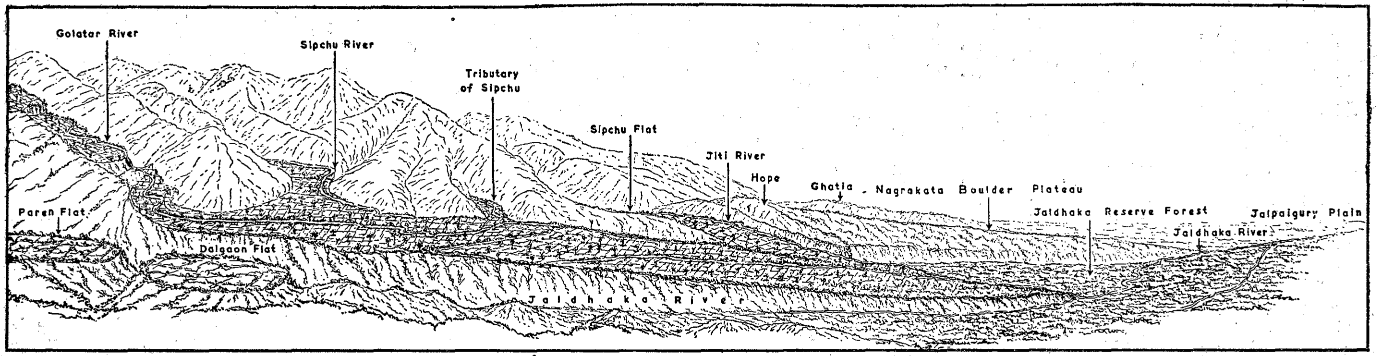

Fig. 3. A panoramic view of the Jaldhaka valley looking east from Rongoo hills (alt. 3500 ft.), showing the glaciofluvial deposits the main valley and the tributary valleys

R. Jaldhaka, and its tributaries Goltar, Sipchu ect. have cut deep gorges through the glaciofluvial deposits. Cultivations and settlements are extensive on glaciofluvial valley fillings ments in the higher hills beyond the front ranges further points towards a widespread scouring of these high hills and their transportation by very vigorous channels and subsequent deposition at the base of the hills near their outlets. The author is of the opinion that glacio-fluvial channels played a very prominent part in this process, when the higher hills were under active mechanical denudation leading to increased supply of debris materials (fig. 2).

(3) The fact that these huge boulder beds overlie unconformably the northward dipping Siwalik (Pliocene-Pleistocene) strata at the base of the Himalayas, indicates that the boulder formation originated sometime in the Pleistocene, after the uplift, tilting and partial erosion of Siwalik beds (fig. 2). Thus the author was led to conceive a widespread Pleistocene glaciation in the high Himalayan hills of Sikkim and Tibet during which the lower hills of Kalimpong and Bhutan experienced some form of periglacial condition. During this period the main stream of the area, the Jaldhaka river brought down a great volume of glacial morainic materials from its upper reaches, while the minor streams like Chel, Neora, Murtee, Sipchu etc. descending down the hill slopes were choked with periglacial debris and solifluction materials. All these glacial and periglacial debris materials were then flushed away and redeposited as huge coalescing fans at the outlets of rivers and streams, thus giving rise to the present extensive boulder beds.

This conception of the author was borne out by other evidences coming to light in course of subsequent field study by the author.

(4) In course of an intensive analysis of shape and form of individual boulders in the lower, middle and upper zone of the Drift beds, the author found that about 60—70 per cent of them have a tabular shape including all its variant forms. The other shapes like wedge, lenslike, nodular, ellipsoid or spherical are present but very poorly represented as secondary characteristics. This fact conforms clearly to the findings of C. K. Wentworth (1936) in the Wisconsin glacial till of the U.S.A., where the tabular form predominated the shape of the boulders and indicated, according to the author, some kind of sliding movement rather than rolling. Of greater diagnostic value is the very high precentage of occurrence of the "flat-iron" shaped boulders, 45—50 per cent in our area. This "flat-iron" shape had been characterised by Von Engeln (1930) as a "type-form" of diagnostic value of glacially transported boulders in his investigations on various glacial tills and this was strongly vindicated by Wentworth in 1936. The finding of about 20 per cent of perfectly developed flat-iron type, surely indicates the origin of these boulders initially under glacial transport and subsequently glacio-fluvial channels might have deposited

them as piedmont gravels. This interpretation conforms to Von Engeln's views that "the flat-iron forms when found may be regarded as of diagnostic significance in determining the glacial or non-glacial origin of conglomerates and tillites about which there is doubt".

(5) A study of other features of individual boulders collected in a profile at the outlet of the river Jaldhaka and about 100 ft. above the present river bed revealed that a number of boulders showed facetted sides with signs of polishing, grooving or deep parallel scars. Even though the typical criss-cross striation marks are absent in these samples, probably due to subsequent obliteration by fluvial action, nevertheless the deep grooves and scars point towards the origin of the boulders under some glacial agency initially. The absence of a perfectly developed striated face, according to Von Engeln, "is no argument against the glacial origin of a boulder conglomerate".

(6) In course of further study on the space-orientation of boulders and pebbles in these drift beds, interesting results were obtained which corroborated the previous findings of Krumbein (1939) and Holmes (1941). The author's interest was to trace, if any, the predominant long-axis orientation of several hundred boulders in the upper and lower zone of a Boulder Plateau; absence of any predominantly preferred direction in the pebbles would suggest their origin under fluvial process or sub-aerial gravity drift, or any alluvial-colluvial process but a strong orienting tendency in them would invariably suggest their deposition under a far stronger, vigorous and semi-viscous medium like glacial or glacio-fluvial agency. With this idea in view till-fabric analysis in the upper and lower reaches of a boulder bed was undertaken in the techniques of petro-fabric analysis of modern petrologists. The results obtained showed clearly a strong preferred orientation by as much as 40 per cent of the pebbles lying within 12 W of North and 24 E of North, with an average direction of 18 E of North. This coincides exactly with the average direction of the elongated hillock on the surface of the boulder bed. About 5—6 miles south and at the edge of the boulder plateau, this preferred orientation has a little wider spread. The two primary direction of preference and the perpendicularly lying transverse preferences found in course of investigations conform clearly to Holmes' observations that the primary and secondary directions of preferences are caused by sliding and rolling movement of boulders under a glacial transporting agency. In any case, the strong directional preferences in the boulder beds of our area suggest their deposition under a vigorous glacio-fluvial agency with subsequent tectonic thrusting phenomena on them.

It ought to be recalled now that De Terra (1939) after an intensive study of the Boulder fans at the base of the Kashmir Himalayas and at the outlets of major Punjab rivers interpreted them as huge bouldery accumulation merging gradually and often imperceptibly to the 2nd glacial moraines of the Pleistocene age. He established clear relationship between the sequences of Pleistocene glaciations in Western Himalayas, tectonic movements in the Kashmir hills and the cycle of degradation/aggradation in the rivers and stream channels draining to the plains of Punjab. He identified these piedmont boulder beds as the "Boulder Conglomerates" of Pilgrim (1919), ascribed their age to the Middle Pleistocene and traced their origin to the 2nd glacial morainic outwash, aided by an accumulation of gravels due to pluvial conditions at the foot-hills during the Himalayan glaciation. He thus characterised this boulder conglomerate fans as "the geologic precipitate of both tectonic and climatic processes", both of which interfered with each other throughout the Pleistocene in the Himalayan region. The warping, folding and thrusting phenomena traced by him in these boulder conglomerate beds indicated clearly the recency of the recurrent tectonic disturbances that began with the Himalayan mountain-building episode and had continued right up to the Upper Pleistocene and even later. In a unique study of the chronology of gravel terraces in the glaciated and non-glaciated regions of the Kashmir Himalayas he had tried to correlate them with the glacial cycles in the Himalayan mountains and pluvial cycles in the piedmont region. The 4 major terraces traced by him along the Himalayan rivers draining to the plains (Tl, T2, T3 & T4) corresponded to the 2nd interglacial, 3rd glacial, 3rd interglacial and 4th glacial phases respectively, the 4 glaciations in the Western Himalayas corresponding to the Günz, Mindel, Riss and Würm and post-Würm glaciations of Penck and Brückner in Europe (Dainelli 1922).

(7) A comparative study of the boulder beds in our area with the boulder conglomerate beds of the Western Himalayas has convinced the author of the similarity in character and stratigraphy of these boulder formations lying about 1 500 miles apart. From the superposition of the boulders in our area on the tilted and eroded Siwalik strata (Pliocene-lower Pleistocene), the Middle Pleistocene, age of the boulder bed is inferred and thus the boulder bed of our area seems to be homotaxial with the boulder, conglomerate of the Western Himalayas. Moreover, the arcuate line of hills and ridges in the middle of the boulder bed on the west and east of the Jaldhaka river points toward middle to later Pleistocene tectonic disturbances in the piedmont zone giving rise to these warped up and folded hills and ridges. In fact the entire boulder formation on both sides of the river Jaldhaka could be conceived as a huge lobe of a boulder fan with its apex at the outlet of the river, subsequently upwarped, tilted and brea-

ched by the river itself right along the middle of the cone and thus dismembering into two separate boulder beds. A typical example of this phenomenon has been traced by De Terra (1939, p. 185—186) on both sides of the Chenab river at the foot-hills of Kashmir. The "drumlinoid form" of hillocks and knoblike pinnacles in the boulder bed of our area gives interesting testimony of upwarping of these beds by pulsating tectonic movement in the later Pleistocene and subsequent streamlining by mass wasting.

(8) The enormity of the boulder beds in thickness and extent as also the very coarse nature of the bouldery materials, in the valley-fills of rivers and streams in our area add further evidence of recurrent diastrophic character of the Pleistocene period in the Eastern Himalayas. This recurrent uplift of the Himalayan mass brought rejuvenation and increased the river gradients, thereby increasing greatly the amount of debris from the hill slopes and glacial moraines. Moreover the increased turbidity in the atmospheric condition due to monsoonic winds brought about nivation, frost-shattering etc. in the periglacial zone and higher precipitation in the piedmont region, thereby dislodging an increased amount of solifluction materials, screes, slope-wash etc. The interference between the diastrophic and climatic cycles with the latter playing the dominant role in the sedimentation of the Pleistocene, as clearly brought to light by De Terra and others (De Terra & Paterson 1939; De Terra & Movius 1943) in north western India, Burma, Java etc. are thus also confirmed by the piedmont boulders of the Eastern Himalayan region.

(9) Finally, the cyclic nature of the Pleistocene glacial phenomena is also indicated by the terrace-sequence in the boulder beds of our area. The present author found the piedmont boulder beds between the river Chel and Daina to have close genetic afinity with the thick mass of bouldery materials occurring as extensive walley-fills in almost all the rivers, especially in the thalweg of Jaldhaka. Similar valley filling in the Himalayan valleys and its climatic significance was noted by La Touche (1910) long ago, but the problem had never been worked out in the Himalayas. The valley of this mighty river shows all throughout its mountainous course an enormous mass of bouldery valley-filling now occurring as terrace remnants high above the stream bed (fig. 3). As in all adjoining rivers, a 3-level terrace system has developed in this extensive valley-fill, with the highest terrace (T1) lying at about 1 800—2 000 ft. above sea level. On both sides of the river about 350—400 ft. down, the second terrace (T2) is found preserved at places, while a 25—30 ft. high terrace overlooks the present river bed. The topmost terrace T1 developed on the surface of the huge valley-fill may thus be taken to have originated

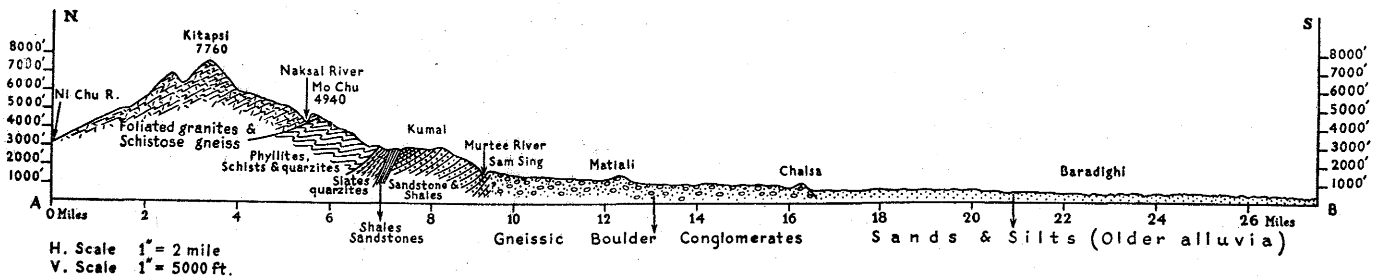

Fig. 4. Geological cross-section along the line A—B shown in the fig. 2

due to aggradation of morainic outwash gravels of the 2nd glaciation, the strongest Himalayan glaciation of the Pleistocene. The 400 ft. of precipitous drop down to the 2nd terrace can be ascribed to the prolonged incision of the 2nd interglacial phase, the longest in the Pleistocene glacial cycle. While the 2nd terrace may be due to another accumulation corresponding to the 3rd glaciation, the lowest terrace may be due to incision of the 3rd interglacial. No true moraines have yet been traced by the author in the Jaldhaka Valley and the actual glaciation of this valley canot yet be proved. But the author found ample evidence of very powerful glaciation in the source region of the Jaldhaka river in South-east Sikkim at about 12 000—13 000 ft. in altitude (present-day glaciers lie at about 18 000 — 19 000 ft.). This region overlooks steeply the Jaldhaka Valley just in the north and it is quite likely that these powerful glaciations in the Sikkim Himalayas gave rise to enormous glacigenic morainic materials which came down as extensive valley--fills in the Jaldhaka Valley and in whose terraced beds the Pleistocene glacial cycles have somewhat been recorded.

CONCLUSIONS

To summarise briefly, the investigations of the author on the piedmont drift deposits in this part of the Eastern Himalayas have established: (a) that these boulder beds did not originate under normal fluvial fanning process, but by fluvioglacial channels depositing huge masses of morainic materials, periglacial debris, solifluction materials slope-wash etc.; (b) that the present boulder beds belong to the "Boulder Conglomerate stage" of the Western Himalayas and their relation to Pleistocene glaciation in Sikkim hills is also in various way suggested; (c) that the recency of Pleistocene tectonic disturbances is inferred from the upwarping and folding in the unconsolidated boulder beds; (d) that the interference of climatic vicissitude and diastrophism during the Quarternary history of the Himalayas is also indicated by the texture and magnitude of the boulder formation; (e) and finally the existence of strong Pleistocene glaciation in the Sikkim Himalayas and of periglacial conditions in the Kalimpong and Bhutan hills, several thousand feet lower than their present-day limits, as also the cyclic nature of the glacial phase are all recorded in the enormous deposit of valley-fills and in the terrace chronology. Almost all of these features are recorded by the author in the Eastern Himalayas region for the first time.

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