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Photogeological survey of the Siwalik Ranges and the Terai Plain, Southeastern Nepal*

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(With 4 Tables, 5 Text-figures and 4 Plates)

I Introduction

Under the Sun Kosi Terai Project of FAO (Food and Agriculture Organization), the executing agency for UNDP (United Nations Development Programme), the writers engaged in the photogeological and hydrogeological survey of the Siwalik Ranges and the Terai Plain in the southeastern Nepal, during two months from December 10, 1968 to February 9, 1969. Geological research on the Siwaliks (Miocene to early Pleistocene) and the Younger deposits (the post-Siwalik deposits, middle Pleistocene to Holocene) in the aforesaid area will offer basic data for the development of groundwater in the eastern Terai Plain.

In this survey, the photogeological study of the Siwalik Ranges was carried out by M. ITIHARA, and the hydrogeological and photogeological study of the Terai Plain, by T. SHIBASAKI and N. MIYAMOTO. The results on the photogeological part are reported here.

II Records of the photogeological survey in the southeastern Napal

Records of the photogeological survey are shown in Table 1, and the route of the field trip for reconnaissance is shown in Fig. 1.

In the surveyed area, the traffic condition is very unsatisfactory except the all-weather hard-top road from Kathmandu to Birganj on the Indian frontier and the East West highway from Simura to Kanchanpur which is now being constructed.

The field survey in the Terai Plain and the Siwalik Ranges was performed by use of Toyota's jeep (land cruiser). But, in spite of the dry season, even the jeep was not able to follow oxcart-tracks, i.e. the most common road in Nepal, without much trouble.

III Outline on the topographical and geological subdivisions of Nepal

The symbol of the Kingdom of Nepal is the snowy crest of the Himalayas including Mount Everest, the highest mountain in the world. In this Kingdom, however, not only high mountainous land but also hilly and low lands (Plate III, 2) are of wide distribution. The relief is extremely varied and ranges from 200 m high in the Terai Plain, Nepalese part of the Ganges Plain, to over 8000 m high in the great Himalayas.

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Table 1. Records of the photogeological survey in the southeastern Nepal (from Dec. 10, 1968 to Feb. 9, 1969)

Date	Route	Remarks
Dec. 10	Tokyo – Bangkok	
" 11	Bangkok – Kathmandu	
" 12 – 18	Kathmandu (geological interpretation of aerial photographs)	
" 19	Kathmandu – Hardinath – Janakpur (by land and air)	
" 20	Janakpur – Jaladh K. (*Khola**) – Chisapani	photogeological survey (Dec. 20 – 24)
" 21	Chisapani – Amtai – Chisapani	
" 22	Chisapani – Selar K. – Janakpur	
" 23	Janakpur – Charnath K. – Auri N. (*Nadi***) – Janakpur	
" 24	Janakpur – Ratu N. – Kamla N. – Ratu N. – Janakpur	
" 25	Janakpur – Jareshwar – Janakpur (hydrogeological survey)	
" 26	Janakpur – Hardinath – Kathmandu (by land and air)	
" 27 – Jan. 1	Kathmandu (geological interpretation of aerial photographs)	by Itihara, Shibasaki & Miyamoto (Dec. 10 – Jan. 1)
Jan. 2	Kathmandu – Dahman Pass – Parwanipur	photogeological survey by Itihara (Jan. 2 – 20)
" 3	Parwanipur – Bagmati R.	
" 4	Bagmati R. – Harpur – Malangwa – Jareshwar – Janakpur	
" 5	Janakpur – Hardinath – Janakpur	
" 6	Janakpur – Raghunathpur	
" 7	Raghunathpur – Amtai	
" 8	Amtai	
" 9	Amtai – Kholubote	
" 10	Kholubote – Kholubote-Hupter Pass – Kholubote	
" 11	Kholubote – Amtai	
" 12	Amtai – Hardinath – Janakpur	
" 13	Janakpur – Hardinath	
" 14	Hardinath	
" 15	Hardinath – Chisapani – Lahan	
" 16	Lahan – Siswari D. (*Dhar****) – Koreiya D. – Lahan	
" 17	Lahan – Rajbiraj – Barmajhia – Fatepur	
" 18	Fatepur – Siwai N. – Fatepur	
" 19	Fatepur – Rajbiraj – Lahan	
" 20	Lahan – Portaha – Janakpur	
" 21	Janakpur	
" 22	Janakpur – Abar – Janakpur	(hydrogeological survey) (Jan. 22 – 23)
" 23	Janakpur – Sursand – Janakpur	
" 24	Janakpur	
" 25	Janakpur – Ranibas – Janakpur (photogeological servey by Itihara)	
" 26	Janakpur – Hardinath – Janakpur	
" 27	Janakpur – Hardinath – Janakpur	
" 28	Janakpur – Harinath – Kathmandu (by land and air)	
" 29 – Feb. 7	Kathmandu (geological interpretation of aerial photographs)	
Feb. 8	Kathmandu – Bangkok	
" 8	Bangkok – Osaka	

* *khola* = stream
** *nadi* = river
*** *dahr* = spine

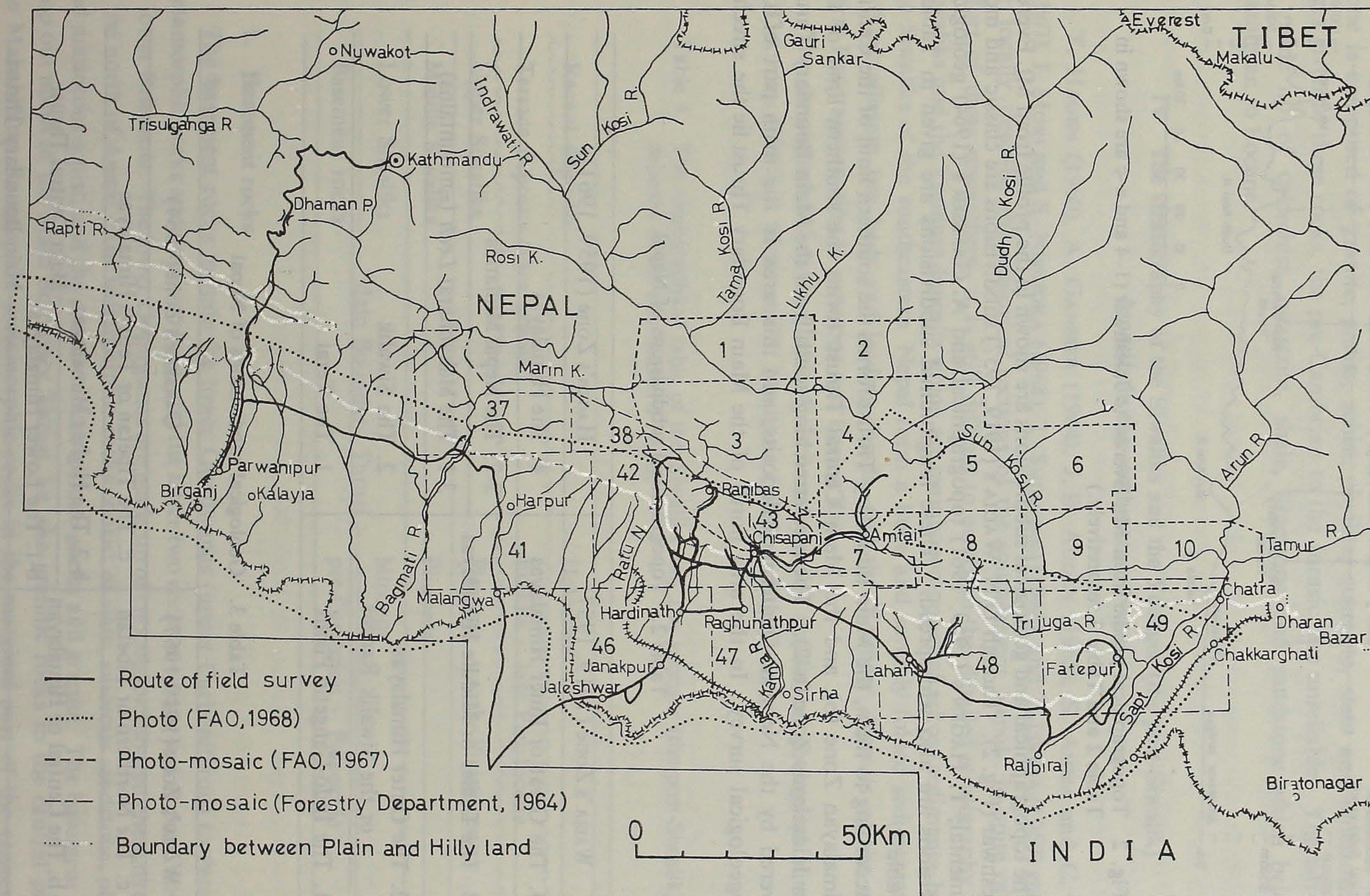

Fig. 1 Map showing the route of field survey and the distribution of aerial photographs

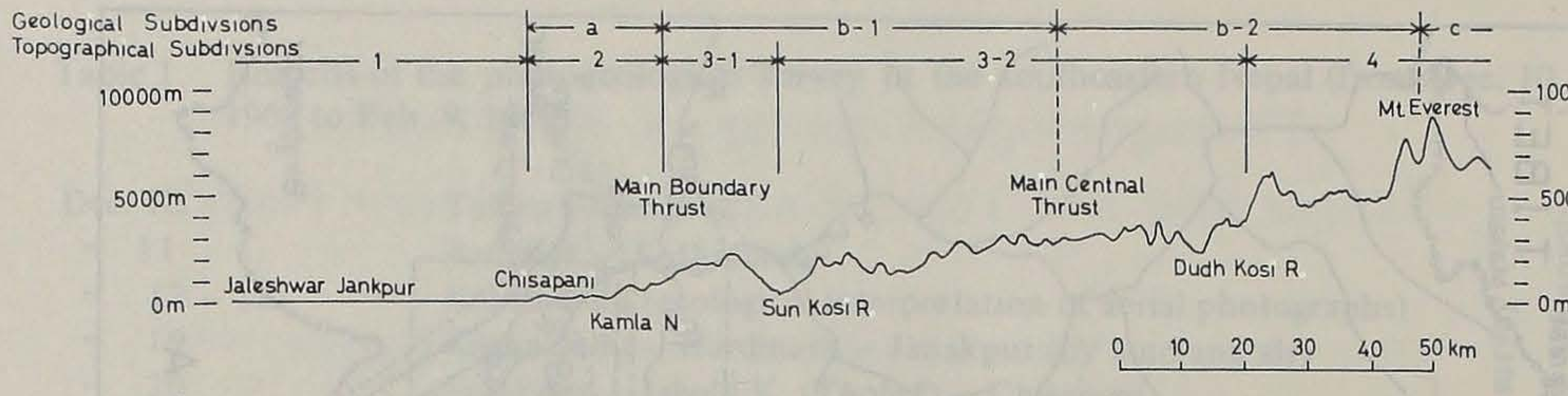

Fig. 2 Topographical profile from Mt. Everest to Jaleshwar (1–4 and a–c are shown in Table 2 and Table 3 respectively.)

The topographical and geological subdivisions are shown in the profile from Mt. Everest to Jaleshwar (Fig. 2). Though D.N. WADIA's (1919, 1957) subdivisions are classic and most fundamental, T. HAGEN's (1959, 1961) topographical and A. GANSSER's (1964) geological subdivisions are also widespread. These longitudinal subdivisions are given in Table 2 and Table 3.

According to them, the Main Boundary Thrust forms the southern limit of the Central or Himalayan Zone (b), and the Main Central Thrust forms the southern limit of the Higher Himalayas Zone (b–2). The area stretching south from the Main Boundary Thrust is covered by the Neogene-Quaternary deposits, and this area is the main part of the photogeological survey. In the area north of the Main Boundary Thrust lie the streches

Table 2. Topographical subdivisions of Nepal

WADIA's Zone (1919, 1957)	HAGEN's Zone (1959, 1961)
4. The Great or Inner Himalayas	4. The Himalayas
3. The Lesser or Middle Himalayas	3-2. The Nepal Midlands
	3-1. The Mahabharat *Lech* (=mountains)
2. The Outer Himalayas or the Siwalik Ranges	2. The Siwalik
1. The Indo-Gangetic Plains	1. The Terai

Table 3. Geological subdivisions of Nepal

WADIA's Zone (1919,1957)	GANSSER's Zone (1964)	
c. The Northern or Tibetan	c. The Tibetan or Tethys Himalayas	
b. The Central or Himalayan	b-2. The Higher Mimalayas	
		Main Central Thrust
	b-1. The Lower Himalayas	
		Main Boundary Thrust
a. The Outer or Sub-Himalayan	a. The Sub-Himalayas	

of the Central or Himalayan Zone (b) and the Northern or Tibetan Zone (c). The former zone is composed of granite, gneiss, schist, phyllite, quartzite, slate and limestone. The ages given to these rocks, the pre-Cambrian to the Jurasic, are unreliable. The latter zone is made up of calcschist, quartzite, shale, limestone and sandstone which belong to Cambrian to Eocene.

IV The stratigraphy of the Siwaliks and the Younger (the post-Siwalik) deposits in the southeastern Nepal

T. HAGEN (1960), A. GANSSER (1964), J. B. AUDEN (1965), S. AMMA and C. AKIBA (1967), I. MORI and S. NISHIOKA (1968), T. SHIBASAKI (1968), and T. ISHIDA (1969) generally or locally describe the geological sections of the southeastern Nepal. In spite of much effort of these researchers, it is still difficult to establish the detailed stratigraphy of the Siwaliks and the Younger deposits which are mainly composed of arkose sediments, because the Siwaliks of the southeastern Nepal form a huge and severely folded sedimentary pile without efficient key beds and leading fossils, and the Younger deposits of the eastern Terai Plain are wanting in outcrops and boring data.

The stratigraphical table (Table 4) is based on the results of geological survey of J. B. AUDEN (1965), I. MORI and S. NISHIOKA (1968) and the writers.

Table 4. The stratigraphical table of the Siwaliks and the younger (the post-Siwalik) deposits in the southeastern Nepal

Recent deposits	Holocene
Terrace deposits (*Dun* gravels)	middle – late Pleistocene
Upper Siwaliks	Pliocene – early Pleistocene
Middle Siwaliks	Pliocene
Lower Siwaliks	Miocene
Main Boundary Thrust	
Basement rocks	pre-Cambrian – Paleozoic

1. Basement rocks

The basement rocks include the lower Gondwanas (upper Carboniferous to Permian), metamorphic rocks and granitic rocks, and the latter two rocks are regarded as pre-Cambrian to lower Paleozoic. The lower Gondwanas are made up of chocolate-coloured chert-like rock at the north of Amtai. The metamorphic rocks consist of slate, siliceous sandstone, phyllite and micaceous schist, and the granitic rocks include gneiss and granite. The basement rocks crop out north of the Main Boundary Thrust, i.e. the granitic rocks in the central part of the Mahabharat Ranges, the metamorphic rocks in the marginal part of the ranges, and the lower Gondwanas, frequently wedged between the metamorphic rocks and the lower Siwaliks, along the Main Boundary Thrust.

2. Siwaliks

The Siwaliks are named after the Siwalik Hills near Hardwar, 160 km north-northeast of Delhi, where the first vertebrate fossils were found. The huge sedimentary pile of the Siwaliks is composed of freshwater Molasse-like sediments, the thickness of which is over 4000–5000 m, and ranges from the middle Miocene to the early Pleistocene (D.N. WADIA, 1919, 1957; A. GANSSER, 1964). The Potwar basin in the northern part of Punjab, Pakistan, is the type area of the Siwaliks. The Siwaliks here conformably overlie the Murrees (early–middle Miocene, over 2000 m in thickness) and are divided into the Lower Siwaliks (middle–late Miocene), the Middle Siwaliks (late Miocene–middle Pliocene) and the Upper Siwaliks (late Pliocene–early Pleistocene) (D.N. WADIA, 1919, 1957; A. GANSSER, 1964; W.D. GILL, 1952). The Murrees and the Siwaliks have conveniently grouped in the "Nimadric* system", but the Murrees have not been found in Nepal.

The Siwaliks of the southeastern Nepal are also divided into the Lower, Middle and Upper parts, but it is uncertain whether these three parts correspond to the Lower, Middle and Upper Siwaliks in the type ares, because of the lack of the fossils. The Siwaliks form the Siwlik Ranges, i.e. the Outer Himalayas, in the southern side of the Main Boundary Thrust.

2–1 Lower Siwaliks (Plate III, 4•5)

The Lower Siwaliks are mainly made up of freshwater arkose sandstone, mudstone and shale and scarcely intercalate very thin coal layers. The cohesion of these deposits is considerably firm. The base of the Lower Siwaliks is not exposed in the surveyed area, so that the whole thickness cannot be determined. But the thickness of the exposed Lower Siwaliks may be around 2000 m. The Lower Siwaliks of the southeastern Nepal form the Inner Siwalik Ranges situated between the Main Boundary Thrust and the Rapti R.–Marin K.–Kamla N.–Trijuga R. line, except for the synclinal zone ranging from the upper course of the Marin K. to that of the Chandaha K.

2–2 Middle Siwaliks (Plate III, 3)

The Middle Siwaliks are mainly composed of arkose sands, silt and mud, and sands are the most predominant costituent. These sediments are generally semiconsolidated, so that the samples of sandy sediments break easily. The hard calcareous strata, however, are intercalated in a few places. The fossils are very scarce, and only a few fossil-woods and lignites are found. The thickness of the Middle Siwaliks measures about 1200 m. The Middle Siwaliks are distributed in the aforesaid synclinal zone and the Outer Siwalik Ranges, i.e. the Churia Ranges, between the Terai Plain and the Rapti R.–Trijuga R. line.

2–3 Upper Siwaliks (Plate III, 1)

The Upper Siwaliks mainly consist of sands and gravels and intercalate silt and mud in places. The grain size of gravels ranges from pebble to boulder, and cobble gravels are common. On the rock type of gravels, metamorphic and granitic rocks of basement fill the role of the main constituent. The top of the Upper Siwaliks is not exposed in the area, but the exposed Upper Siwaliks may be about 700 m in thickness. The distribution is limited to the southern and northern marginal parts of the Outer Siwalik Ranges (the Churia Ranges).

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* "Nimadric" is a compound of "*Himadric*", meaning snowy range and an alternative for Himalaya, with the Sanskrit prefix "*Ni*", meaning under or downward (W. D. GILL, 1952).

3. Younger deposits (post-Siwalik deposits)

The Younger deposits are distributed in the Terai Plain and along the river courses in the Siwalik Ranges, as the Terrace alluvial deposits and the Recent alluvial deposits.

3–1 Terrace deposits (*Dun* gravels)

The Terrace deposits are well developed in the Terai Plain, in the area between the Inner Siwalik Ranges and the Outer Siwalik Ranges (the Churia Ranges) and along the river courses in the southern marginal part of the Outer Siwalik Ranges. The Terrace deposits between the Inner Siwalik Ranges and the Outer Siwalik Ranges are called "*Dun* gravels", because "*Dun*" means the wide open valley such as the Rapti R., the Marin K., the Kamla N. and the Trijuga R.. As far as the writers observed the outcrops in the Siwalik and its surrounding areas, the Terrace deposits, the thickness of which is several to ten meters, are generally composed of sands and gravels and intercalate thin silt layers in places. The depositional surface of the deposits form the Higher Terrace (relative height from river floor, about 50 m), the Middle Terrace (do., about 20 m) and the Lower Terrace (do., 6–7 m). The top part of the Higher and Middle Terrace deposits consists of red-coloured lateritic soil.

In the Terai Plain, the contents of the Terrace deposits can be revealed only by a few deep boring data. According to the deepest boring in the surveyed area, at Sukhachina near Parwanipur (Fig. 3), the subsurface Terrace deposits are made up of uncemented or only weakly cemented clay, sands and gravels and have a thickness of approximately 270 m, and the Upper Siwaliks composed of cemented sands and gravels occur at a depth of 271–322 m. The Terrace deposits of the Terai Plain are considered to be a wedge-shaped sedimentary pile which is pinched northwards to the foothills and thickens southwards to the plain (T. Shibasaki and N. Miyamoto, 1971).

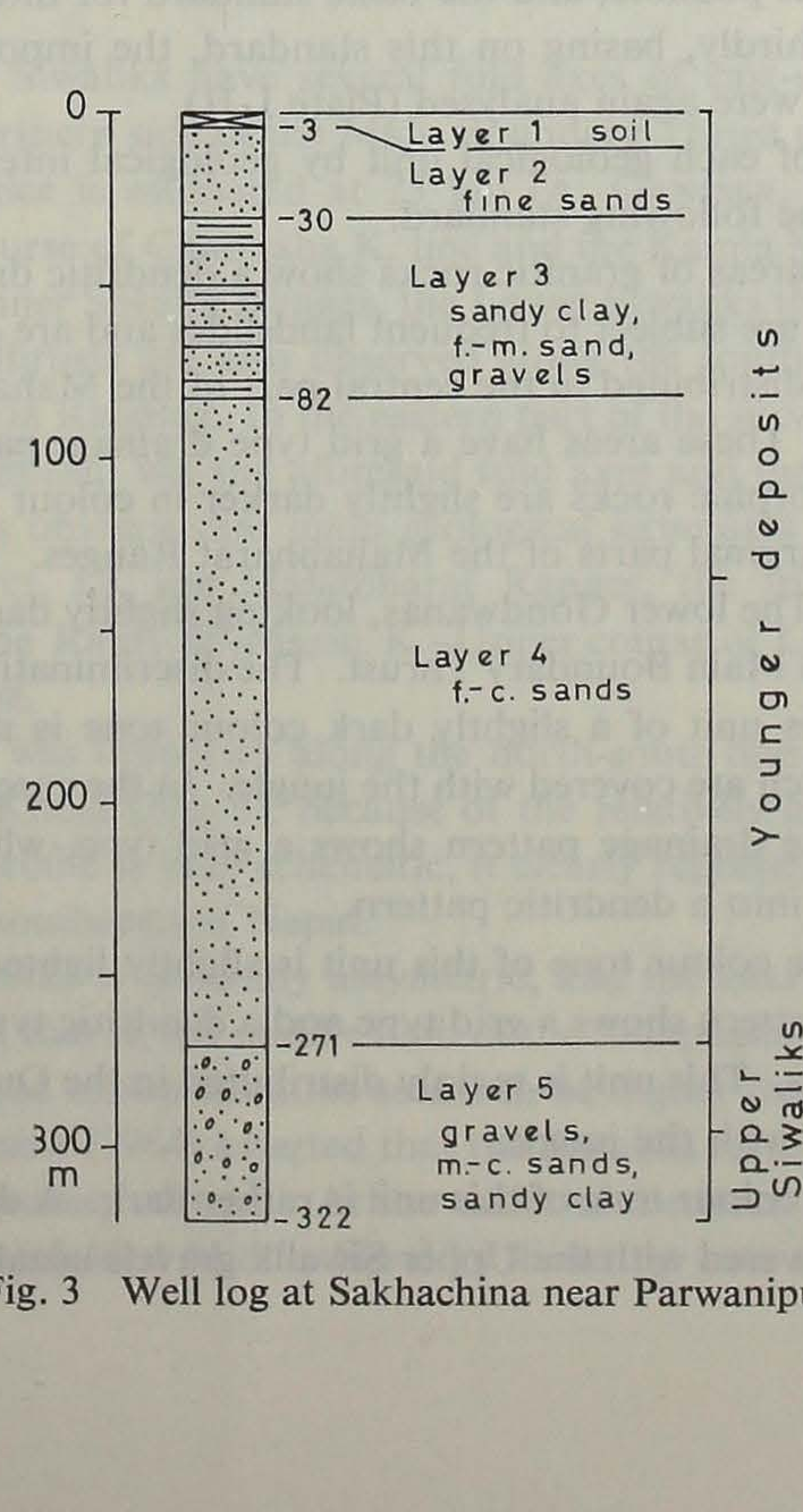

Fig. 3 Well log at Sakhachina near Parwanipur

The hydrogeological survey is still being cotinued by T. SHIBASAKI and N. MIYAMOTO, under the Sun Kosi Terai Project of FAO, and they are beginning to clarify the subsurface geological structures of the southeastern Terai Plain.

4. The Recent deposits (the Holocene deposits)

The Recent deposits mainly form the flood plains along the present river courses. The deposits are well developed in the lower and middle courses of a few large rivers such as the Bagmati R. and the Sapt Kosi R.

V Geological interpretation of the aerial photographs

Aerial photographs were interpreted for the purpose of understanding the geological structure of the Siwaliks and the Younger deposits in the southeastern Nepal. The following three kinds of aerial photographs were used for the purpose: a) Aerial photographs of Forestry Department, Nepal, taken in 1964 on a scale of 1/12.000. b) Aerial photographs of UNDP/FAO taken in 1967 on a scale of 1/20,000. c) Aerial photographs of UNDP/FAO taken in 1968 on a scale of 1/35,000. In addition to the above, these photo-mosaic sheets (scale: one inch to one mile, i.e. 1/63.360) were also used. The distribution of the aerial photographs is shown in Fig. 1.

It is impossible to interpret all of these enormous aerial photographs in detail and in the same level. Therefore, first the localities showing conspicuous geological structures were chosen by interpretation on the photo-mosaic sheets and existing geological data (J.B. AUDEN, 1965; I. MORI and S. NISHIOKA, 1968). Secondly the field survey of these localities was performed as much as possible, and the basic standard for interpretation of aerial photographs was sought. Thirdly, basing on this standard, the important aerial photographs and photo-mosaic sheets were again analysed (Plate I・II).

The discrimination of each geological unit by geological interpretation of aerial photographs was based on the following standard.

Granitic rocks: The areas of granitic rocks show a dendritic drainage pattern with light colour tone. These areas are subject to frequent landslides and are often cultivated as paddy field. Granitic rocks are distributed in the central part of the Mahabharat Ranges.

Metamorphic rocks: These areas have a grid type drainage pattern. owing to the bedding schistosity. Metamorphic rocks are slightly darker in colour tone than granitic rocks and distributed in the marginal parts of the Mahabharat Ranges.

Lower Condwanas: The lower Gondwanas, looking slightly dark, are locally distributed in the northern side of the Main Boundary Thrust. The discrimination of this nuit is difficult.

Lower Siwaliks: This unit of a slightly dark colour tone is mainly distributed in the Inner Siwalik Ranges which are covered with the jungle. In the case of steeply dipping strata with Cuesta structure, the drainage pattern shows a grid type, while in the case of gently dipping strata it changes into a dendritic pattern.

Middle Siwaliks: The colour tone of this unit is slightly lighter than that of the Lower Siwaliks. The drainage pattern shows a grid type and a dendritic type in the same way as the case of the Lower Siwaliks. This unit is mainly distributed in the Outer Siwalik Ranges. The surface is mostly covered with the jungle.

Upper Siwaliks: The colour tone of this unit is rather dark. A dendritic drainage pattern is developed. The hills covered with the Upper Siwalik gravels usually have roundish ground surface without vegetation. This unit is distributed in the northern and southern marginal parts of the Outer Siwalik Ranges.

Terrace gravels (*Dun* gravels): In savage areas the Terrace plains are usually covered with dense vegetation, so that the colour tone is dark. In the Terai Plain most of the Terrace plains are covered with paddy field.

The Recent deposits (the Holocene deposits): The Recent deposits are developed along river courses and form flood plains.

VI Geological map

After the photogeological procedure mentioned in chapter V and geomorphological analysis on the one inch to one mile maps (scale: 1/63.360) by Survey of India, the geological map (Fig. 4) was drawn up, using the base map of a scale 1/457,200.

In this geological map, the results of the above interpretation and analysis are expressed under the following divisions: 1) Basement rocks composed of granitic rocks, metamorphic rocks and the lower Gondwanas, 2) The Lower Siwaliks, 3) The Middle and Upper Siwaliks, 4) The Higher Terrace deposits, 5) The Middle Terrace deposits, 6) The Lower Terrace deposits, 7) The undivided Terrace deposits, 8) The Recent deposits (the Holocene deposits).

It was very difficult that, over all the surveyed area, the distinctions are made between the Middle Siwaliks and the Upper Siwaliks and among the Higher, Middle and Lower Terrace deposits. These open problems have to be solved by future investigation.

VII Geological structures

The severely folded Siwaliks have several fold axes of east-southeast direction. The basement rocks in the northern side of the Main Boundary Thrust cover the Lower Siwaliks, and their covering distance is estimated at 25 km (A. GANSSER, 1964). Along the Rapti R.–Marin K.–Uupper course of Chandaha K. line and the Kamla N.–Trijuga R. line, i.e. the southern margin of the Inner Siwalik Ranges, the Lower Siwaliks thrust up over the Middle-Upper Siwaliks. Some thrusts are also observed along the southern margin of the Outer Siwalik Ranges (the Churia Ranges). In the eastern part of the surveyed area faults of north-south direction are recognized, but the aforesaid fold axes and thrusts generally show east-southeast direction. It is obvious that main geological structures well correspond to main geomorphological features, i.e. the Mahabharat Ranges, the Inner Siwalik Ranges, the Outer Siwalik Ranges, the Rapti R.–Marin K.–Upper course of Chandaha K. line and the Kamla N.–Trijuga R. line.

A geological profile was drawn up along the north-south line of Janakpur–Hardinath–Ranibas–the Chandaha Khola (Fig. 5), because of the relatively abundant geological data. Though this geological profile is only schematic, it clearly represents the outline of the geological structures in the southeastern Nepal.

The fold of the Siwaliks is generally assymetric, and the axes of anticline and syncline exist near a fracture zone, that is, the middle limb of the fold passes into a fracture zone. The degree of the folding of the Lower Siwaliks seems to be higher than that of the Middle and Upper Siwaliks. A. GANSSER (1964) asserted that the Siwaliks form structures with a normal and not a reversed sedimentary column. At the outlet of the Ratu N. to the Terai Plain, the writers found that the overfolded Middle Siwaliks thrust up over the Upper Siwaliks. But,

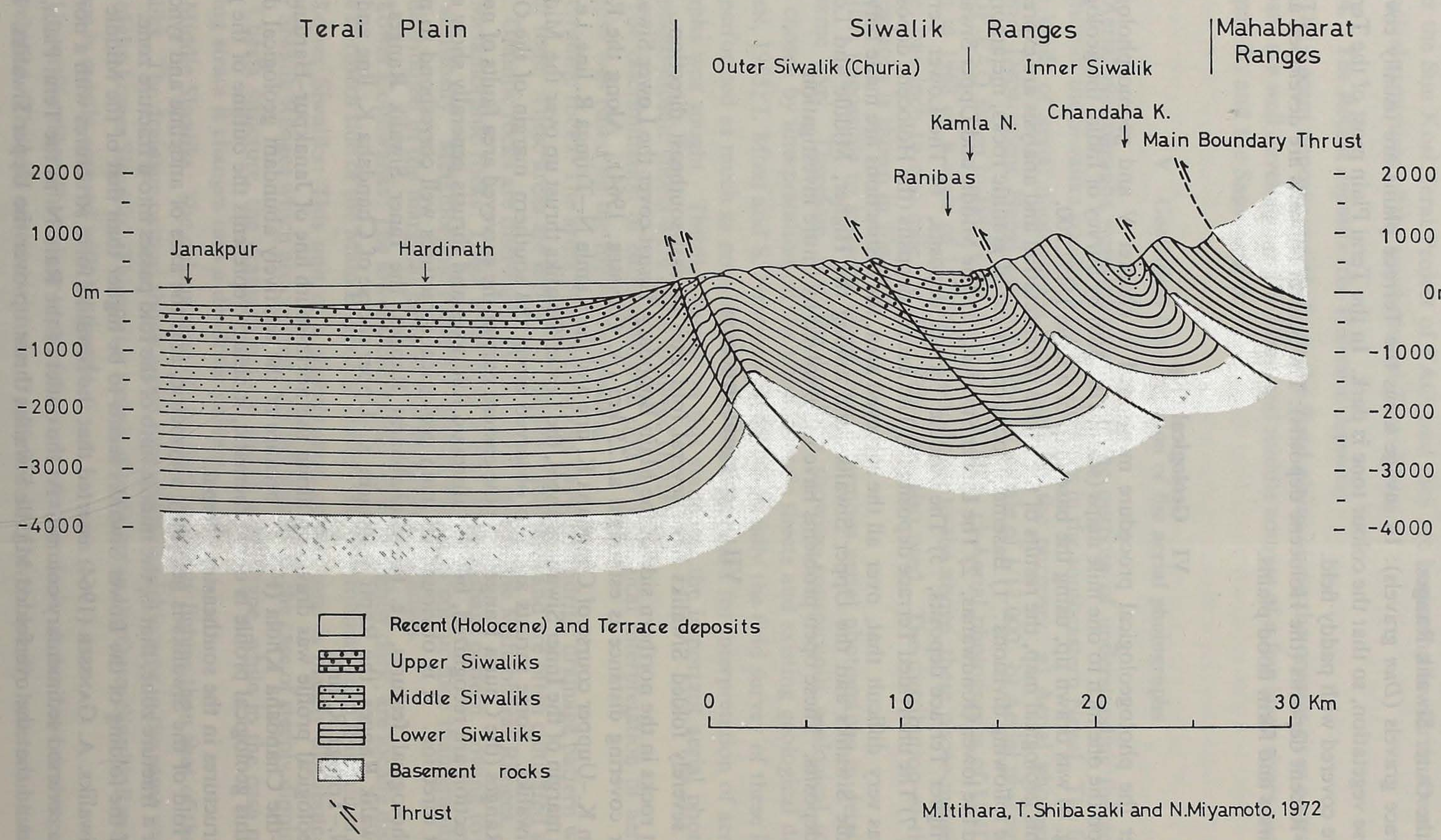

Fig. 5 Schematic geological profile (Janakpur–Hardinath–Ranibas–Chandaha K.)

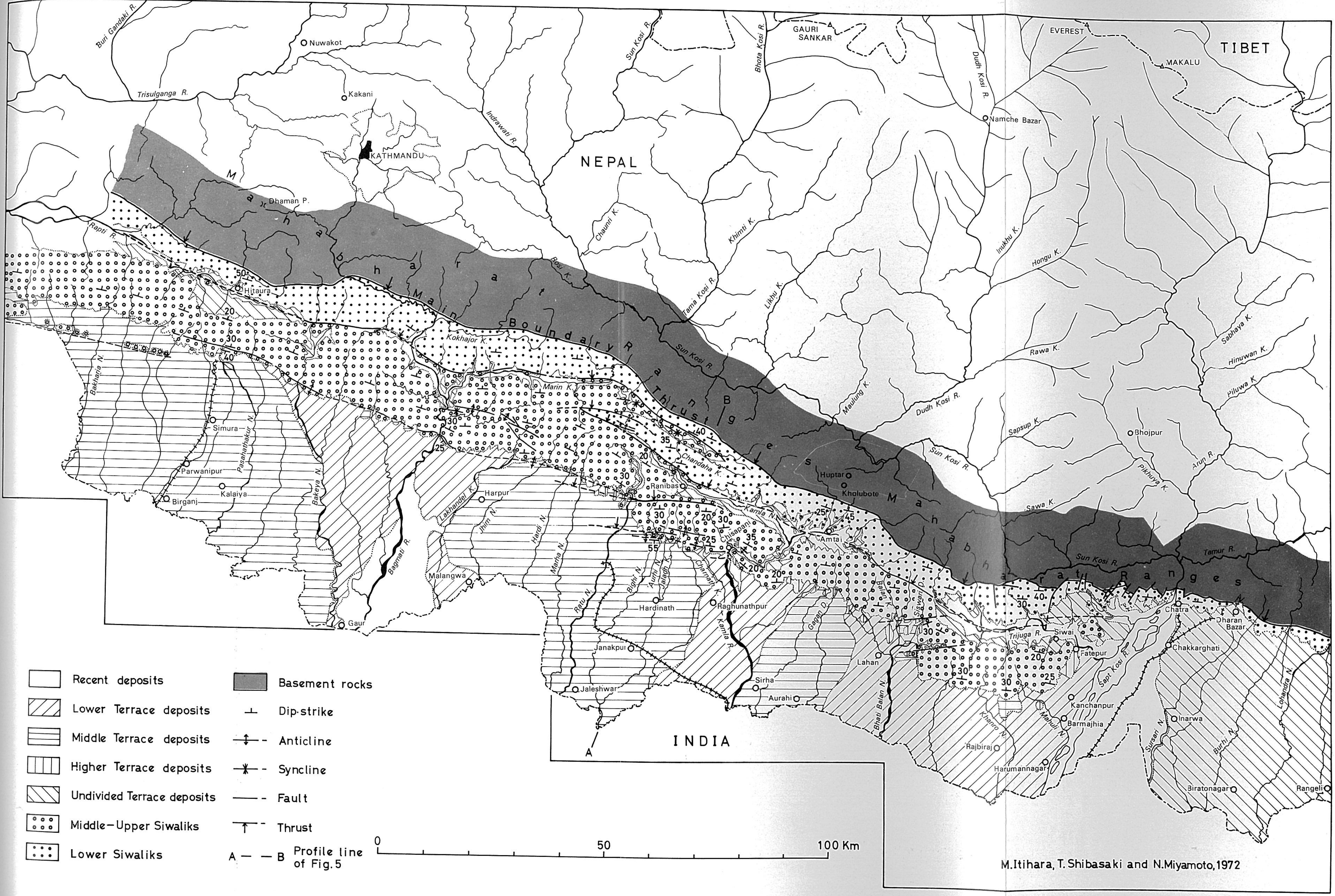

Fig. 4 Geological map of the Siwalik Ranges and the Terai Plain in the southeastern Nepal

except for fracture or thrust zones, the Siwaliks of the southeastern Nepal generally dip to the north, on an average dipping degree of 30°, with a normal sedimentary column (Plate II•IV).

Furthermore, it is noticeable that at the aforesaid outcrop of the outlet of the Ratu N., the Middle Terrace deposits, overlain unconformably the Upper Siwaliks, are not cut by the thrust. The results of the writer's survey support W. D. GILL's (1952) Siwalik phase of Himalayan orogenesis, i.e. the Siwalik orogeny, the period of which is clearly defined as post-Siwaliks and pre-Younger deposits, and A. GANSSER's (1964) opinion "folding and faulting in the Siwaliks is of early to middle Pleistocene age, and must have preceded the overthrusting of the Lower Himalayas along the Main Boundary Fault.". Some researchers describe the thrust Siwaliks over the Terrace deposits and the progressive steepening of the Terrace plains to the north and suggest the latest crustal movements (T. HAGEN, 1960; A. GANSSER, 1964). Nevertheless, the writers attach much importance to that the structual difference between the Siwaliks, especially the Upper Siwaliks, and the Terrace deposits is very remarkable. This structual difference between the early Pleistocene and the middle–late Pleistocene deposits is smilar to that of Japan which is characterized by "the culmination of the Rokko movements" (N. IKEBE and K. HUZITA, 1966; M. ITIHARA, 1966).

The similarity between neotectonic natures of Nepal and Japan seems to show a feature of global neotectonic movements.

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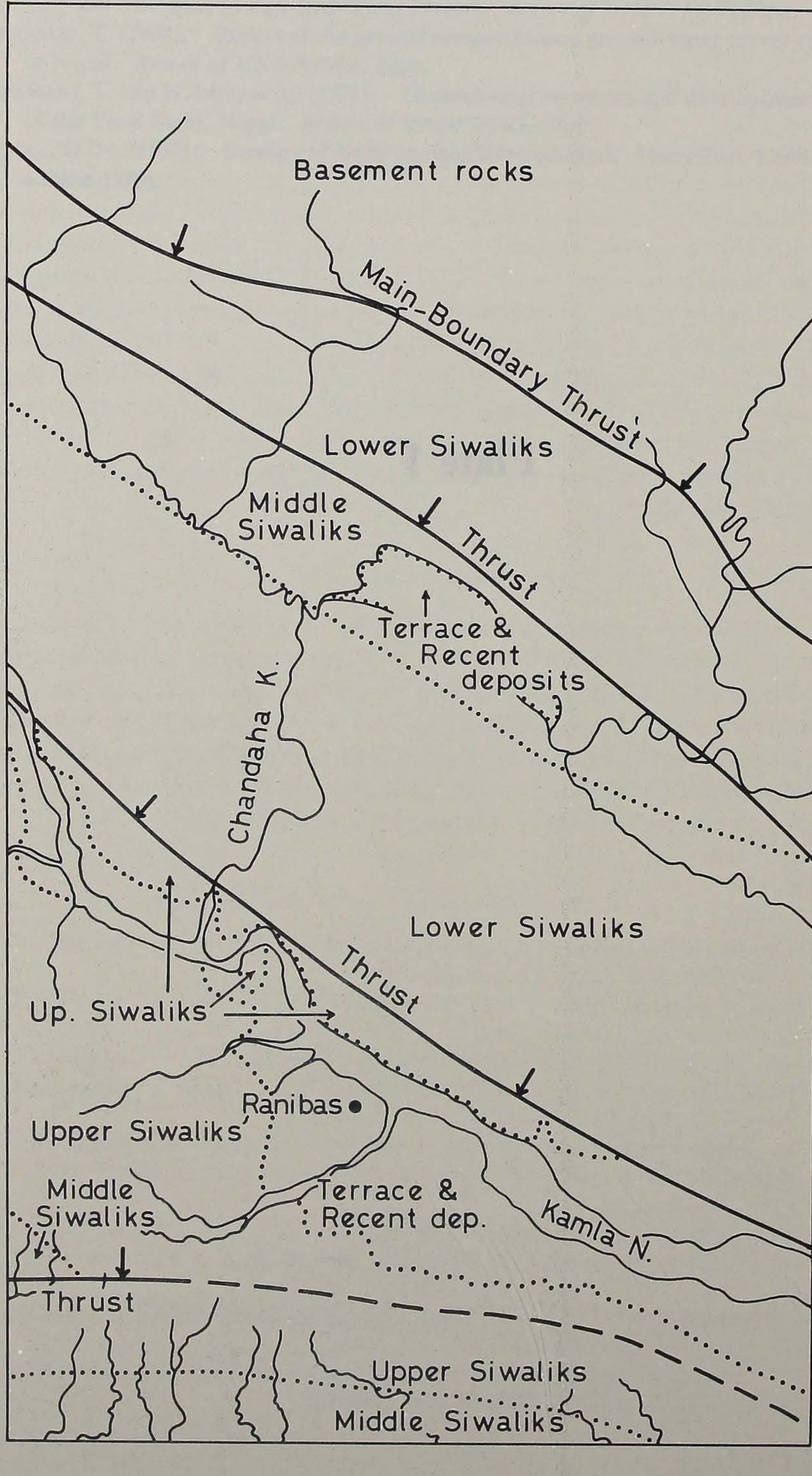
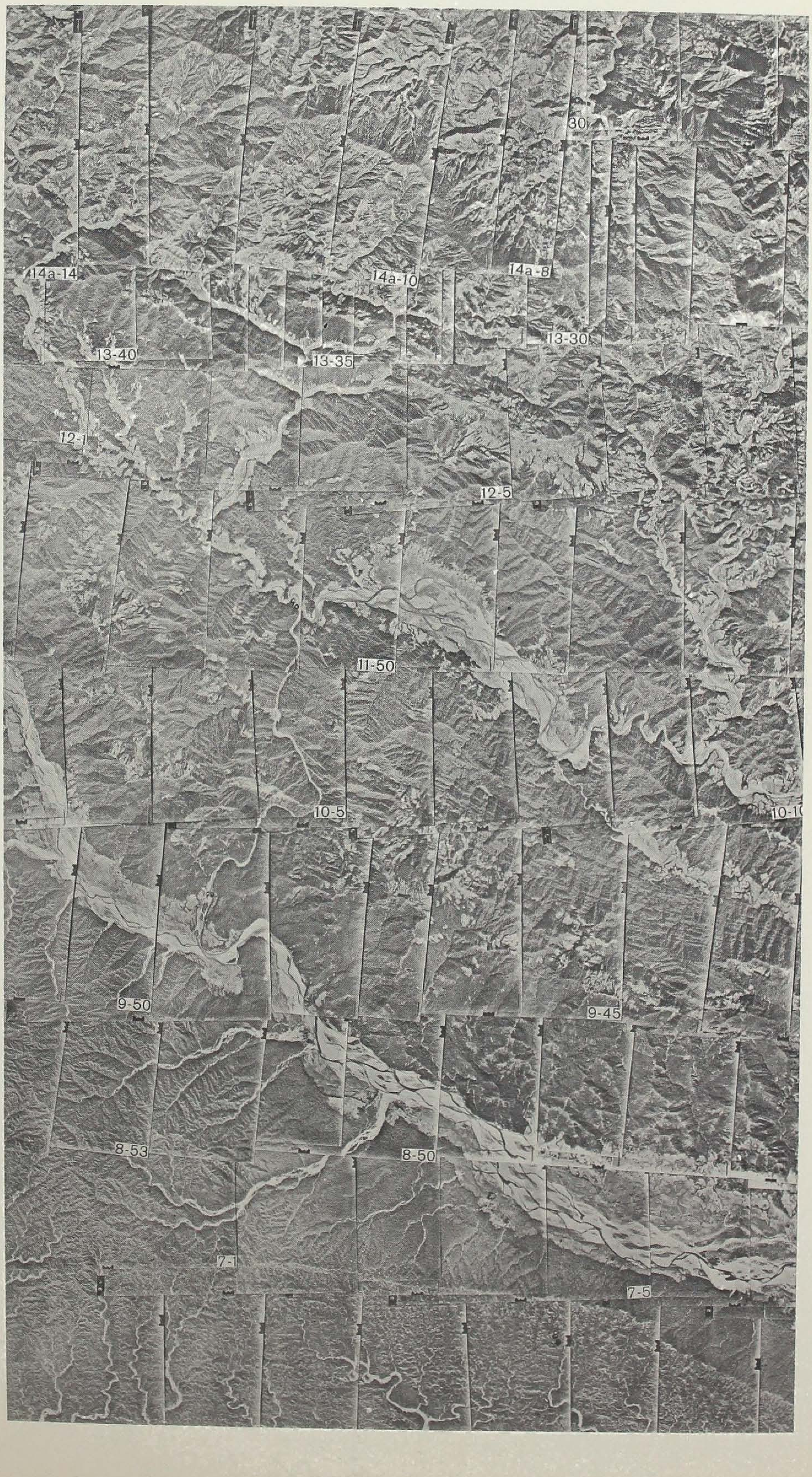
Plate I

Explanation of Plate I

Aerial photo-mosaic of the Chandaha Khola–Ranibas area. From the central part of photo-mosaic sheet 3 (Fig. 1). Scale: about one inch (2.54 cm) to two miles (3218 m).

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7-1
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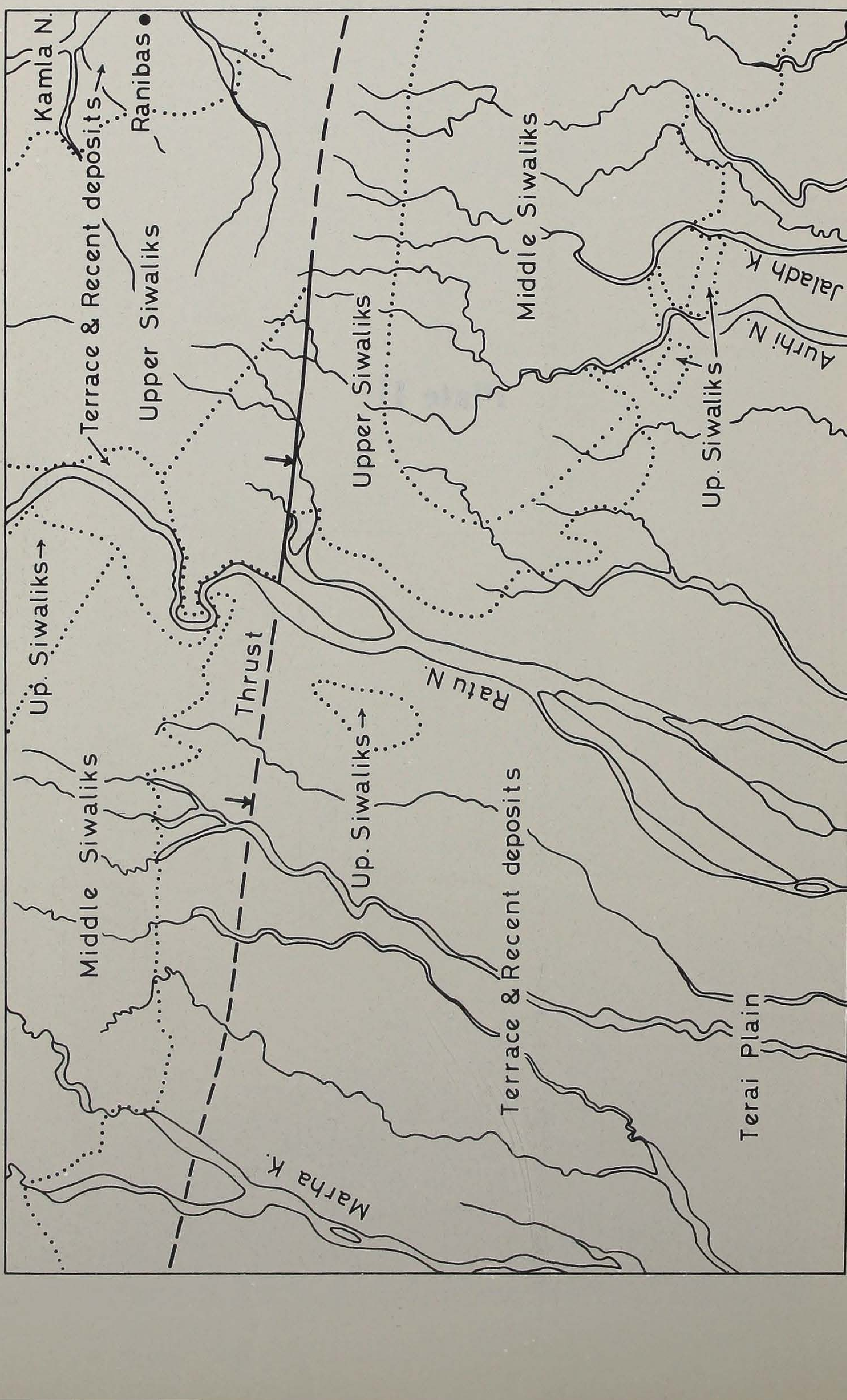
Plate II

Explanation of Plate II

Aerial photo-mosaic of the area southwest of Ranibas. From the central part of photo-mosaic 42 (Fig. 1). Scale: about one inch (2.54 cm) to two miles (3218 m).



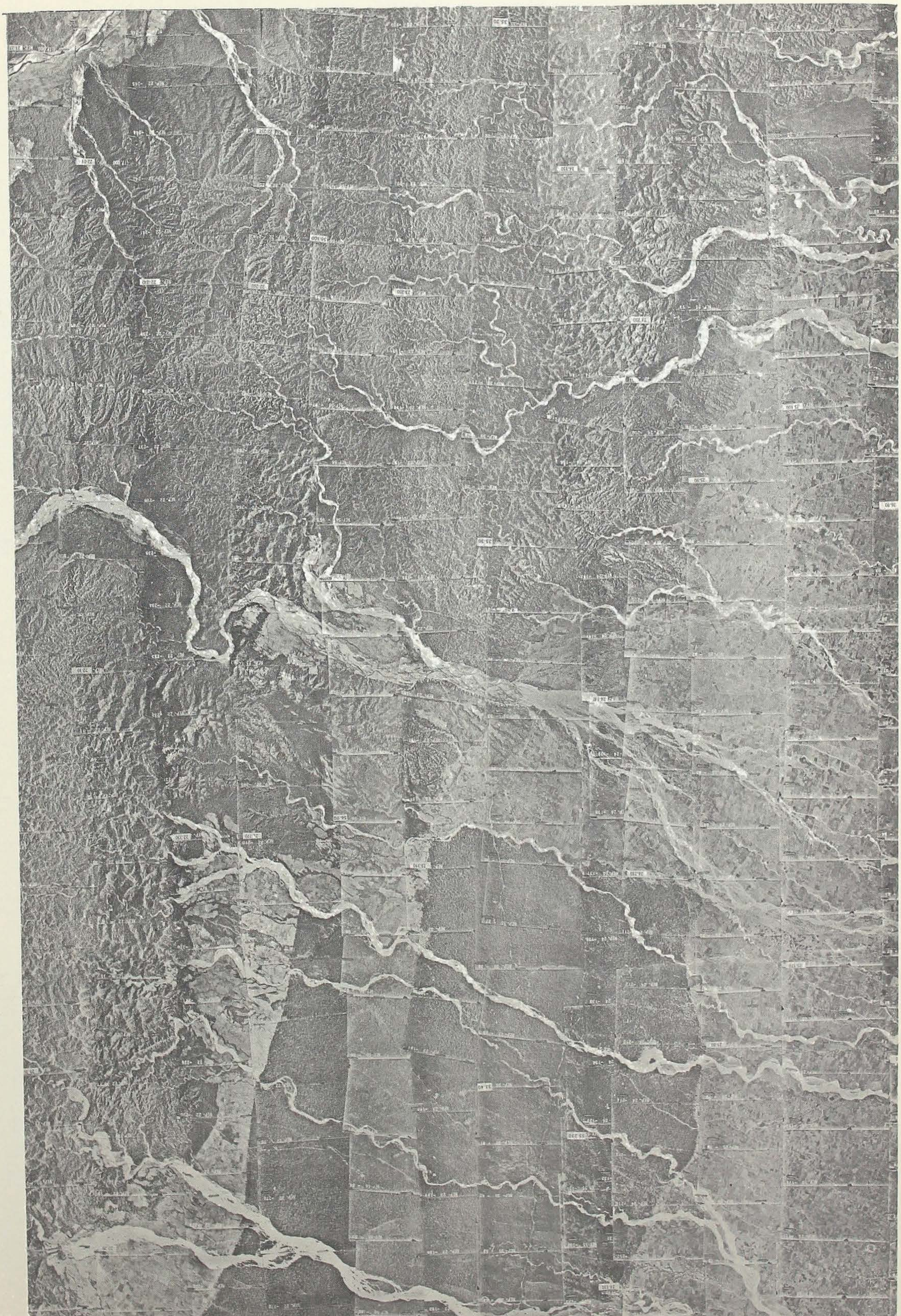


Plate III

Explanation of Plate III

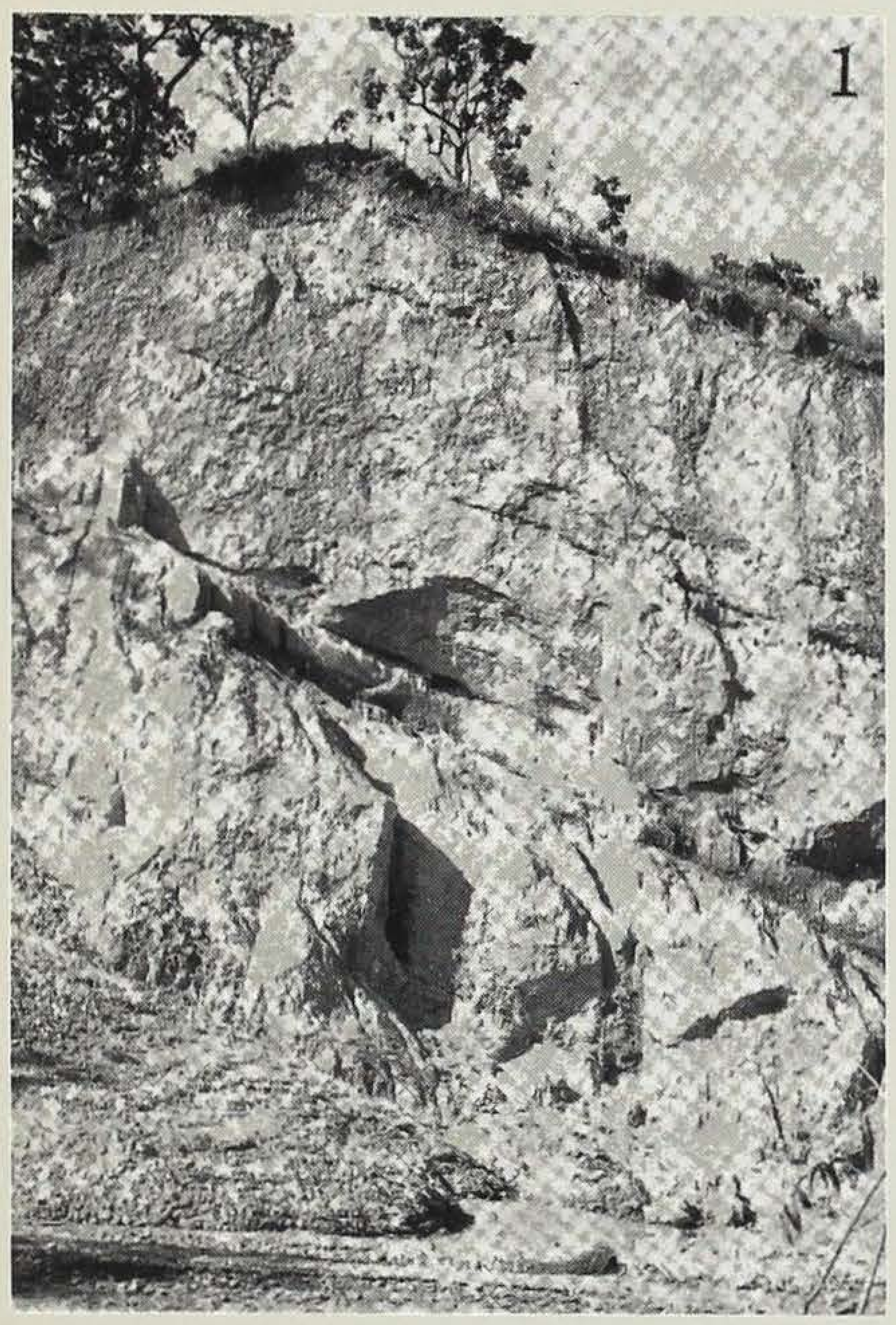
1 An outcrop of Upper Siwaliks in the upper course of the Jaladh Khola. Upper Siwaliks are mainly composed of sands and gravels.

2 A view of the Outer Siwalik Ranges (the Churia Ranges) from the Terai Plain east of Lahan. The plain is covered by paddy field. A frontal big tree is *Shimal* tree.

3 Outcrops of Middle Siwaliks along the Charnath Khola. Middle Siwaliks consist of sands and silt. A thrust zone exists in the central part of the frontal outcrop.

4 An outcrop of Lower Siwaliks near by Amtai. Lower Siwaliks are not well cropped out and are covered by the jungle, the main tree of which is *Säl* tree.

5 Surface textures of Lower Siwaliks freshwater mudstone.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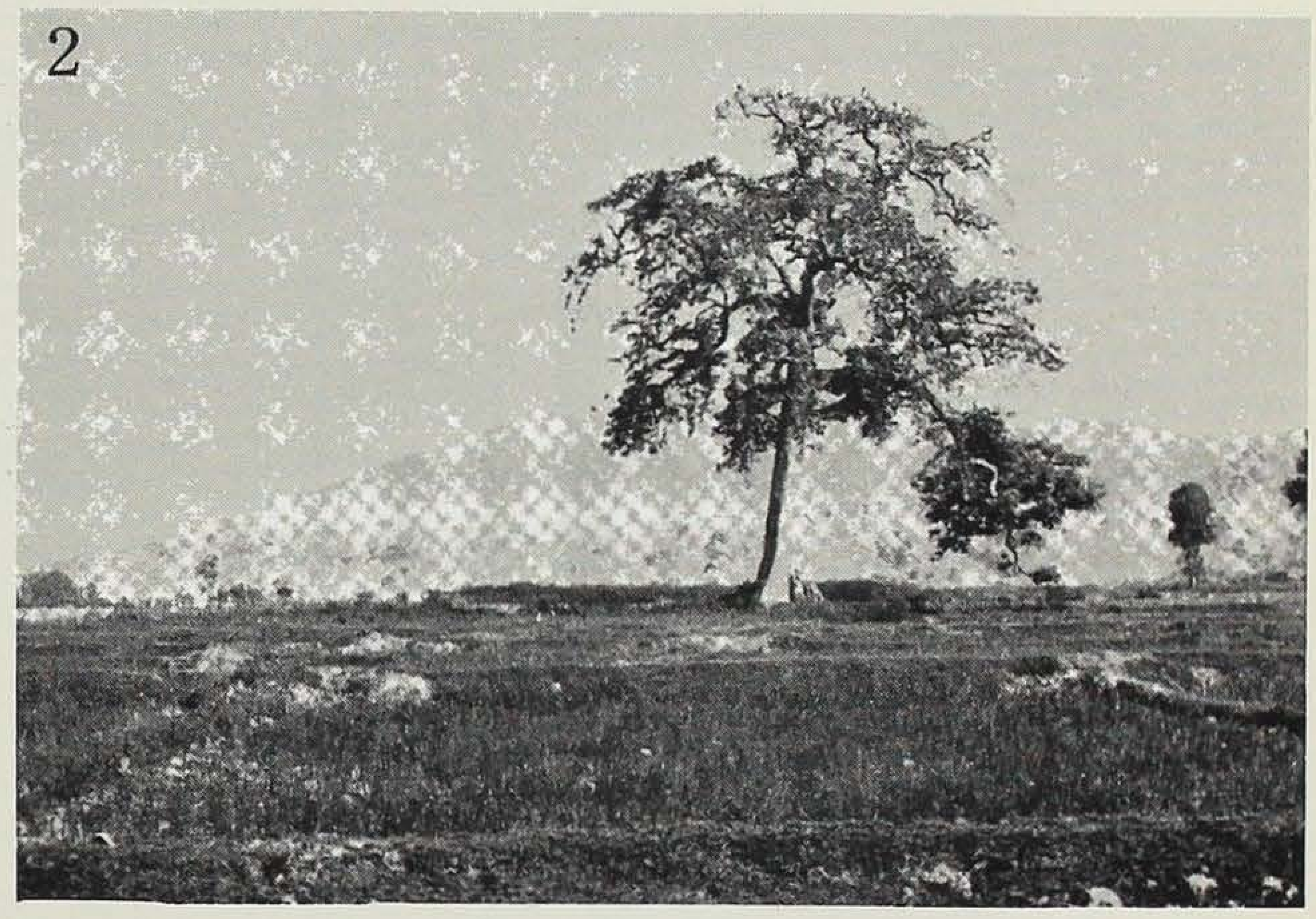
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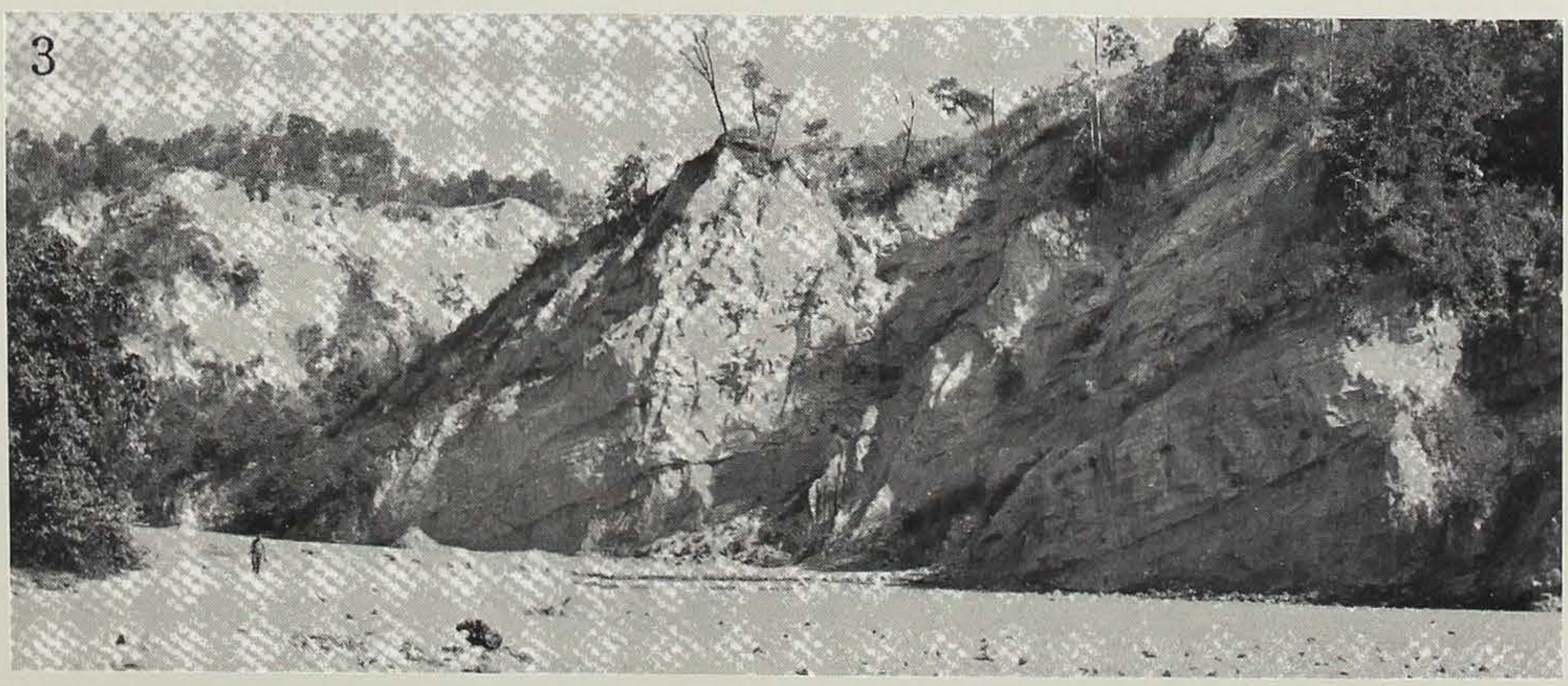
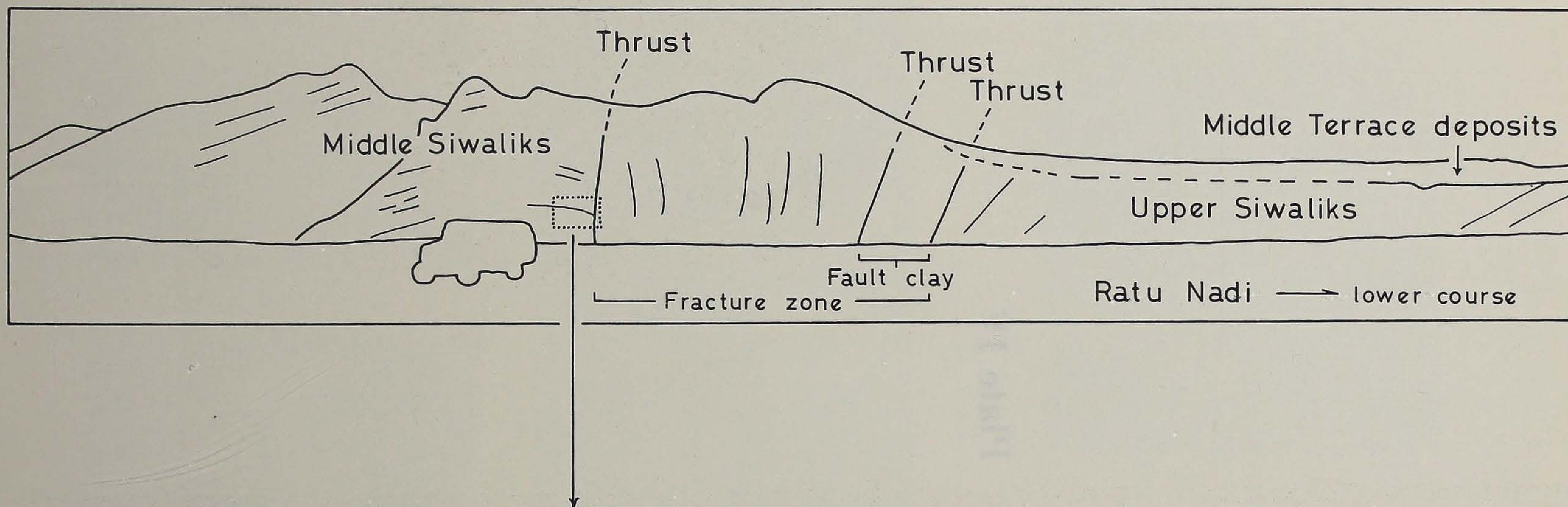
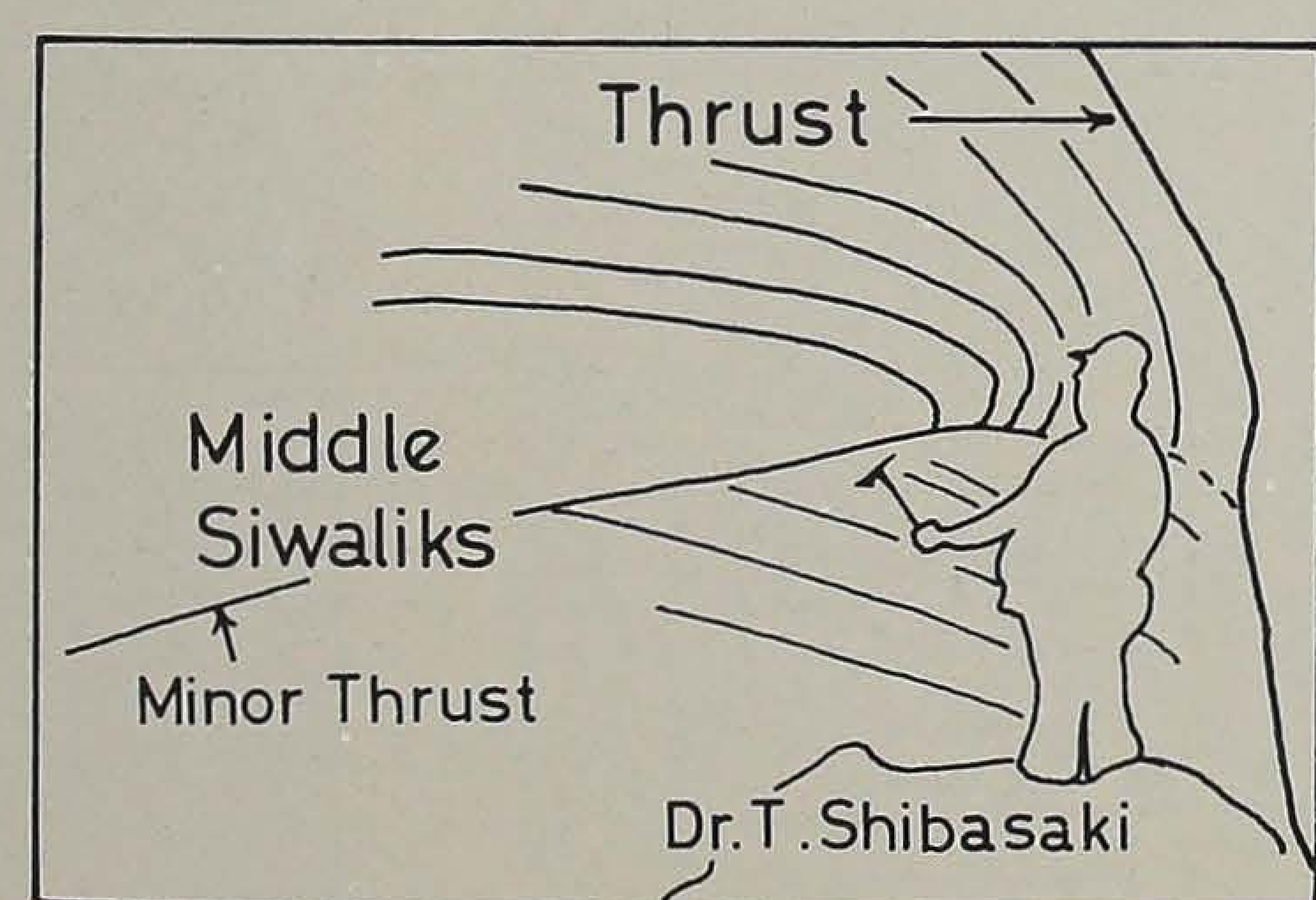

3


4


5

Plate IV





Explanation of Plate IV

1 Outcrops at the outlet of the Ratu Nadi to the Terai Plain.
2 Near the fracture zone, a minor thrust is found in Middle Siwaliks.