PART II

The Geological and Geomorphological Background to the Hazards

Background of the Area

The Himalayan Belt can be subdivided into the following four tectonic zones from north to south respectively (Fig. 2.1).

- Tibetan-Tethys Zone
- Higher Himalayas
- Lesser Himalayas, and
- the Sub Himalayas or Siwaliks.

The Tibetan-Tethys Zone is made up of sedimentary rocks and lies in the north of the high mountains. It is followed in the south by the Higher Himalayas. The Higher Himalayas are represented by high-grade metamorphic rocks with a few granite intrusions. The Lesser Himalayas lie to the south of the Higher Himalayas. They are bordered in the north by the Main Central Thrust (MCT) and in the south by the Main Boundary Thrust (MBT). The Lesser Himalayas are made up of medium to low-grade metamorphic rocks, some igneous rocks, and sedimentary rocks. The Lesser Himalayas can further be subdivided into the Midlands and the Mahabharat Range (Fig. 2.1). The Lesser Himalayas overlie the Siwalik Belt along the MBT situated to the south. The Siwaliks (also called the Churia Hills) are composed of fragile and soft mudstone, sandstone, and conglomerates.

The Bagmati watershed (Fig. 2.2) extends south of the Higher Himalayas to the Siwaliks and the *terai* plain. The river flows from the north of Kathmandu and reaches Gaur in the *terai*. It originates from the Sheopuri Hills which form the watershed boundary at the highest elevation of 2,732 m and the river flows towards the south and south-east (Fig. 2.2). It passes through the high-grade metamorphic rocks of the Kathmandu Complex and then through the low-grade metamorphic and sedimentary rocks of the Nuwakot Complex.

A few granite intrusions (Fig. 2.3) are observed in the central part of the Lesser Himalayas. The river finally crosses the fragile Siwalik rocks and reaches the *terai*.

The Bagmati River crosses five important thrust faults (Fig. 2.2). Two of them, the Mahabharat Thrust (MT) and the MBT, pass each other very closely (Fig. 2.2) between the village of Pyutar and the Kokhajor *Khola*. Similarly, the other two faults observed in the Siwaliks pass close to each other between Jamire and Karaonje. Their proximity has created a wide crushed zone full of instabilities of various kinds. Between Pyutar and the Kokhajor *Khola*, huge rockslides prevail on the steeper slopes and debris fans are situated on the lower reaches. The two faults in the Siwaliks have contributed to the formation of the wide Bagmati Valley between Jamire and Karaonje, and they have also created a large debris fan in the Chaura Khola (Fig. 2.2).

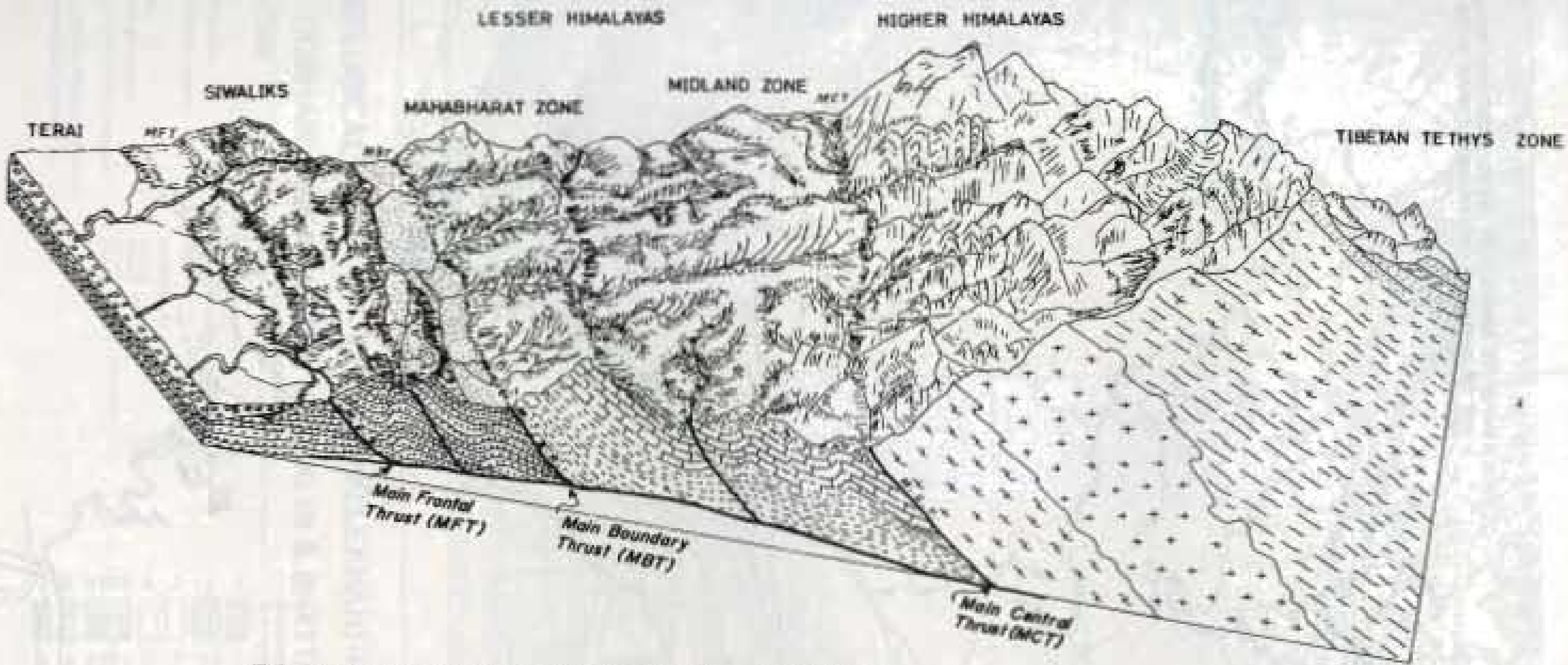
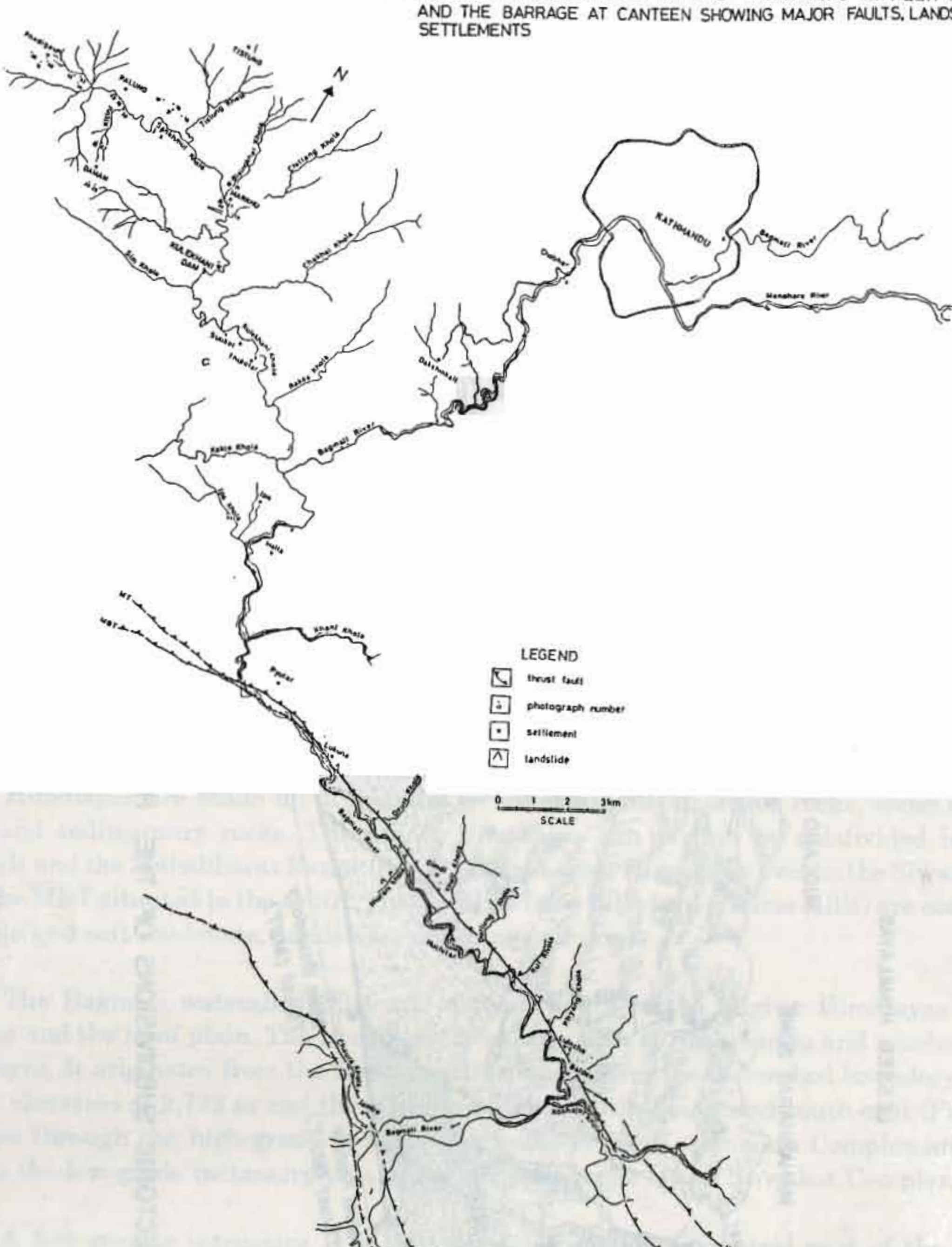


FIG.2.1: TECTONIC SUBDIVISIONS OF THE HIMALAYAS

FIG. 2.2: MAP OF THE BAGMATI RIVER AND ITS TRIBUTARIES BETWEEN KATHMANDU AND THE BARRAGE AT CANTEEN SHOWING MAJOR FAULTS, LANDSLIDES, AND SETTLEMENTS



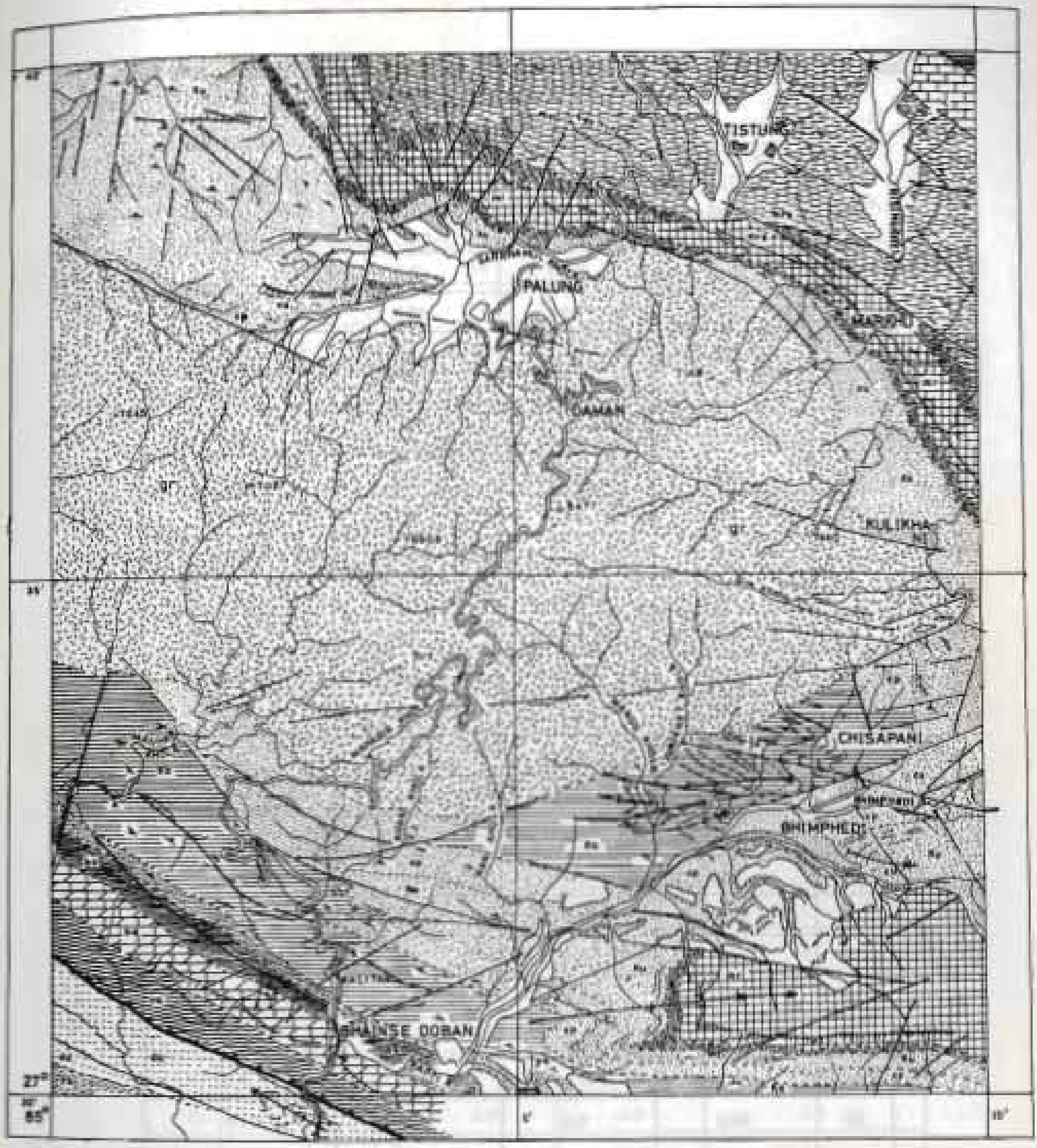


FIG.2.3: GEOLOGICAL MAP OF TISTUNG-KULEKHANI-BHAINSE DOBHAN AREA (AFTER STOCKLIN & BHATTARAI, 1978)

LEGEND

QUATERNARY

NUWAKOT GROUP (UPPER)

INTRUSIVE ROCKS

PHULCHOWKI GROUP

Chandragiri Limestone (Cambro-Ordovician)

BHIMPHEDI GROUP

Table 2.1: Daily Automatic Rainfall Records at Simlang and Tistung, July 1993
(After Department of Soil Conservation Records)

Date	Station at Simlang		Station at Tistung	
	Rainfall, mm	Maximum intensity, mm/h	Rainfall, mm	Maximum intensity, mm/h
1	16.0	7.3	19.0	8.0
2	18.2	9.8	12.0	6.0
3	0.5	0.5	0.0	0.0
4	0.4	0.4	1.0	1.0
5	0.0	0.0	0.5	0.5
6	4.3	4.3	0.5	0.5
7	4.2	2.0	5.5	5.5
8	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0
11	5.5	3.5	3.5	3.5
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	4.5	2.0	10.0	4.0
15	0.5	0.5	0.0	0.0
16	8.8	3.7	7.0	2.5
17	59.0	25.0	47.5	21.0
18	4.2	3.0	7.5	7.0
19	4.5	2.0	3.5	1.5
20	389.0	67.0	539.5	70.0
21	50.0	12.0	39.0	7.0
22	40.0	6.0	66.0	21.5
23	28.0	13.5	30.0	18.0
24	28.0	10.0	9.5	4.0
25	3.5	1.6	0.0	0.0
26	9.2	4.8	27.0	18.0
27	0.0	0.0	0.0	0.0
28	8.9	4.0	13.0	6.0
29	0.4	0.4	2.5	2.0
30	0.0	0.0	1.0	0.5
31	3.0	2.8	1.0	0.5

Table 2.2: Daily Automatic Rainfall Records at Simlang and Tistung, August 1993
(After Department of Soil Conservation Records)

Date	Station at Simlang		Station at Tistung	
	Rainfall, mm	Maximum intensity, mm/h	Rainfall, mm	Maximum intensity, mm/h
1	11.7	6.5	21.0	9.0
2	0.5	0.5	36.0	29.0
3	7.5	3.8	3.0	1.0
4	0.0	0.0	1.0	0.5
5	11.0	4.0	10.0	6.0
6	2.8	1.0	4.5	2.5
7	5.0	3.0	8.5	5.0
8	3.0	1.0	10.0	2.5
9	32.2	16.0	25.0	11.5
10	157.0	28.0	227.5	45.0
11	38.5	10.0	41.5	20.0
12	1.1	1.0	1.0	0.5
13	7.7	6.0	5.5	2.5
14	18.5	10.0	11.0	7.5
15	32.5	12.0	9.5	4.0
16	0.0	0.0	0.0	0.0
17	0.0	0.0	3.5	1.5
18	0.3	0.3	23.5	6.0
19	17.8	5.0	1.0	1.0
20	0.0	0.0	8.0	2.0
21	15.0	3.0	0.0	0.0
22	0.0	0.0	4.0	2.0
23	4.0	2.0	0.0	0.0
24	0.0	0.0	22.5	15.0
25	37.5	10.0	34.0	13.0
26	21.8	8.0	2.0	1.0
27	0.0	0.0	0.0	0.0
28	4.5	1.0	3.5	2.0
29	1.0	1.0	6.5	4.0
30	2.5	1.0	6.5	2.5
31	7.5	5.5	6.0	4.5

The longitudinal profile of the Bagmati River (Fig. 2.4) exhibits several breaks in slope. Owing to the presence of gneisses, the river gradient is rather steep between the Sheopuri Range and the Kathmandu Valley. The gentler slope around the valley is due basically to the lacustrine and fluvial deposits in the basin. Steeper slopes south of the valley (between Dakshinkali and the Khani *Khola*) are related to the resistant rocks of the Lesser Himalayas. The gradient of the river becomes remarkably steep, especially while crossing the granite intrusion (Fig. 2.4). The Bagmati River flows onwards along the MBT and the MT with an almost uniform slope. Finally, it crosses the Siwaliks along a gentler gradient and reaches the *terai* with very gentle slopes.

Geomorphologically, the Bagmati watershed and its adjacent region can be subdivided into the following tectonic landforms: the Mid-hills, the Mahabharat Range, the Siwalik Hills, and the *terai*. Apart from these, such features as intermontane valleys, alluvial fans, river terraces, and floodplains are the other important secondary landforms observed in the region.

Mid-hills

The Mid hills (or Midlands) range in altitude from 1,000m to 3,000m. They are represented by a rather dissected topography with dendritic, centripetal, and sub-parallel drainage patterns. Residual soils are observed on the ridges, whereas colluvial soils and talus deposits are seen on the slopes. Occasionally river terraces and alluvial fans are developed on the lower gentler slopes (Plate 1, Part II)*.

The Midlands are made up of metamorphic and igneous rocks (Fig. 2.4, Plate 2). Granite is extensively distributed around Palung, Daman, Mandu, and between the Kulekhani Dam and Ipa. The territory covered by granite is deeply weathered to yield sand, pebbles, cobbles, and boulders. Generally, randomly-oriented joints are observed in the granite and the joint spacing varies from 20 cm to three metres. In most places, four sets of joints prevail. The groundwater percolates through the joints down to depths of from five to 10 metres and considerably increases the pore-water pressure leading to debris and rockslides.

As a result of chemical weathering along the joint surfaces, the large boulders are formed by the intersecting joint sets (Plates 2 and 3). The granite is made up of potash feldspar, plagioclase, quartz, biotite, muscovite, and tourmaline. Generally it is coarse-grained and occasionally a mixture of very coarse-grained and fine-grained.

The intensely fractured and folded phyllite and slate of the Tistung, Sopyang, Kulekhani, and Chitlang formations are the other important zones of instability. Huge rotational and translational slides are triggered off on them. One of the massive sliding areas lies in the catchment of the Agra *Khola*. The villages of Chisapani, Agra, and Chaubas are severely damaged by rock and soil slides. Large landslides also occur to the south of Khanikhet in the Ipa *Khola*, the Deuta *Khola*, The Kul *Khola*, the Niureni *Khola*, and the Kokhajor *Khola* (Fig. 2.2).

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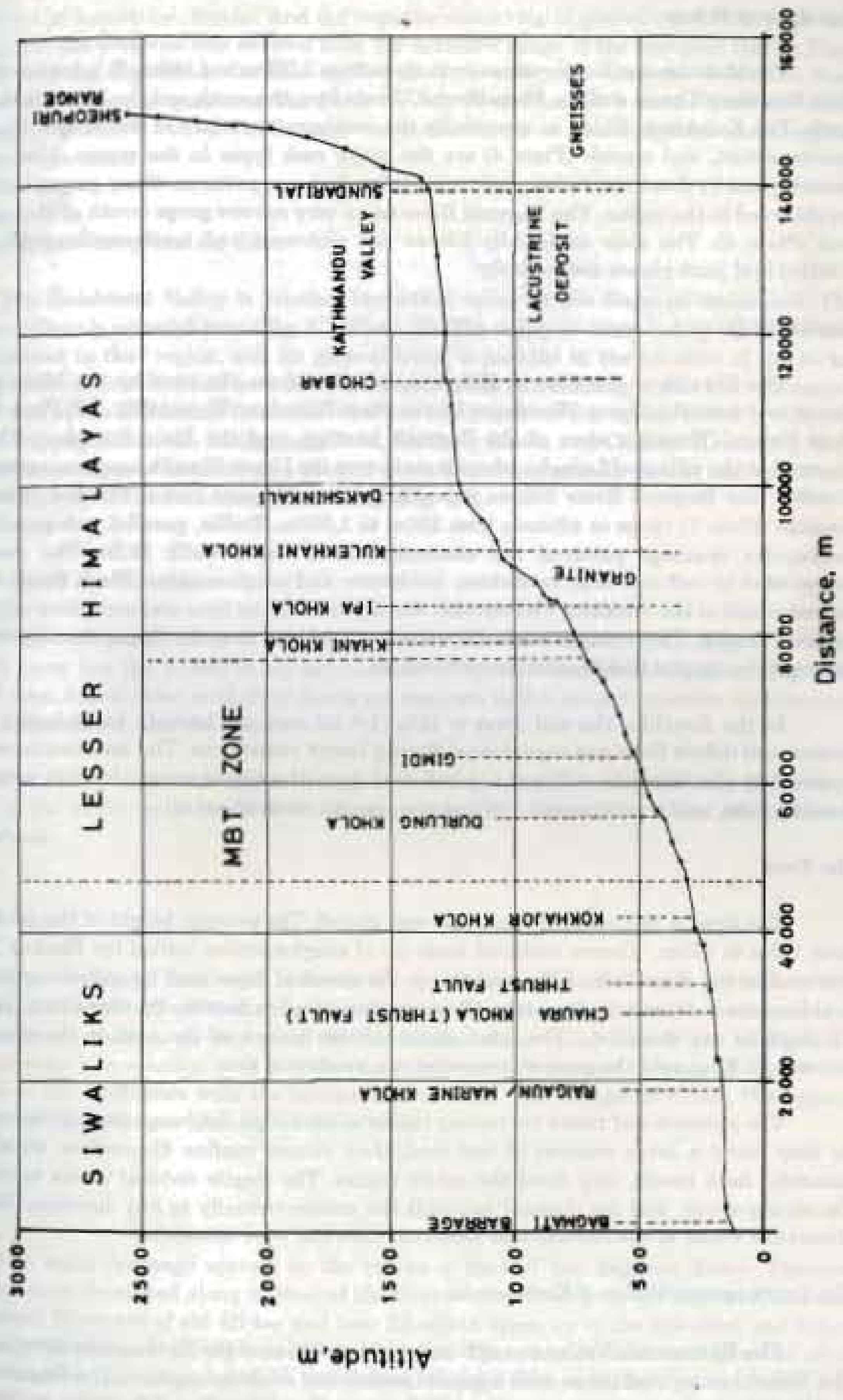
* Unless otherwise stated, all plates from this section are to be found in Part II of the Plates' Section at the end of the document.

FIG. 2.4: LONGITUDINAL PROFILE OF THE BAGMATI RIVER



Mahabharat Range

The Mahabharat Range varies in altitude from 2,000m to 4,000m. It is bounded by the Main Boundary Thrust and the Mahabharat Thrust from the south and the Mid-hills from the north. The Kulekhani *Khola* is essentially the northern boundary of the range. Quartzite, granite, schist, and marble (Plate 4) are the major rock types in the region. The range is characterised by dendritic, radial, and rectangular drainage patterns. Steep gorges and banks are observed in the region. The Bagmati River has a very narrow gorge (south of Malta) in the area (Plate 5). The river essentially follows the east-west and north-south trends of the foliation and joint planes respectively.

Siwalik Hills

The Siwalik or the Churia Hills are delimited from the *terai* by the Main Frontal Thrust and from the Lesser Himalayas by the Main Boundary Thrust (Fig. 2.2, Plate 6). The Main Frontal Thrust is seen at the Bagmati barrage, and the Main Boundary Thrust is observed at the village of Luinche where it rests over the Upper Siwalik conglomerates. In the Siwaliks, the Bagmati River follows essentially the south-east trend. The low hills of the Siwaliks (Plate 7) range in altitude from 200m to 1,500m. Trellis, parallel, sub-parallel, and rectangular drainage patterns are characteristic of the Siwalik Hills. The rocks are represented by soft and loose sandstone, mudstone, and conglomerates. Flash floods are also characteristic of the Siwaliks. The streams are dry most of the time and are active only in the monsoon season. They bring reworked boulders and pebbles from the Upper Siwaliks and also undercut the fragile Middle and Lower Siwaliks.

In the Siwaliks, the soil cover is thin (1-3 m) and, the bedrock being loose, intense erosion and debris flows are experienced during heavy rainstorms. The intermontane basins observed in the Siwaliks suffered a great deal from the recent event. In that area, sheet flooding, fans, and river channel shifting phenomena were common.

The *Terai*

The *terai* is composed of sand, silt, and gravel. The average height of the *terai* varies from 100m to 150m. Coarse material made up of conglomerates (called the Bhabar Zone) is observed in the Siwalik foothills, and this is the result of deposition by coalescing fans. The boulder sizes in them vary from tens of centimetres to a few metres. Further south, sand and silt deposits are observed. The most characteristic feature of the *terai* is the rapid river channel shifting, and the present low relief is a product of this.

The streams and rivers traversing the *terai* have high discharge during the monsoon. As they carry a large amount of bed load, they cannot confine themselves within their channels. As a result, they flood the entire region. The fragile natural levees may breach almost anywhere, and the channel can shift the course virtually in any direction. Recently, almost the whole of the Sarlahi and Rautahat districts were inundated.

The Intermontane Valley of Kathmandu

The Kathmandu Valley is a syn-tectonic depression of the Kathmandu Synclimorium. The Valley has an oval shape with a typical centripetal drainage pattern. The Bagmati River and its tributaries originate from the hills surrounding the valley. The valley is filled by a thick series of lacustrine, fluvial, and fan deposits consisting of gravel, sand, silt, peat, and clay. Most of the material was derived from the northern range of the Sheopuri Gneiss Zone. However, the fan deposits to the east and south of the valley are made up of detritus from limestone, phyllite, and quartzite. The floods on July 19 and August 9 also affected the valley considerably (Plates 8 and 9). The damage was concentrated on the floodplains and along the terraces of the rivers.

The Kulekhani Valley and the Dam

The Kulekhani Valley is another important valley in the Bagmati watershed. The Kulekhani Dam is situated here (Fig. 2.2, Plate 10). The valley is controlled by the joints and faults present in that region, and its general trend is parallel to the foliation of the rocks. Slates, phyllites, marbles, and quartzites are found in the surrounding areas. The submerged surface area of the Kulekhani Reservoir (*Indrasarobar*) is about 2.2 sq.km. Water is collected from the Palung *Khola*, the Bisingkhel *Khola*, Chitlang *Khola*, and Chakhel *Khola* (Fig. 2.2). The Kulekhani Dam is situated on a faulted contact between granite (south) and schist and quartzite (north) of the Kulekhani Formation (Fig. 2.3).

The Valleys in the Siwaliks

Wide valleys are seen in the Marin *Khola* and the Chaura *Khola* (Fig. 2.2). The Bagmati River has the widest valley between the villages of Jamire and Raigaun (Fig. 2.2). Alluvial fans, debris flows, and sheet floods are common in this area. Numerous mid-channel bars and islands are also observed.

The ability of the streams to transport debris increases during the time of flooding. Erosion of the valley walls by slides and flows provides thousands of tonnes of debris during such periods.

Alluvial Fans

Several alluvial fans were active in the granites, in the slates and phyllites of the Midlands, and in the Siwaliks during the rainstorm. The fans are situated where mountain streams change gradient as they reach the flat surface of the valley floor (Plate 11, Fig. 2.2). As the streams lose velocity, they also lose their capacity to transport debris and deposit the material at the confluence with the mainstream or river. The villages of Kitini, Phedigaun, Palung, and Karaonje are situated on these fans.

River Terraces

The main drainage system in the region is that of the Bagmati River. Terraced landforms have developed along it. Most of the terraces observed in the Kulekhani *Khola* and the Bagmati River are of old fill-top and new fill-strath types up to the Siwaliks; and below them, they become new fill-top and fill-strath types. There are at least four levels of river terraces between the villages of Malta and Baldeo. Villages such as Malta, Pyuitar, Gimdi, and Huchitar are situated on old fill-top terraces. The terrace height for old fill-top terraces generally varies from 75 m to 150 m, and often they are about 100 m higher than the present river bed, whereas the recent fill-strath and fill-top terraces range in height from three to 25m. Severe damage to the recent terraces can be observed almost all along the Bagmati River (Plates 7 to 11).

Floodplains and Channel Bars

Rather wide floodplains are observed along the Bagmati River below the village of Baldeo (Fig. 2.2). They are the most vulnerable areas for flooding (Plate 12). Often they contain paddy fields. A huge amount of debris brought by the tributaries is observed to rest on the floodplains. The mid-channel bars of the Bagmati River are often cultivated (Plate 13) and suffer from serious flood hazards. Occasionally, the schools are built on the point bars and floodplains which are the areas at very high risk (Plate 14). During flooding, the schools may be surrounded by floods and could even be washed away.

Mass Movements and Floods

Geological processes, such as landslides, debris flows, sheet flooding, river bank scouring, river and stream channel shifting, inundation of settlements and cultivated lands, and deposition of sediments, were active during the recent rainstorms and flooding. Short descriptions of the most important types of processes operating during the recent event are given in this part.

Landslides

The term landslide is used to denote the downward and outward movements of slope-forming materials along surfaces of separation (Varnes 1978). Landslides are rather quick, mass-wasting processes. The landslides were widespread and contributed to the loss of hundreds of lives in the study area. Moreover, the slides were the source not only of gravel and fines but also of huge amounts of wood debris (Plate 15). Landslides caused extensive damage to dry cultivated land, roads, and settlements. The total damage caused by the slides and debris flows is difficult to assess owing to the short duration of the present study. But the fact that more than 2,000 small and large (from 25 square metres to more than a square kilometre) landslides occurred along the Tribhuvan highway as well as hundreds in the Bagmati Watershed means that the damage was substantial.

Large slides were especially common on the north-facing dip-slopes, whereas shallow slides were observed on the counter dip-slopes and on the slopes of granite. Mass movements were mainly of four types: debris slides (Fig. 2.5, Plate 16), rockslides (Fig. 2.6, Plate 17), debris flows (Plate 18), and deep-seated rotational slides (Fig. 2.7). Plane rockslides occurred on steep slopes where bedrock was close to the surface (Fig. 2.6, Plate 17). Debris and soil slides occurred on slopes that were either deeply weathered or covered by colluvium and/or residual soils of thicknesses ranging from one to six metres (Plate 16). River bank scouring (Fig. 2.8) was the main cause of road washouts.

The most severe damages occurred in zones of intense precipitation (i.e., the Tistung, Agra, and Daman areas), on alluvial fans, around the Bagmati River banks, and on the gently dipping *terai* plains.

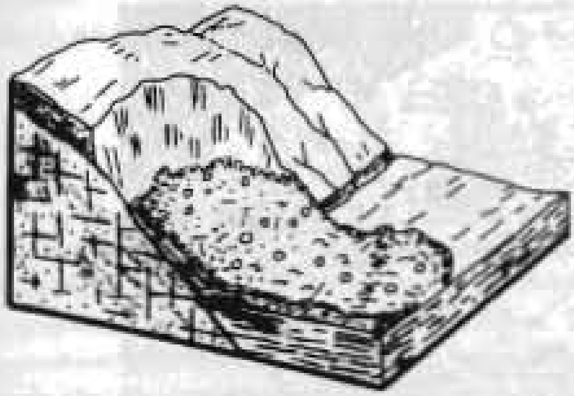


Figure 2.5: Sketch of a Debris Slide

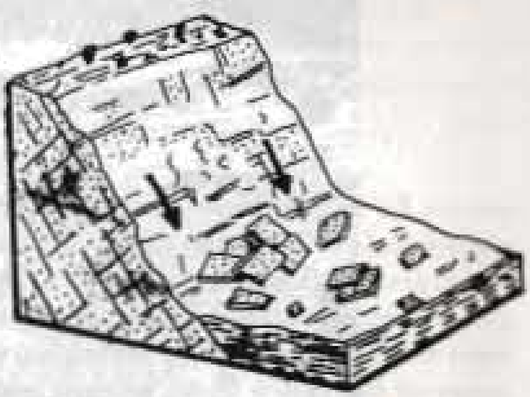


Figure 2.6: Sketch of a Plane Rockslide

Causes of Mass Movements

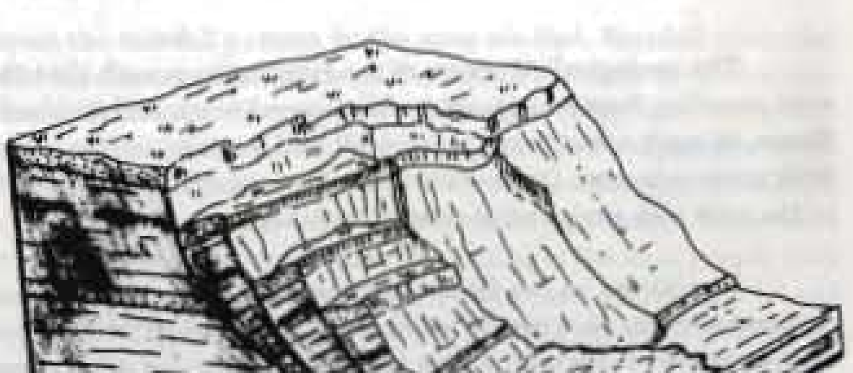


Figure 2.7: Sketch of a Rotational Slide

The most important factor leading to landslides and debris flows was the heavy rainstorm. Because of intense precipitation, the slopes around Jhapre, Tistung, Phedigaun, Agra, Palung, Chisapani, Daman, Gimdi, Baldeo, Karaonje, Mahabhir, Jurikhet, Bhimphedi, Mandu, Bhainse, Malekhu, Belkhu, Mahadev Besi, and Raigaun failed in several places leaving numerous landslide and erosion scars (Plates 1 and 2). River scouring and gully erosion were the other secondary factors leading to slope failures.

The factors which are more or less steady and inherent in the constituent rocks and soils can be grouped into the *primary causes* of failure. The basic primary cause is the force of gravity. But, apart from this, many other factors may play their roles. Some of the most important of them are: rock and soil types and their strength, rock structure (folding, faulting, jointing, foliation, bedding), soil depth, porosity, and permeability.

The factors that are either variable or very short-lived can be grouped into the *secondary causes* or *triggers*. They are seismicity; intensity of precipitation; land use; natural slope conditions; rock and soil weathering conditions; presence or absence of gullies, streams, and rivers; and groundwater conditions.

Figure 2.8: Sketch of bank scouring by a river

The geological structure of the Himalayas is such that there are several roughly east-west trending fractures (faults) with several weak and crushed zones (Figures 2.1 and 2.2). Hence, in such areas, numerous small and large landslides aligned along, or parallel to, the fault zones are seen. On the other hand, orientation of fold axis, bedding, foliation, and joints in the rock also play a vital role in landsliding.

Landslides in the Himalayas are very often complex and with more than one factor governing them. As a result, we observe a complex landslide. For example, a plane rockslide may be followed downslope by a wedge rockslide and debris flow.

Vegetation plays a vital role in slope stability and in the processes of soil erosion. The erosivity of rainfall increases during the monsoon, but the ability of vegetation to protect the topsoil also increases, resulting in reduced rates of surface erosion as the monsoon progresses. However, the mass wasting probability increases during the monsoon because the subsoil becomes saturated with moisture (Galay 1987). Generally, the vegetation cover increases the shear strength of the soil through its root network and protects the slope from landslides. However, if the landslide is deeper than the root penetration depth, the vegetation can no longer stabilise the slope.

Pore-water pressure is another important factor leading to slope failures. The most important aspect of pore-water pressure in rock and soil is that it reduces normal stress but does not affect shearing stress.

Flash Floods and Debris Torrents

Flash floods are events with very little time lapsing between the start of the flood and peak discharge. They are often associated with short intervals between storm incidence and arrival of the flood wave, but this is not always the case. Floods of this type are particularly dangerous because of the suddenness and speed with which they occur. Flash floods are more common with isolated and localised intense rainfall originating from thunderstorms. Debris torrents resulting from flash floods were observed at Kitini, Palung, in Mandu *Khola*, Jurikhet *Khola*, and in Kul *Khola*.

Floods

The basic cause of river flooding is the occurrence of heavy rainfall. Not all serious inundations of land or damage from floods, however, are due to this hydrological phenomenon alone. Often other factors operate either to exacerbate an already occurring flood problem or to create an entirely separate flood problem. These factors are associated most often with the promotion of hydraulic surcharge in water levels. They include the presence of natural or man-made obstructions in the flood path such as bridge piers, floating debris wires, and barrages. Also induced are the generally unforeseen river-surge events caused by sudden dam failure, land-slip, or mud flow (UNDRO 1991).

A Note on Rainfall Pattern and Flood Travel Time

Tables 2.1 and 2.2 depict the rainfall pattern in the area studied. Rainfall of similar magnitude was also recorded at the Daman, Markhu, and Kulekhani stations. From the data available, and from the present field visit, it was discovered that floods and landslides occurred between July 19 and 20 in the upper reaches of the Bagmati River, especially in the watersheds of the Kulekhani, Bhimphedi, Mandu, Malekhu, Belkhu, and the Agra *Khola*. On the other hand, floods and intense rainfall were observed between July 20 and 21 in the area between Gimdi and the lower reaches of the Bagmati River. According to the local people from the upper catchment, the flood on August 10, 1993, was bigger than that during July 19 and 20. However, the devastating flood in the lower catchment occurred during the night of July 20-21. A flood of lesser magnitude occurred in the morning of July 20.

These observations indicate that there were at least two separate areas with different cloudburst timings (i.e., the Kathmandu-Palung-Kulekhani-Bhimphedi-Malekhu and the Baldeo-Raigaun-Marin *Khola*-Canteen areas). It seems that the thunderstorm producing the intense rain was gradually moving from north to south almost at the same pace as that of the flood. Probably the cumulative effect of the rainfall event resulted in the catastrophic floods in the lower reaches of the Bagmati and other rivers reaching the *terai*.

Field Assessment of Damages by Mass Movements and Floods

Mass Movements on Highways and Adjacent Regions

The floods and heavy rain caused severe damage to the roads. The damage was confined to the gullies, steep soil slopes, and slopes with highly weathered rock. Rockfalls, plane and wedge rockslides, debris slides, and rotational soil slides were most common, whereas gully erosion and alluvial fans either destroyed or blocked the road in several places. The road very close to the river channel also suffered from bank scouring, whereas, in several places, small debris fans debouched on to the road. The landslides were triggered off, either by extensive bank scouring in the gully or by increase in the pore-water pressure in the weathered rock. Generally, a perched water table was formed at the interface between the impervious granite and the weathered upper layer of rock and soil.

River bank scouring was most common around Jogimara, near Bishal Tar, west of Malekhu, on the right bank of the Malekhu *Khola*, in the vicinity of Belkhu, Galchhi, Mahadev Besi, and Naubise. A short description of the damage to the road is presented below.

Damage to the Tribhuvan Highway and Adjacent Area

There were more than 2,000 landslides (with major landslides in more than 200 places) ranging in size from tens of square metres to thousands of square metres. There were about 20 places with severe washouts. Areas where heavy damages occurred were Naubise (Km 26), around Jhapre (Km 49 to Km 53), between Sikharkot and Daman (Km 71 - Km 76), between Aghor and Mahabhir (Km 89-98), around Bhainse Dobhan, and at Bulbule (Km 122-123). More than 100 metres of retaining walls and 23 culverts were damaged. The bridges at Mahabhir, Bhainse (Plate 19), and Trikhandi (Plate 20) were completely washed out, and the bridges over the Sopyng *Khola* and the Sankhamul *Khola* were partially damaged.

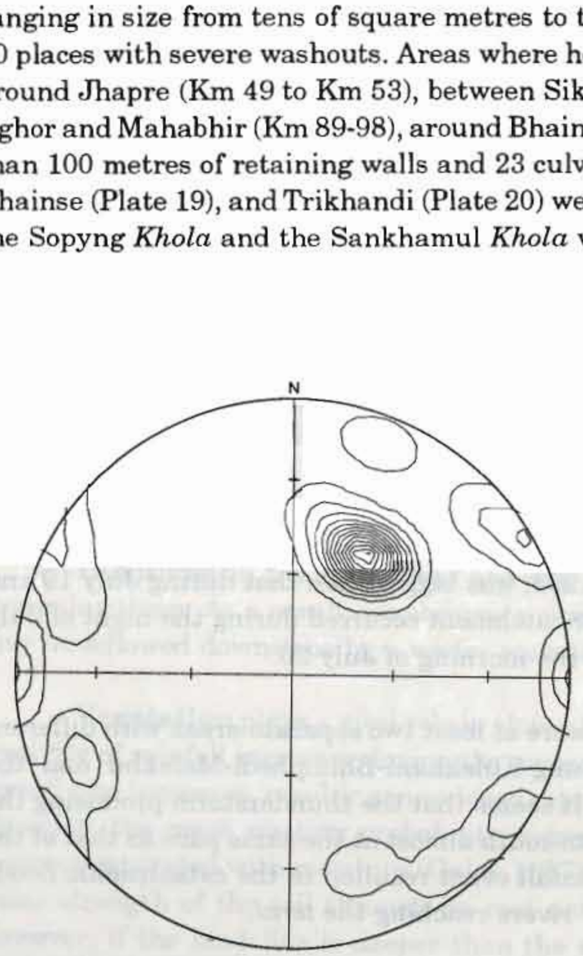


Figure 2.9: Stereographic projection of joints, Km 64 on the Tribhuvan Highway. Upper hemispherical projection. (See also Plate 9)

Plane Rockslide North of Okhar Bazaar

A large plane rockslide can be seen at Km 64 on the Tribhuvan Highway (Plate 21). The slide is on the Tistung Formation where the rock consists of highly fractured slate and quartzite. There are four distinct sets of joints developed in it (Fig. 2.9). The stereographic projection of joints (Fig. 2.9) clearly reveals that the basic mechanism of failure was caused by sliding along the bedding/foliation plane. The same type of plane rockslides and wedge rockslides can be observed around Jhapre (Km 51-52). Some of them also seem to be rotational slides in the rock.

Landslides and Gully Erosion on the Slope North of Okhar Bazaar

The study of landslides on the counter dip slopes near the village of Okhar *Bazaar* (Fig. 2.10) revealed that the total soil displaced by slides and gully erosion was about 6,700 cubic metres within an area of 21,400 square metres; which works out at 0.31 cubic metres per square metre (i.e., 1680x0.31=520 kg/m^2) of the total area. The total landslide area was about 8,500 square metres; which works out at 40 per cent of the total surface area. The average natural slope was about 35 degrees, whereas the central part of the failed slope was about 41 degrees. The contoured stereographic projection (Fig. 2.11) shows the distribution pattern of the joints.

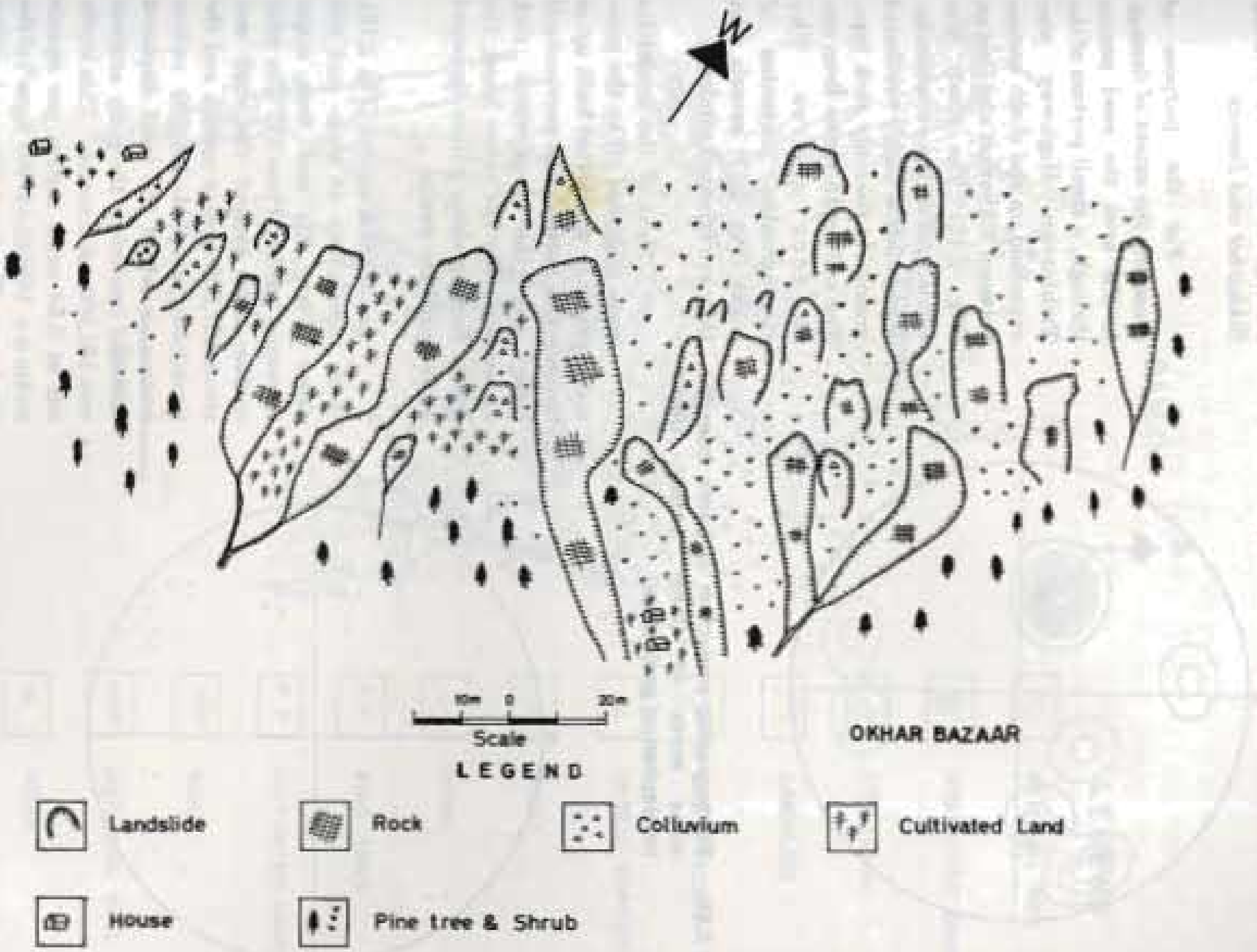


FIG.2.10: ENGINEERING-GEOLOGICAL MAP OF A WESTERN PART OF OKHAR BAZAAR

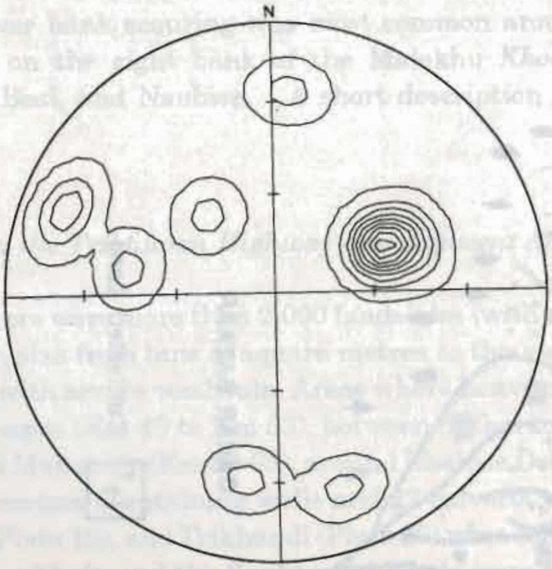


Figure 2.11: Stereographic projection of joints from the slope north of Okhar *bazaar*. Upper hemispherical projection.

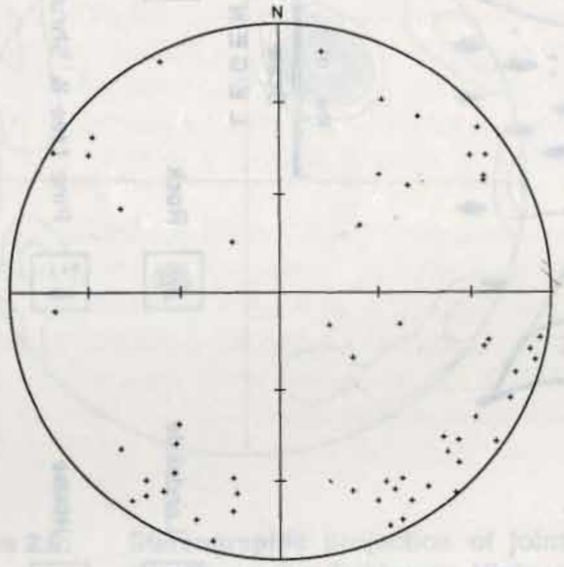


Figure 2.13: Stereographic projection of joints from the road section between Sikharkot and Daman. Upper hemispherical projection.

Damage to the Road between Sikharkot and Daman

For the purpose of assessing the extent of damage in the area the road passes through, a small portion of the Tribhuvan Highway was examined on the climb section between Sikharkot and Daman (Fig. 2.12). The study was carried out on the switchbacks. Moderately to highly weathered granite is the only rock type. The soil depth varies from one to four metres. The stereographic projection of joints (Fig. 2.13) reveals that they are oriented randomly.

Most of the landslides were triggered off by the pore-water pressure which had built up at the interface between the pervious soil layer and the impervious rock underneath. On the other hand, the debris flowing along gullies damaged and scoured the banks.

In a 2,185m stretch (Fig. 2.12), there were about 44 rock- and soil slides (Plate 22) and four major torrential gullies (Plate 23). The total surface area around the road was about 297,500 square metres and the landslides occupied 109,200 square metres, in which the total displaced material (excluding the gully erosion) was 161,000 cubic metres. This works out at 0.54 cubic metres per square metre (i.e. 1680x0.54=907 kg/m^2) of the total area. The landslides and gullies occupied about 36 per cent of the total surface area. The average depth of failure was 1.5 m, whereas the average natural slope was 31 degrees and the failed slope in the central part was 41 degrees. The total length of damaged road section (including the damages on the adjacent slopes) was 828 m (i.e., 38% of the total road length).

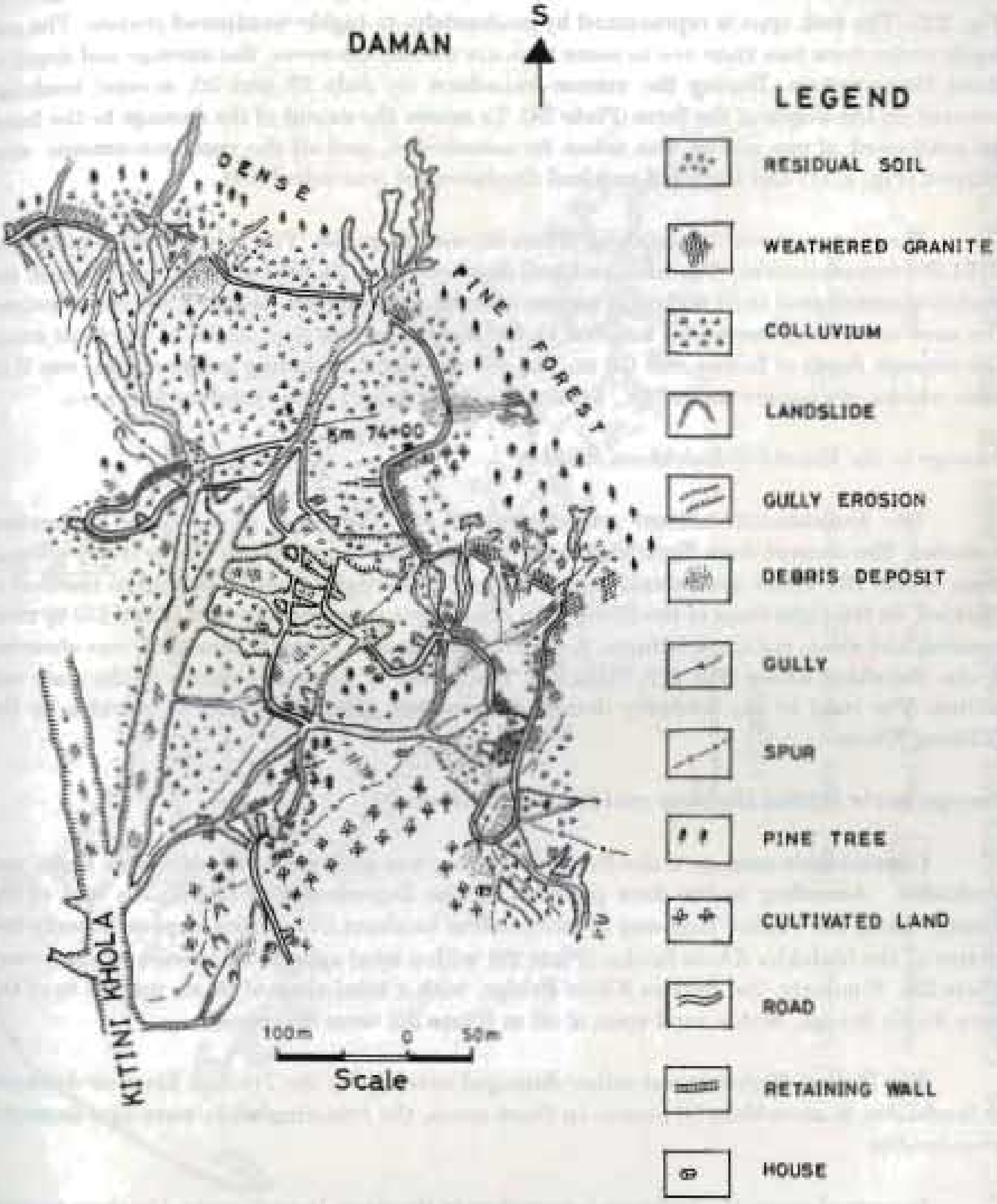


FIG.2.12: ENGINEERING-GEOLOGICAL MAP OF A PART OF THE TRIBHUVAN HIGHWAY BETWEEN SHIKHARKOT AND DAMAN

Mass Movement at the Daman Horticultural Farm

The Daman Horticultural Farm is located on the ridge at an altitude of about 2,300m (Fig. 2.2). The rock type is represented by moderately- to highly-weathered granite. The soil depth varies from less than one to more than six metres. However, the average soil depth is about three metres. During the intense rainstorm on July 19 and 20, several landslips occurred on the slopes of the farm (Plate 24). To assess the extent of the damage to the farm, the catchment of two gullies was taken for assessment, and all the mass movements were mapped (Fig. 2.14) and the total rock/soil displacement was calculated.

There were about 73 landslides (Plate 25) and 12 gullies (Fig. 2.14) within a total area of 51,600 square metres. The total rock/soil displaced was 34,100 cubic metres, of which the landslide contributed to 31,800 cubic metres and the gully erosion yielded 2,300 cubic metres. The area covered by landslides totalled 11,650 square metres (i.e., 22.6% of the total area). The average depth of failure was 0.8 m. The soil displaced (including gully erosion) was 0.61 cubic metres per square metre (i.e., 1,680x0.61=1014 kg/m^2) of the total surface area.

Damage to the Kunchhal-Kulekhani Road

The Kunchhal-Kulekhani gravelled road was damaged considerably on several stretches. The descent from Kunchhal to the village of Tistung is one of the severely affected areas (Plate 16). There are several soil slides and torrential gullies. The road to the east of Taukhel, on the right bank of the Bisingkhel *Khola*, was severely damaged (Plate 26) by river scouring and steep, cut slope failures. A small landslide dam (already breached) was observed in the Bisinkhel *Khola* (Fig. 2.2, Plate 27). The failure is a plane rockslide in the slate and marble. The road is also severely damaged about two kilometres east of Markhu by the Chitlang *Khola*.

Damage to the Prithvi Highway and Its Surroundings

Considerable damage to the Prithvi Highway was incurred by floods, debris flows, and landslides. According to the data provided by the Department of Roads, the cost of the damage along the Prithvi Highway is estimated to be about 572 million rupees. Twenty-two metres of the Malekhu *Khola* Bridge (Plate 28) with a total span of 44 m were washed away (Plate 29). Similarly, the Belkhu *Khola* Bridge, with a total span of 66 m, and 66 m of the Agra *Khola* Bridge, with a total span of 88 m (Plate 30) were destroyed.

The Prithvi Highway was either damaged severely by the Trishuli River or damaged by landslides in more than 50 places. In those areas, the retaining walls were also damaged considerably.

In several areas, the highway is very close to the river. In such areas, the river scoured the road and deposited from one to three metres of sand and gravel (Plate 31). Several suspension bridges were also either washed away or severely damaged during the same event. On the other hand, the flood, and rock- and soil slides damaged the road and adjacent slopes at Naubise, Galchhi (Plate 32), around Mahadev Besi, Belkhu, Gajuri, Malekhu, Benighat, Bishal Tar, and Jogimara. During the same event, the Blue Heaven Restaurant, situated on the left bank of the Trishuli River, about 500 m west of Malekhu, was washed away completely. A long stretch of the river terrace on the right bank of the Trishuli River to the west of Belkhu was scoured (Plate 33).

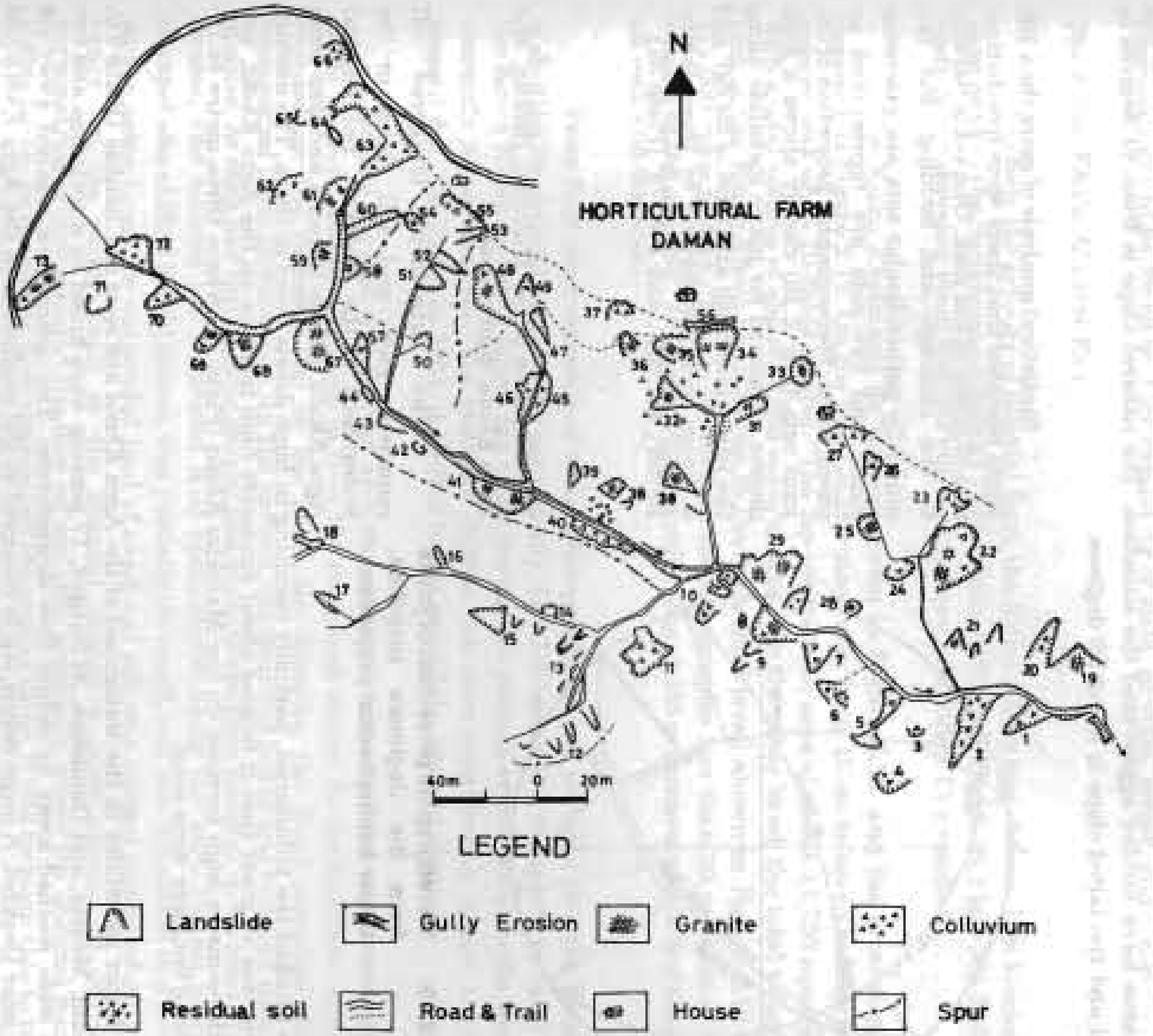


FIG. 2.14: ENGINEERING-GEOLOGICAL MAP OF A PART OF THE HORTICULTURAL FARM, DAMAN

The Jogimara Landslide and Its Triggers

The Jogimara landslide (Plate 34) is probably the most hazardous landslide on the Prithvi Highway. It has carried several buses into the Trishuli River and hundreds of people have lost their lives. The slide is located on the left bank of the Trishuli River on the Benighat Slates and Jhiku Limestone bands. The rocks are extremely jointed and the joint spacings vary from a few centimetres to tens of centimetres in the slate and from tens of centimetres to a few metres in the limestone. The approach road to the limestone quarry and the blasting in the area have further aggravated the situation. The natural slope is from 40 degrees to vertical and the failed slope is about 30 degrees.

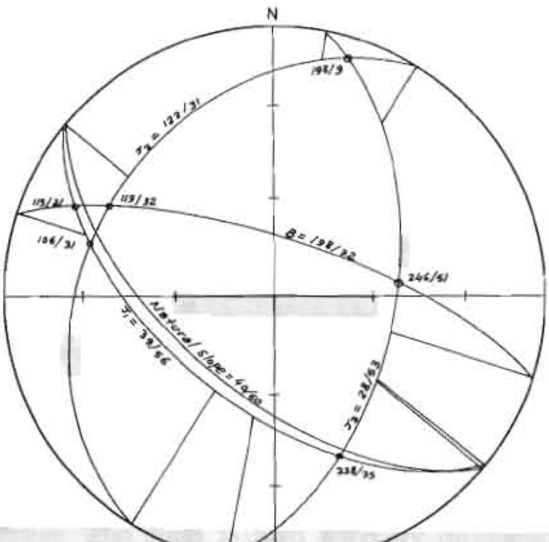


Figure 2.15: Stereographic projection of joints from the Jogimara rockslide. Upper hemispherical projection.

Statistical analysis of more than 100 joints revealed that there were five distinct sets of joints in the rock. One set is parallel to the cleavage and bedding, the two mutually perpendicular sets are extension joints and two sets are represented by shear joints. Stereographic projection of the joint sets (Fig. 2.15) clearly shows a high degree of hazard for plane rockslide along the joint plane with attitudes of 39°/56° and a wedge rockslide formed by three joints: 39°/56°, 122°/31°, and 198°/72° (Plate 35).

The Situation in the Malekhu, Belkhu, and Agra Khola Watersheds

The rainstorm triggered off numerous rock- and soil slides in the watersheds of the Malekhu, Belkhu, and Agra *Khola*. Debris torrents and fans seem to have blocked the tributaries, partially resulting in huge debris flows in them. The amount of debris was so great that it formed about six-metre high terraces on the Agra *Khola*, and about three-metre high terraces on the Malekhu *Khola* (Plate 36) where three-metre to 10-metre long boulders were seen.

Major rockslides in the watershed of the Agra *Khola* are seen at Chaubas (Plate 37), Chisapani, Mouria, and Dandabas. At Sulikot, 17 persons were killed by a rockslide and two houses were washed away by debris flow downstream. The debris flow washed away six houses near Deokhel. A large debris fan is observed at the confluence of the Agra *Khola* and the Chalti Khola. In that area, a cemetery and several temples were damaged also. Another big fan is observed to the west of Devithan where two houses were washed away.

The bridges over these rivers were washed away completely or partially. The basic reason for bridge collapse was low bridge height and narrow span. Generally, the river channel upstream is from 1.5 to two times wider than at the bridge site. The huge tree trunks brought by the rivers were entrapped by the piers and thus also contributed to collapse of the bridge.

Field Study of Alluvial Fans

Numerous small and large alluvial fans were active during the rainstorm. They caused extensive damage to the villages, cultivated land, and infrastructure. The sediment load transported by them was variable, depending upon the rock and soil types from which they originated and upon flow velocity. Huge boulders were observed in the channel and on the fan originating from such resistant rocks as granite, quartzite, marble, and limestone. Smaller fragments are to be found on fans consisting of slate, phyllite, schist, and shale.

The Kitini Khola Alluvial Fan

To study the activity of alluvial fans, the Kitini *Khola* was chosen. It is located on the right bank of the Sankhamul *Khola* at Thana *Bazaar* (Fig. 2.2, Fig. 2.16, Plate 38). Debris flow destroyed cultivated land, washed out nine houses, and killed 11 persons.

The Kitini *Khola* and its fan are shown in Figure 2.16, and the cross-sections are depicted in Figure 2.17. On the fan, boulder sizes vary from 10 cm to seven metres and their volume was up to 70 cubic metres. The fan occupies an area of about 11,750 square metres with a total volume of about 58,750 cubic metres. On the other hand, the total volume of the part of the Kitini *Khola* channel (up to the high flood level) shown in Figure 2.16 is about 179,000 cubic metres. This indicates that the fan occupies less than 30 per cent of the total volume of the channel. The longitudinal profile (Fig. 2.18) is concave with a few steep slopes on rock and terraces.

From field observations and aerial photographs, it was revealed that the Kitini *Khola* is shifting its channel and the fan periodically. In 1915 (according to reports by local people), the Kitini *Khola* formed a larger fan (than during the present event) towards the west of the currently active channel. The boulders in that fan were considerably bigger than in the present fan. Similarly, in 1954, it shifted to the east of the present channel.

Most of the load was derived from the previously deposited fan or terraces, and some of the material was also brought in from the steep rock slopes. As the boulders were already rounded on the terraces and in the older fan deposits, the flood reworked them and transported them downstream. In the process, the boulders rolled and bounced making a lot of noise. As they had high kinetic energy and momentum, they knocked down trees, destroyed houses, and scoured the cultivated land encountered along the way. In this process, the channel also shifted its old course, was partially dammed, and was bifurcated in a few places. At the same time, the suspended load of sand and silt was ejected or spilled over the low banks (on the paddy field) as the channel carried a large amount of debris which asymmetrically concentrated the flow on one side, especially where the channel made short zigzag turns. As the debris flow approached the gentler slope, it was no more able to transport all the bed load, and hence the material debouched at the confluence with the Sankhamul *Khola* where the fan is about 200 m wide and five metres thick (Fig. 2.16, Cross-section A-A' of Fig. 17).

The Phedigaun Alluvial Fans

Phedigaun (Fig. 2.2, Plate 39) is located at an elevation of about 1,830 masl. It is one of the most severely damaged areas where 52 houses were destroyed (Plates 40, 41, 42) and 62 persons were killed.

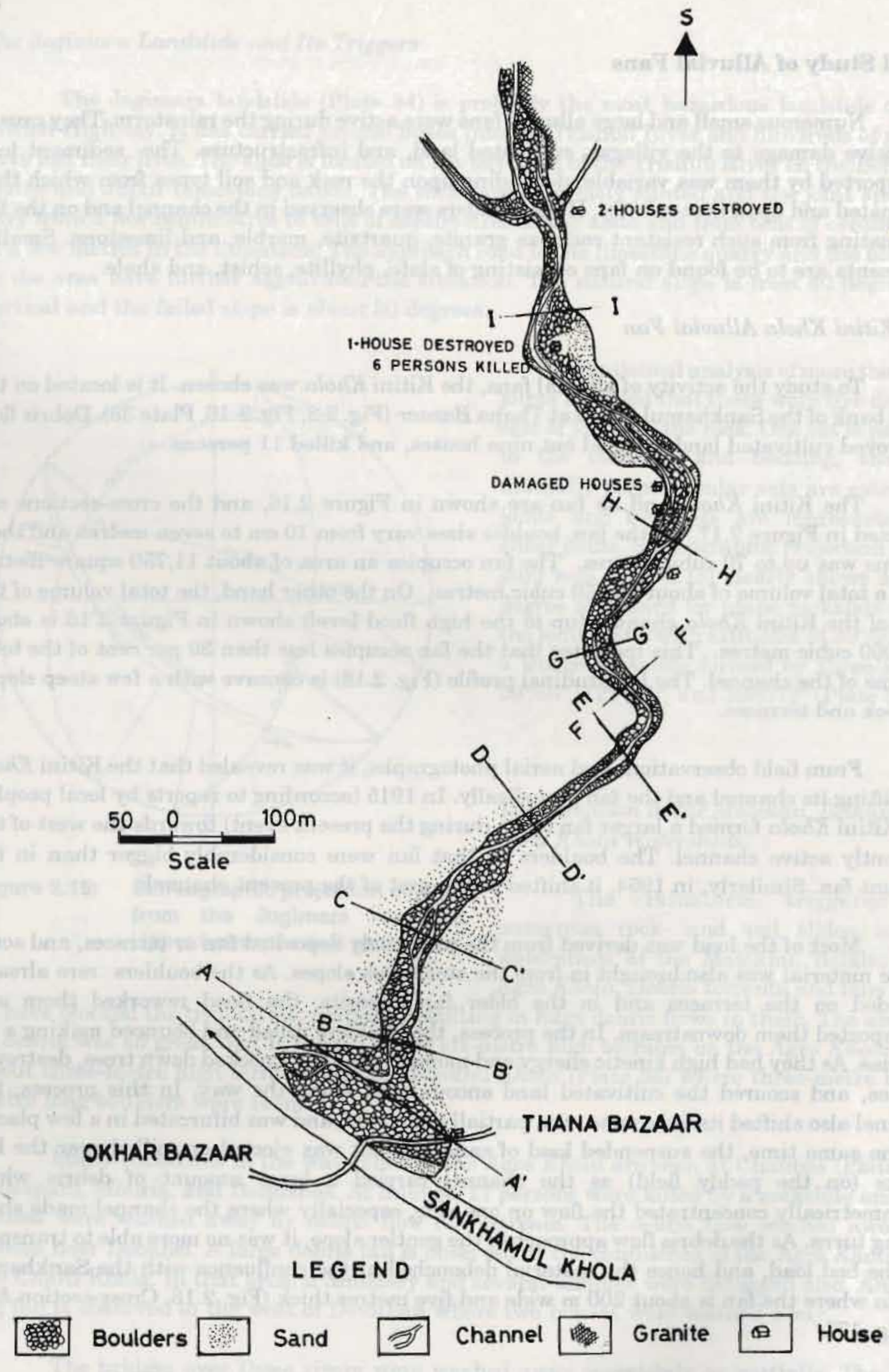


FIG.2.16: THE KITINI KHOLA FAN AT PALUNG

FIG. 2.17: CROSS-SECTIONS OF THE KITINI KHOLA

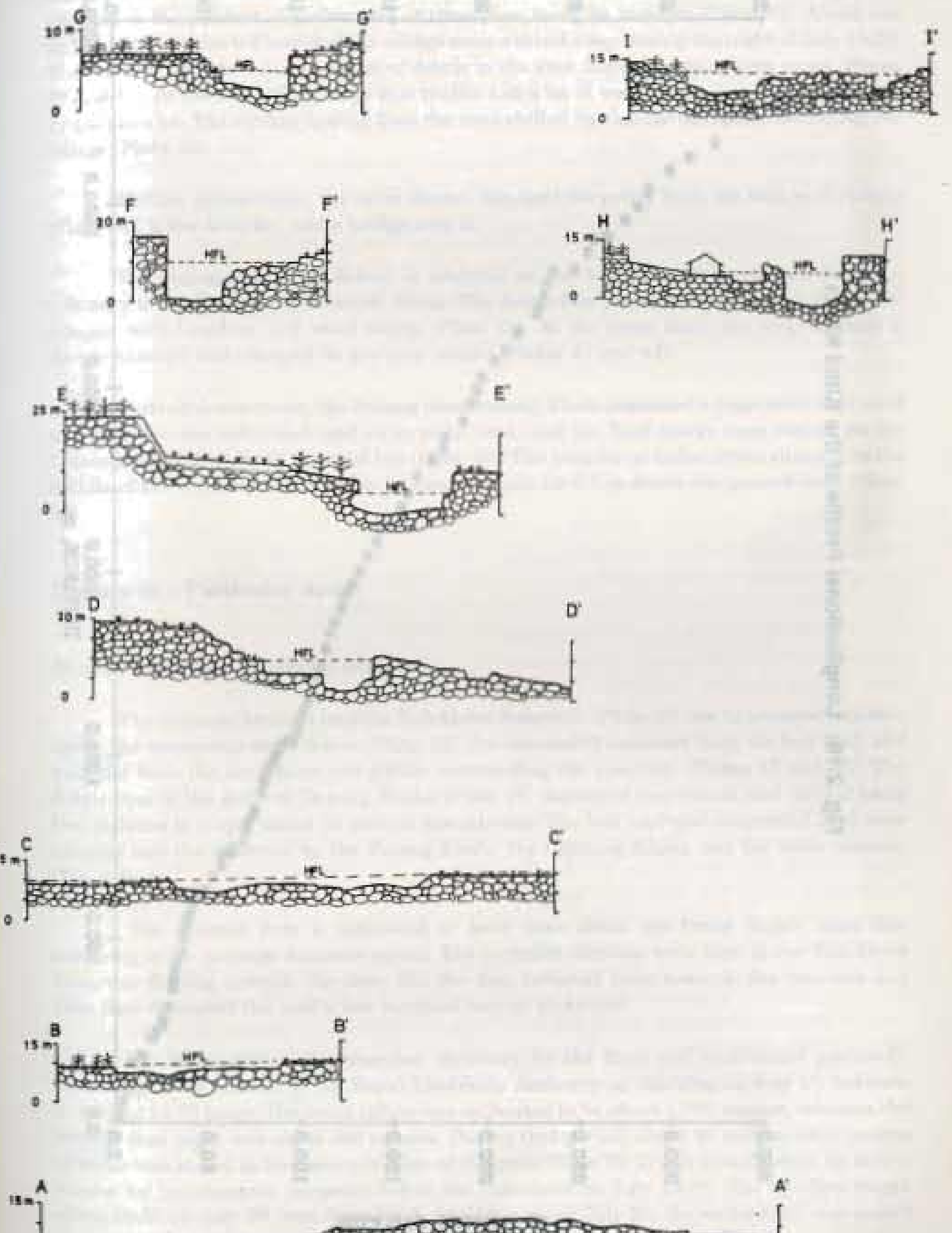
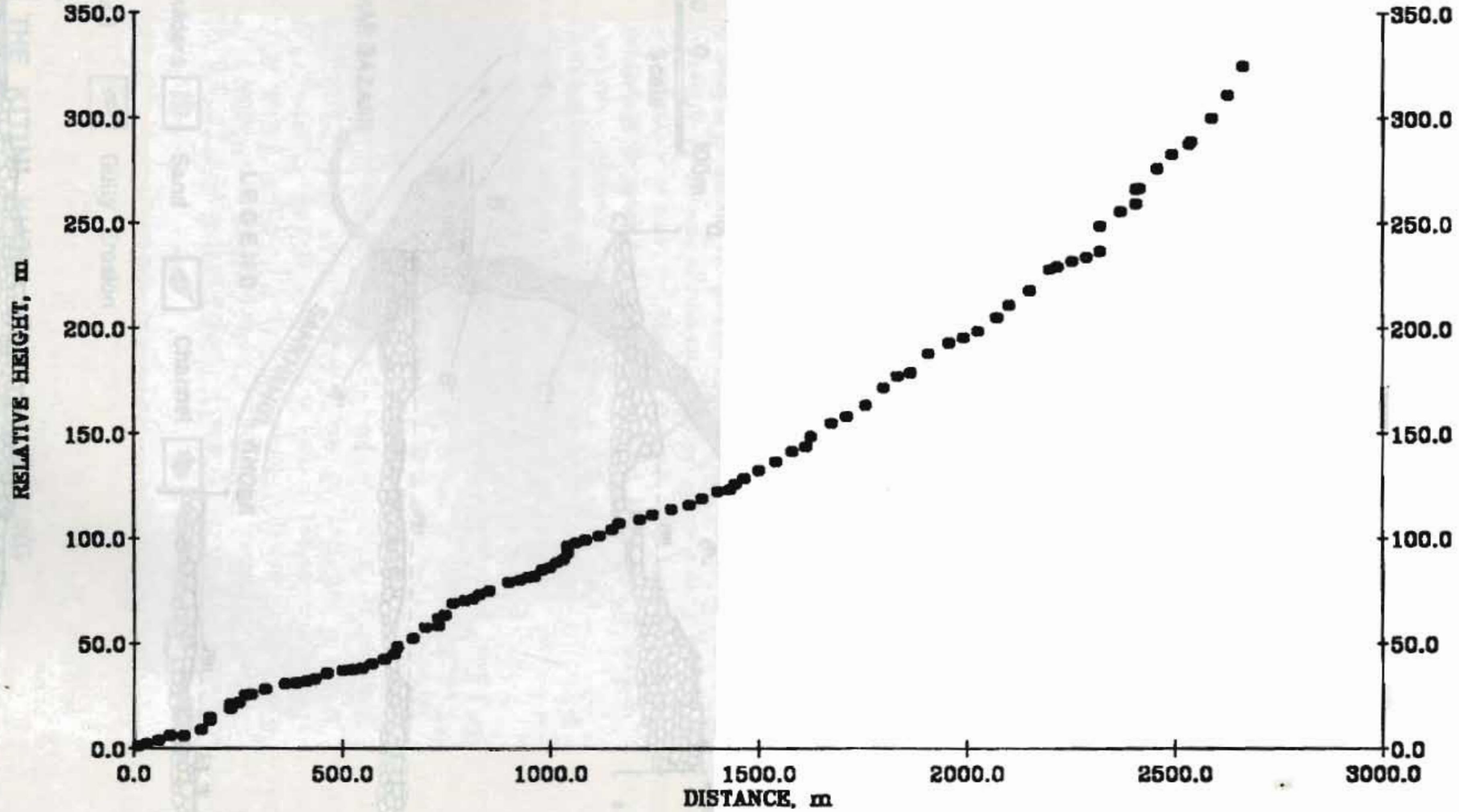


Fig. 2.18: Longitudional Profile of the Kitini Khola



The mountain slopes are steep and vary from 30 degrees to 40 degrees. There is a large plane rockslide on the northern slope south of Phedigaun. Similar soil and rockslides are also observed in the catchments of the tributaries. The alluvial fan on which the village was situated is the product of coalescence of three fans from the streams (Plate 39). About two sq.km. of the cultivated land and the village were washed away during the night of July 19-20. The streams brought a huge amount of debris in the area during the rainstorm event (Plates 39 and 40). At the same time, large tree trunks and a lot of wood debris were also brought in by the streams. The stream flowing from the west shifted its channel abruptly, destroying the village (Plate 39).

Further downstream, the same stream damaged the paddy field, the village of Palung (Plate 42), a few temples, and a bridge over it.

The Janakalyan High School is situated on the left bank of the Gharti *Khola*, a tributary to the Palung (Sankhamul) *Khola*. The debris flow in the stream filled up the school campus with boulders and wood debris (Plate 43). At the same time, the river scoured a deeper channel and changed its previous course (Plates 43 and 44).

Further downstream, the Palung (Sankhamul) *Khola* deposited a huge amount of sand and gravel on the cultivated land on its right bank, and the flood marks were noticed on the houses about 70 cm above the sand bar (Plate 45). The temples at Indrenithan situated in the middle of the terrace were filled up by sand and silt for 0.7 m above the ground level (Plate 46).

Damage in a Particular Area

Damage around the Kulekhani Reservoir

The material brought into the Kulekhani Reservoir (Plate 10) can be grouped into four types: the suspended wood debris (Plate 15), the suspended sediment load, the bed load, and material from the landslides and gullies surrounding the reservoir (Plates 47 and 48). The debris flow in the gully at Dalsing Pakha (Plate 47) destroyed two houses and carried away two children to a spot about 75 metres downstream. The bed load and suspended load were brought into the reservoir by the Palung *Khola*, the Chitlang *Khola*, and the other streams (Fig. 2.2).

The siltation rate is estimated to have been about ten times higher than that occurring in the average monsoon period. The turbidity currents were seen in the Kulekhani Reservoir flowing towards the dam. But the dam reflected them towards the reservoir and then they deposited the load a few hundred metres upstream.

The dam acted as the retention structure for the flood and contributed positively. According to the officials of the Nepal Electricity Authority at Markhu, on July 19, between 21:00 and 24:00 hours, the mean inflow was estimated to be about 1,000 cumecs, whereas the outflow that night was about 300 cumecs. During that period, about 45 million cubic metres of water was stored in the reservoir. One of the gates (Gate No 2) was already open up to five metres for maintenance purposes before the rainstorm on July 19-20. The overflow began about 00:30 on July 20 from Gate No 2. At 9:00 a.m. on July 20, the water level was raised by 26.37 metres, relative to that of 16:00 hrs on July 19. Owing to this alarming situation of a very rapid rise in water level, the second gate (Gate No 1) was opened at 9:00 am. The details of the gate opening are given in Table 2.3.

Table 2.3: Details of Gate Opening and Closing at Kulekhani Dam

Date/ Major events	Water level, m	Time
July 19, 1993	1498.63	9:00
	1499.33	16:00
The penstock pipe at Jurikhet was destroyed at 21:40		
July 20, 1993	1524.62	7:00
	1524.70	8:00
Gate No 1 was open up to 15 cm at 9:00 a.m.	1525.05	9:00
	1525.02	10:00
Gate No 1 was open up to 35 cm at 11:30 a.m.	1524.90	11:00
	1524.86	12:00
	1524.58	13:00
The intake gate was closed manually between 10:00 and 14:00	1524.40	14:00
	1523.90	16:00
	1523.46	20:00
	1523.34	24:00

Kulekhani Khola between the Dam and the Confluence with the Bagmati River

Many landslides and debris flow deposits are observed along the Kulekhani *Khola* below the dam. Plane rockslides are observed on the right bank of the Kulekhani *Khola* about 500m west of the confluence with the Chakhel *Khola* (Fig. 2.2). These slides have been active for quite a long time. One of the largest landslides and the resulting fan was observed between the villages of Thulo Tar and Sulikot (Fig. 2.2, Plate 11). The joint pattern is presented in Figure 2.19 and it shows that the failure was a wedge slide.

Field observation of the confluence of the Bagmati River and the Kulekhani *Khola* showed that there was no damming effect by the Kulekhani *Khola*.

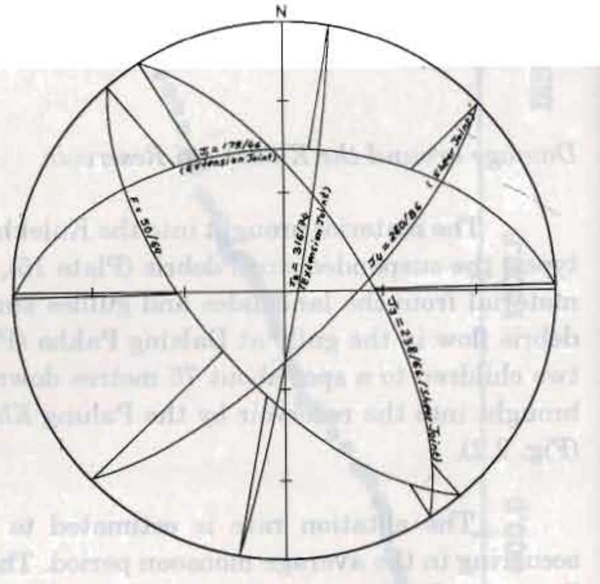


Figure 2.19: Stereographic projection of joints from the area between Sulikot and Thulotar. Upper hemispherical projection.

The Bagmati Valley between Ipa and Gimdi

The Bagmati Valley between Ipa and Gimdi is characterised by the presence of a deep entrenched gorge in marble and granite (Plate 5). At Baguwa (about 1 km north of the confluence with the Khani *Khola*), on the Kanti Rajpath, it can be inferred that there was a past landslide dam. A huge landslide zone is seen at the Ipa *Khola* (Plate 49) with a large debris fan below. It is the Mahabharat Thrust zone (Fig. 2.2). Landslides and debris flows were also observed at the Deuta *Khola* and the Neureni *Khola*.

The Bagmati Valley between Gimdi and Kokhajor Khola

The Bagmati River between the Gimdi and the Kokhajor *Khola* essentially follows the Main Boundary Thrust and the Mahabharat Thrust (Fig. 2.2). The Siwaliks are seen along the right bank of the valley, whereas the schists, marble, and quartzites are exposed along the left bank. Several soil and rockslides can be observed on the river banks and hillslopes. Large slides and slumps can be seen at the Kul *Khola* and the Phyang *Khola*. Alluvial and debris fans formed by smaller rivers are characteristic of the region. They have partially dammed the Bagmati River. There is a large rockslide on the left bank of the Kokhajor *Khola*, about one kilometre upstream from the confluence. According to the local people, the landslide occurred on July 21, 1993. However, there was no evidence of damming by it on the Bagmati River.

Sheet Flooding in Karaonje

The village of Karaonje (Fig. 2.2) is situated on the right bank of the Bagmati River on the alluvial fans (Plates 50 and 51). Most of the material was derived from the Upper Siwalik conglomerates. The gullies reworked and transported the pebbles downstream. During the period of intense rainfall, the channel could not contain the water within its very low banks and the sheet flood spilled over the entire alluvial fan. As a result, the houses were buried or destroyed by the debris.

Damage to Raigaun

Raigaun is situated on the right bank of the Bagmati River, opposite the confluences of the Marin *Khola* and the Chiruwa *Khola* (Fig. 2.2). Ward No 6 of the village (Plates 12 and 52) was severely affected by flooding on the Bagmati River during the night of July 20-21. The highest water level occurred between 1:00 and 6:00 a.m. on July 21, and the flood subsided between 6:00 and 7:00 a.m. During the flooding, several houses were washed away or inundated, resulting in heavy loss of cattle, cultivated land, and property.

The settlement was on the floodplain within the natural levees. The high water level was about 20m above the present river level. Probably the backwater flow from the barrage was one of the factors contributing to the unprecedented rise in water level. There was clear evidence of backwater flow in the Chiruwa *Khola* (Fig. 2.2). However, there was no evidence of damming of the Bagmati River by the Marin *Khola*.

Damage below Raigaun

The area below Raigaun suffered from inundation along the Bagmati River and from the debris flows, landslides, and gully erosion on the upper slopes. The backwater flow from the Bagmati River was seen in the Sangle *Khola* (Plate 53) situated to the south of Raigaun (Fig. 2.2), where the high flood level was from 1.5 to two metres above the present stream level. The channel was evenly filled up by medium to fine sand, making the bed almost horizontal (Plate 53).

Damage to the Bagmati Barrage

The Bagmati Barrage at Canteen is situated just on the Main Frontal Thrust (Fig. 2.2) which separates the Siwaliks from the alluvial deposits of the *terai*. The adjacent Siwalik rocks are intensely folded and are represented by grey, green, red, yellow, and brown mudstones and sandstones. The barrage was severely affected by the flood, and a loss worth more than 150 million rupees is estimated.

The dimensions and other technical parameters of the barrage (Plate 54) are presented in Table 2.4. There is a large mid-channel bar upstream from the barrage (Plate 55) and it continues downstream. The total volume of the channel bar downstream from the barrage was 148,400 cubic metres. The channel bar upstream from the barrage was almost three times larger, and, therefore, the total gravel deposit in the bar is estimated to be about 550,000 cubic metres.

Table 2.4: Details of the Bagmati Barrage

Barrage length	403.5 m
Dam site elevation	125.0 m
Barrage crest level	126.0 m
Barrage road level	134.7 m
Pier width	2.0 m
Barrage gate width	9.0 m
Number of gates	50
Number of head regulators	12
Design flood	8000 cumecs

After a flood of smaller magnitude (about 4,000 cumecs) on the morning of July 20, the gates were opened. The catastrophic flood came during the night of July 20-21 between 1:00 and 6:00 a.m.

Large trees (more than 30 m long) and wood debris (Plates 55, 56, 57) were some of the underestimated loads. The large tree trunks blocked the barrage as the gates were too narrow to let the wood debris pass through them. As a result, the entire barrage became clogged by the sediment and wood debris. It acted as a large dam and the flood started overflowing the raised gates (Plates 57 and 58). In this process, the eastern and western guide bunds were washed away. The flood and debris destroyed the control tower on the eastern bank at 5:30 a.m. (Plate 59) and washed away the settlements and cultivated land downstream (Plate 60).

The sediment sluices were buried by the sediment, being unable to carry away the bed load. As there were no sediment ejectors, a lot of sand and gravel was deposited in the canals (Plate 59). Neither were there any log-catching structures upstream. The western sediment sluice contained less sediment than the eastern one, indicating uneven flow of the bed load.

Such factors as the damming effect of the barrage by wood and sediment debris and subsequent backwater flow, as well as the morphology and size of underwater channel bars and other larger bed forms, should be taken into consideration in estimating the peak discharge. It is extremely difficult to assess the exact slope of the channel floor and the amount of bed load at the time of high flood. It is important to notice that, after the flood, there was a large amount of sediment load on the gates (Table 2.5). The preliminary calculations showed that more than 20 per cent of the total gate outlet area was covered by debris.

Table 2.5: Siltation of the Bagmati Barrage after the Flood of July 21, 1993

Gate No	Depth of sediment, m
7	2.04
8	2.76
9	3.02
10	3.19
11	3.52
12	3.66
13	3.47
14	3.63
15	4.02
16	3.73
17	3.62
18	3.69
19	3.16
20	3.21
21	3.12
22	2.45
23	2.13
24	2.30
25	3.16
26	2.75
27	1.33
28	1.50
29	1.65
30	1.00

Damage to the Kulekhani Penstock Pipe

The Kulekhani penstock pipe was damaged by the debris torrent from the Jurikhet *Khola* (Plate 61) at 21:40 on July 19. The damage amounted to about 200 million rupees of equipment. The Jurikhet *Khola* is a tributary to the Mandu *Khola*, whereas the Mandu *Khola* itself joins with the Bhimphedi *Khola*.

The penstock bridge over the Jurikhet *Khola* was very low. There were heavy bank protection and debris retention structures (retaining walls) in the stream, most of which were also washed away. The huge amount of debris was derived from a large landslide upstream. The outflowing water from the destroyed pipe was insignificant in comparison to the debris torrent from the Jurikhet *Khola*.

Damage to the Kulekhani I

Tailrace Tunnel and Intake of Kulekhani II

The portal of the Kulekhani I tailrace tunnel and the intake of the Kulekhani II are located in the Mandu *Khola* (Plate 62). During the night of July 19-20, cloudburst in the catchment of the Mandu *Khola* (around the village of Aghor) and the Bhimphedi *Khola* (around Chisapani) gave rise to debris torrents in the streams. The result was severe damage to the tailrace tunnel and intake site at the Mandu *Khola* and to the road, settlements, and cultivated land downstream. The village of Mandu was almost completely destroyed by landslides. A mother and her child were buried in a landslide and rescued after 24 hours.

A 15 m long and 10 m high 'Indreni' boulder of granite (Plate 63) was lying about 25m upstream from the intake canal of the Kulekhani II, hence it did not contribute directly to the destruction. Other old boulders of smaller dimensions (6-10 m long) were observed on the terraces downstream, indicating similar debris flow in the past.

The road between Bhainse and Bhimphedi was almost completely washed away and numerous landslides occurred on the slopes.

Damage by the Manohari Khola

The Manohari *Khola* (Plate 65) breached the dykes about 150 m downstream from the bridge on the East-West Highway and entered into the cultivated land of the Chitwan Valley.

Further downstream, the Burhi Rapti *Khola* also shifted its course, resulting in extensive damage to villages and cultivated land.

Conclusions

The number of landslides and the extent of inundation during the rainstorm from July 19-21, 1993, were extraordinarily high for that region. There were more than 2,000 landslides along the Tribhuvan Highway alone. Apart from heavy rainfall; inadequate design of the barrage; inappropriate location of the powerhouse and the penstock; as well as deforestation; steep slope cultivation and encroachment on to highly hazardous areas were other factors leading to the heavy loss of infrastructure, lives, and property. On the other hand, the Kulekhani Dam acted as a retention structure and played a positive role during that event. Steep rock slopes followed by a flat valley provided ideal conditions for the occurrence of debris torrents and flash floods. Floods and torrents led to the forming of alluvial fans. Some of the alluvial fans seem to be active from time to time. For example, the debris flow in the Kitini Khola alluvial fan also occurred about 41 and 78 years ago.

In the hills of the country, natural slopes have been modified by the people without sound knowledge of their stability. In other instances, infrastructures have been designed without taking the extent and power of natural processes into account. Hence, it is clear that the extensive damage was exacerbated by them.