Factors Controlling Landslides

About 90 per cent of landslides take place during the monsoon or winter rains in the Northwestern Himalayas. In addition to other landslide destabilising factors, the rains play a vital role in triggering most of the landslides in the Himalayas. From south to north, the Indian Himalayas can be divided into different climatic zones, for example, the tropical, sub-tropical, sub-temperate, semi-arid, and arid zones. The precipitation pattern also varies across these climatic zones. Monsoon precipitation is largely received south of the Higher Himalayas and rainfall may vary from 150mm to 300mm, depending upon the local topography and location. The Himalayan region, e.g., Ladakh and Spiti, lying north of the Higher Himalayan ranges, has an arid to semi-arid climate and receives less than 50mm of monsoon rains. The winter rains that bring snow at higher altitudes are more pronounced in the western than in the eastern Himalayas.

Monsoon Rains and Landslides

On 18th September 1880, a large debris avalanche, including slide material, killed 143 persons in the upper part of Nainital town. It swept the Victoria hotel, some buildings, and the Naina Devi temple into Nainital Lake. This disastrous event took about half a minute and was preceded by several hours of incessantly heavy rain (260-290mm). Prior to this catastrophic event, the development of a 1.25km long crack on the slate-marl succession of Sher-Ka-Danda was observed in 1867 (Middlemiss 1910). On 17th August, 1899, in another event following incessant rain, an enormous mass of infrakrol slates slumped down into the Balia stream, burying a brewery settlement near Nainital.

The road system in Sikkim and the Darjeeling Hills has suffered extensive damage in the past and is still prone to landslides, subsidence, lateral mass movements, and toe erosion. Heavy rains were the principal contributing factor to landslides and mass movement in 1911, 1914, 1968, and 1973. The whole area experiences heavy rainfall, varying from 3,000mm to 6,000mm per year. Also, there are frequent cloudbursts when the intensity of the rainfall is as high as 600mm in a day and, at times, 200mm for a period of two to four hours. The precipitation during cyclonic storms is in the order of 500mm to 600mm per day, and a cyclonic storm continues for two to three days (Soin 1980). The rainfall recorded from 2nd to 4th October 1968 and 11th to 13th October 1973 was 403mm and 461mm respectively.

Types of Damage and Their Causes

Surface sheet erosion is caused by high-intensity short-duration rainfall on steep slopes comprised of weathered and foliated rocks which are already oversaturated. Gully erosion is caused by the inability of natural channels to cope with heavy discharge resulting from high-intensity precipitation and cloudbursts. Soil mass movement involving the flow of loose soil strata is facilitated through percolation of rainwater and can also be triggered by toe erosion. The rock strata, with joints, folds, and unfavourable dip conditions, activated by percolation of water through the weak planes, causes rockfall. Erosion at the toe of the road, slopes, retaining walls, and toe walls is caused by scouring and further facilitated by heavy rainfall. Toe erosion also causes landslides, and it is aggravated where a meandering river hits the base of the hill slope. In the landslip zone, the subsidence observed is caused by the movement of underlying strata by subsoil flow/runoff.

Remedial Measures

Surface/sheet erosion is treated through good surface drainage and compacting of the soil on the slopes. Catchwater drains, surface drains, turfing, benching of slopes, chemical stabilisation, bituminous mulching, and afforestation have been found to be successful means of arresting landslides.

Gully erosion is controlled through catchwater drains, checkdams, check walls, and drop channels. The walls and drains are founded on unerodable strata, and the drain floor is made impervious.

Mass movement of soil in wet conditions is prevented by constructing retaining structures, surface drains on the strata, catchwater drains, and benching to ease the slopes.

The effect of rockfall is reduced by removing the overburden and overhanging rocks. Easing of slopes has been found to be effective, and breast walls have worked where the overburden is not high. Subsidence has been controlled using deep drains, benching slopes, side drains, and formation filling.

Case History of the Naina Devi Landslide in Himachal Pradesh

The Naina Devi temple, an important Hindu pilgrimage site, and the town of Nainital are situated in one of the Siwalik ranges in Bilaspur district, Himachal Pradesh. The temple is located on the highest peak of the Naina Devi *Dhar* (range) and the town is built on the southwestern slopes. The ridge is separated by a saddle, and to the south of saddle lies a broad valley in which houses are located.

Raju and Jalote (1980) reported the Naina Devi landslide. It rained excessively during the monsoon of 1978. A crack was observed in the floor of the temple warehouse on 1st August 1978, following heavy rains on the previous day. On the following days, a number of cracks were observed in the surrounding areas, including the bus stand. Subsidence or vertical displacement of from 15cm to 30cm was observed on 6th August, and an appreciable widening of the cracks was observed on the following days. The lower spur in the valley, adjacent to a small stream, is reported to have slid on 24th August, following heavy rains. This slide damaged the houses located on the spur and blocked the stream's course. On the morning of the 25th, a widening of the fissures at the bus stand was noticed and the ground mass started moving, slowly threatening the structures. All inhabitants abandoned their houses and moved to safer places in the town. The downward movement of the ground started at seven a.m and, in a span of two hours, the whole mass of debris, 143 structures belonging to 46 families, and a portion of the road and some portions of the steps to the temple were carried down the slope over a distance of 150m.

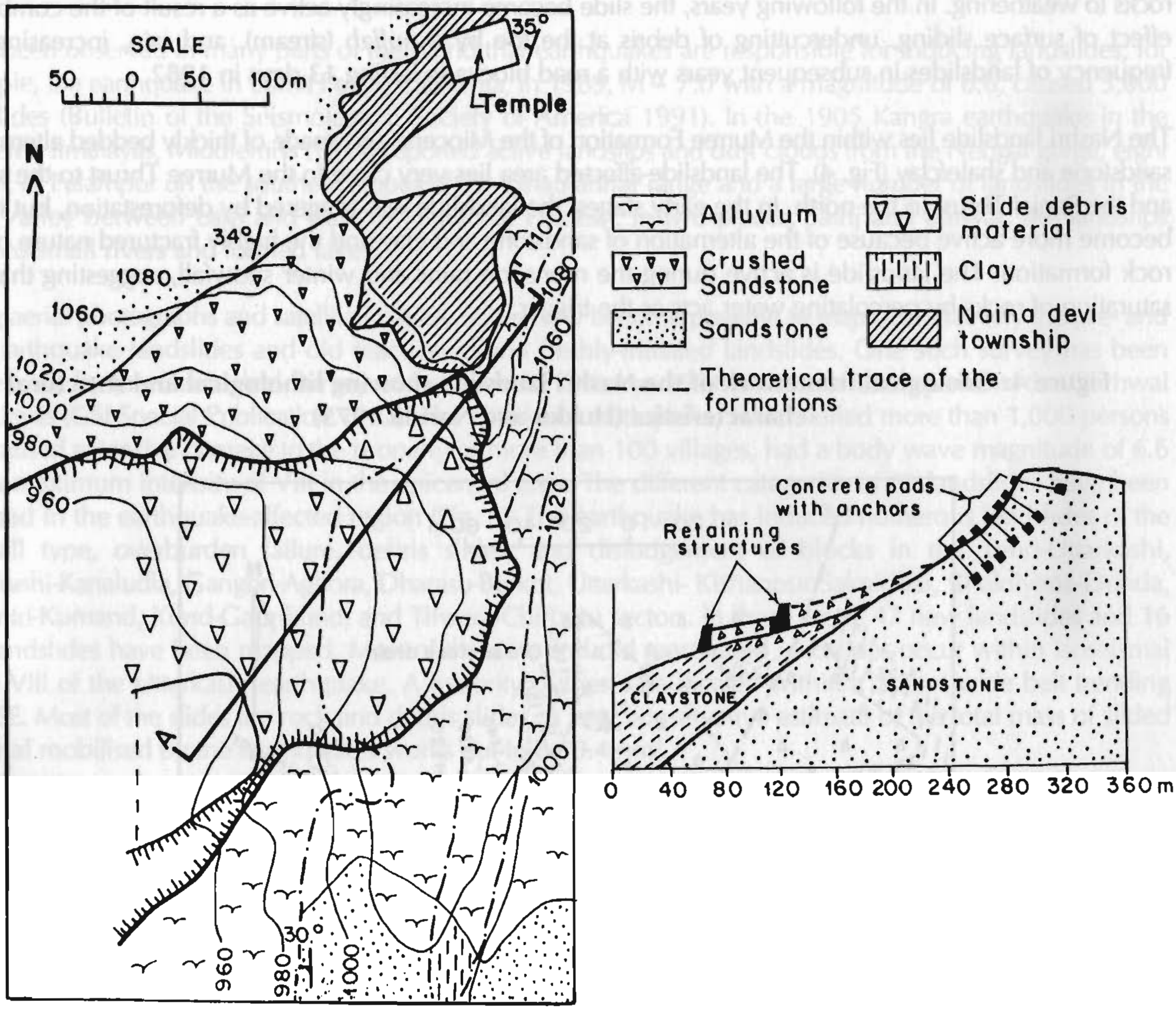
The Naina Devi range, where the temple and town are located, is a linear hill range constituting the southwestern limb of an anticline. The Lower Siwalik formations, comprised of sandstone and claystone, occur on the ridge. The length of the area affected by the slide is 880m and the width is 480m. The slide material is mainly composed of sandstone debris of various sizes, embedded in sandy soil overlying purple claystone. The claystone dips towards the valley at angles ranging from 30° to 35° (Fig. 3). The whole village and the bus stand were originally constructed on this overburden. The area has been stable for a very long time. The landslide was a result of the unprecedented heavy rains that oversaturated the overburden material, resulting in increased weight and porewater pressure and reducing the cohesion and shear strength of the material, especially at the interface of the claystone and overburden.

Remedial measures were suggested by the Geological Survey of India (GSI) team (Fig. 3) in order to stabilise an area of over 20,000sq.m. Retaining structures at locations shown in the figure, with weep holes to allow seepage, were suggested. On steep slopes, where circular failure had occurred in fractured and weathered sandstone, concrete pads with suitable anchors into massive sandstone were suggested. The easing of the slopes, small retaining walls, and proper drainage were recommended for the eastern slopes.

Deforestation and Landslides

Tree roots play an important structural role on hill slopes. The roots, winding through the soil and often penetrating bedrock, add strength to the soil in the same way that steel rods reinforce concrete. When trees

Figure 3: Geological setting of the Naina Devi landslide (upper figure) and remedial measures (lower figure) (Krishnaswamy 1980)



are felled, these roots begin to decay; the hill slope gradually loses its resistance to failure, resulting in landslides. Studies in the Western Cascade Range of Oregon, USA, on clear-felled, unstable, and steep hill slopes, revealed that landslide erosion was 2.8 times greater on such slopes than on comparable forested land (Haigh 1984).

It is estimated, on the basis of satellite imagery, that Uttarakhand, the area covering the hill districts (Kumaon and Garhwal) of Uttar Pradesh, has only 37.5 per cent of its area under forest cover. The deforestation of Uttarakhand has occurred very rapidly in the last five decades, finally reaching alarming proportions and giving birth to the *Chipko* Movement; a movement of the people to save the forests. Deforestation in the Uttar Pradesh Himalayas has also increased floods in the Gangetic plains.

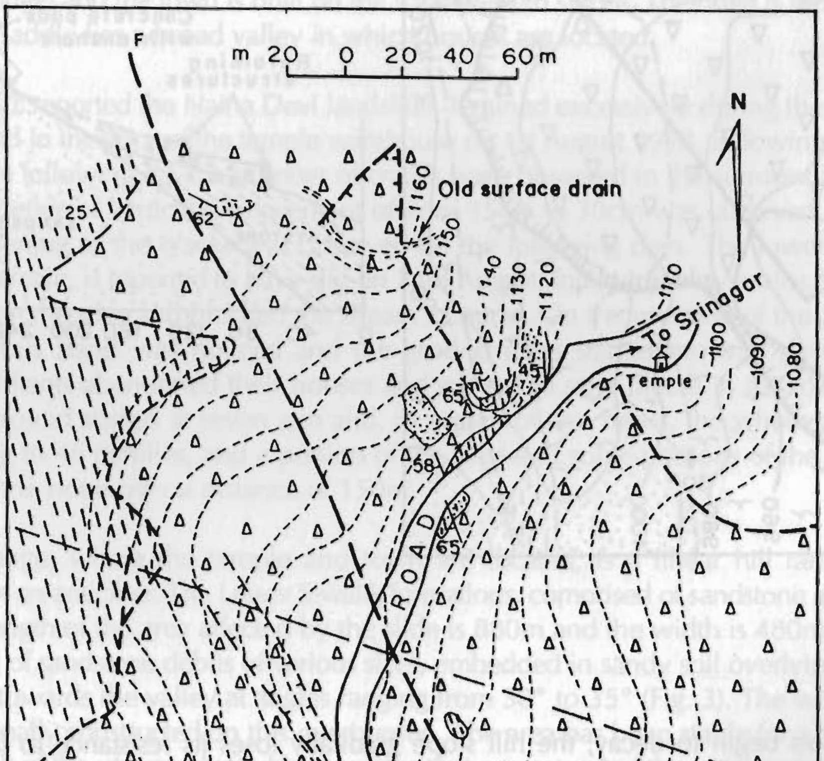
Road construction has been another conspicuous contributor to deforestation, causing massive landslide problems. New hill roads have been built quickly and cheaply across uncharted territory, ancient landslide zones, and active scree slopes. Explosives have been used liberally, and these have opened up fissures in the fractured rock slopes.

Case History of Nashri Landslide

The Nashri landslide is situated 131km from Jammu on the Jammu-Srinagar national highway. This slide has been a major problem for the last 40 years, obstructing vehicular traffic during the monsoon and winter rains. The slide covers an area 400m wide along the road and 1,000m long along the slope. The landslide started in 1953 as a small scar below the road, after a jungle fire destroyed its protective vegetative cover and exposed rocks to weathering. In the following years, the slide became increasingly active as a result of the combined effect of surface sliding, undercutting of debris at the toe by a *nullah* (stream), and rain, increasing the frequency of landslides in subsequent years with a road blockade lasting 13 days in 1982.

The Nashri landslide lies within the Murree Formation of the Miocene age, made of thickly bedded alternating sandstone and shale/clay (Fig. 4). The landslide-affected area lies very close to the Murree Thrust to the south and the Panjal Thrust to the north. In the early stages, the landslide was triggered by deforestation, but it has become more active because of the alternation of sandstone and clay and the highly fractured nature of the rock formation. The landslide is active during the monsoon rains and winter snowfall, suggesting that the saturation of rocks by percolating water acts as the trigger.

Figure 4: Geological framework of the Nashri landslide showing lithological and structural characteristics (Hukku and Narula 1975)



The Central Road Research Institute (CRRI) investigated this slide in June-July 1983, at the request of the Border Road Organisation. The various remedial measures suggested after the investigation include augmentation of surface drainage by constructing a system of catchwater drains, trench drains, chutes, and intercepting drains besides biotechnical stabilisation and installing concrete restraining piles (Fig. 5).

Earthquakes and Landslides

It has been observed in many parts of the world that earthquakes are responsible for inducing landslides; for example, the earthquake in Loma Prieta, California, in 1989, M= 7.0 with a magnitude of 6.6, caused 3,000 landslides (Bulletin of the Seismological Society of America 1991). In the 1905 Kangra earthquake in the Western Himalayas, Middlemiss (1910) reported active landslips and dust clouds from the Neogal gorge, eight km NE of Palampur on the southern slopes of the Dhauladhar range and a large number of landslides in the Beas Valley between Larji and Kulu in Himachal Pradesh. In two places, Sainj and Barwar, the landslips blocked small rivers and formed lakes.

Using aerial photographs and satellite imagery, it has now become possible to map quantitatively the pre- and post-earthquake landslides and old reactivated and freshly-initiated landslides. One such survey has been carried out by the Geological Survey of India for the October 1991 Uttarkashi earthquake in the Garhwal Himalayas (GSI Special Publication 1992). The Uttarkashi earthquake, which killed more than 1,000 persons and caused extensive damage to the property of more than 100 villages, had a body wave magnitude of 6.6 and a maximum intensity of VIII in the epicentral area. The different categories of 63 landslides have been mapped in the earthquake-affected region (Fig. 6). The earthquake has induced numerous landslides of the rockfall type, overburden failure, debris slides, and dislodgement of blocks in the Tehri-Uttarkashi, Uttarkashi-Kanaludia, Gangori-Aghora, Dharasu-Burkot, Uttarkashi- Kishanpur Saknidhar, Bhaldiyana-Dunda, Phauntri-Kumand, Kund-Gaurikund, and Tilwara-Chirbutu sectors. In these areas, 47 new landslides and 16 old landslides have been mapped. Most of the new and old reactivated landslides occur within isoseismal Zone VIII of the Uttarkashi earthquake. A majority of these are located within a 2.5km wide belt trending NW-SE. Most of the slides are rock and debris slides. A very conservative estimate of the total mass of slided material mobilised by the earthquakes works out to be $0.4mm^3$.

Geology and Landslides

Lithology and structural characteristics are the two main factors in geology which influence landslides. Lithology means rock type and structural characteristics include geometry and the mechanical properties of joints, bedding planes, faults, and folds. Laban (1979), following an airborne reconnaissance survey of Nepal, concluded that geological structure and lithology accounted for more than 75 per cent of all observed landslides. A similar conclusion was arrived at in part of the Garhwal Himalayas by Joshi (1987). Haigh (1984) observed that instability along the roads in the Garhwal Himalayas was influenced by joints and bedding planes dipping out of slopes. Based on his own study in the Middle Himalayas in Nepal and on reviewing the findings of other workers, Gerrard (1994) concluded that geology and human activities play a considerable role in triggering landslides in the Himalayas.

In the Himalayas, the Main Central Thrust, Main Boundary Thrust, and Himalayan Frontal Thrust are the principal thrust faults which are neotectonically active. All these thrust zones have a predominant influence on landsliding and many of the larger and catastrophic landslides are associated with movements along these thrusts (Nakata 1982, Valdiya 1985).

According to Bartarya and Valdiya (1989), lithology is the most important factor governing landslides in the Gaula catchment area of Nainital in the Kumaon Himalayas, but the localisation of landslides within lithologies is the result of fractures, shear zones, and dip of the beds. In their (Bartarya and Valdiya's) study area, the granites, quartzites, and basic volcanics are most prone to landsliding. The volcanic rocks and quartzite of the Bhowali and Blaini formations have caused 189 landslides; the Amritpur granite, 108 landslides; and the sandstone of the Siwaliks and schist of the Ramgarh Group, 49 landslides. Landslide density also varies with respect to geological formations, e.g., the Amritpur granite has the greatest density of landslides ($2.6/km^2$), followed by the Infrakrol Formation ($2.33/km^2$), the Bhowali quartzite ($1.58/km^2$), and the Siwalik Group ($1.12/km^2$).

Figure 5: Control measures adopted for the Nashri landslide

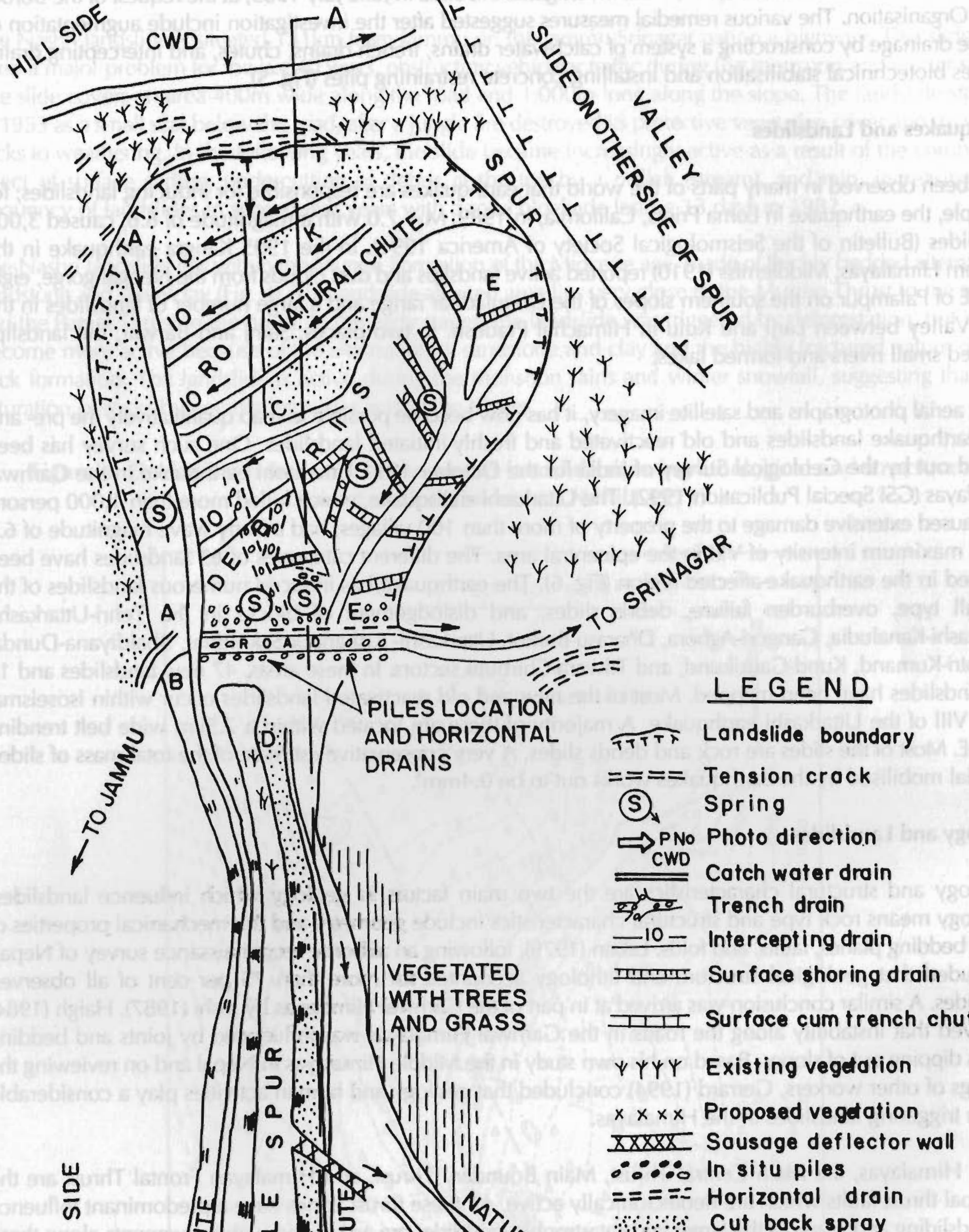
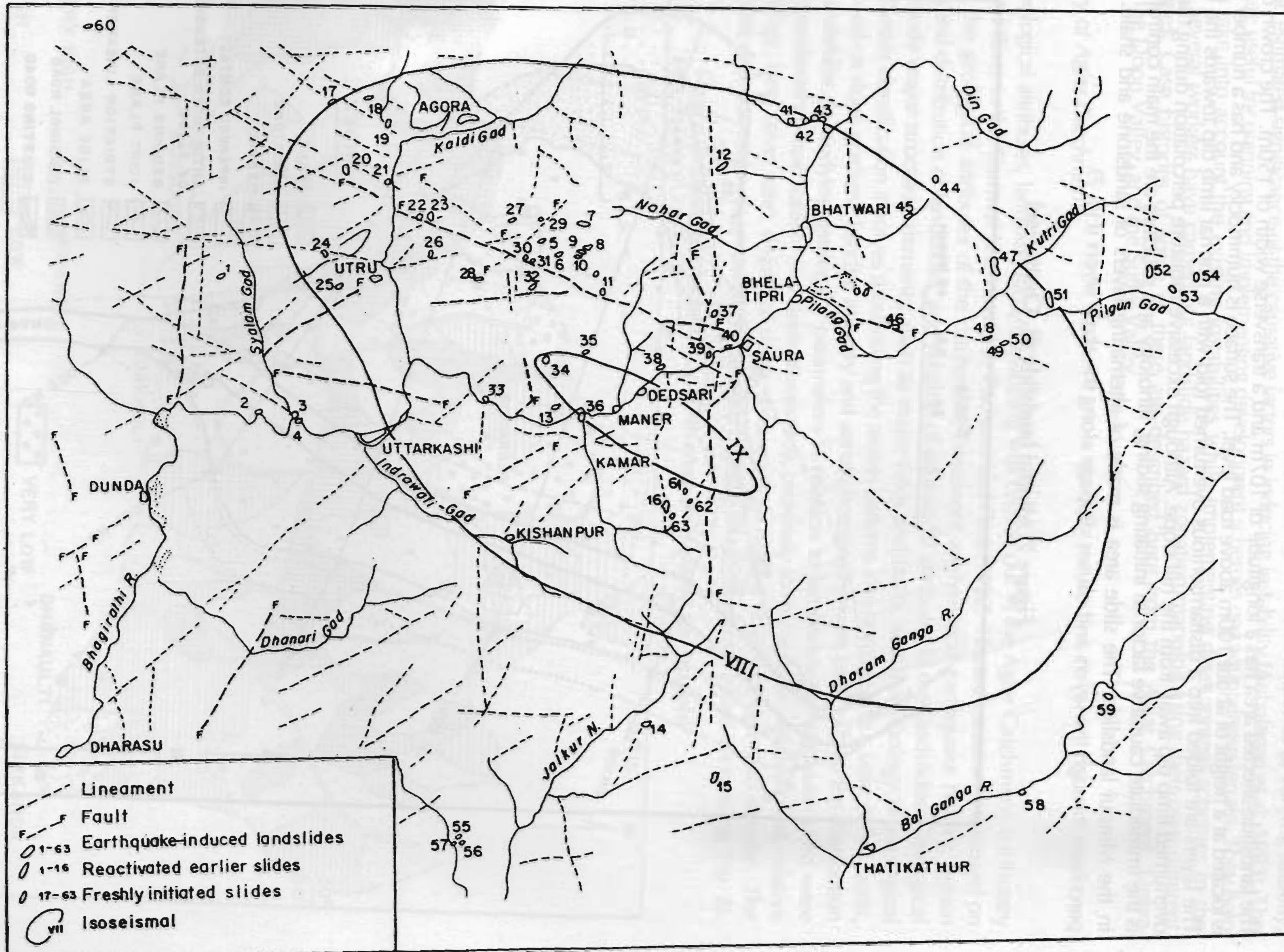


Figure 6: Map showiong October 1991 Uttarkashi earthquake-induced landslides based on pre- and post-earthquake IRS list II FFC imagery and aerial photographs (October 1991 Uttarkashi earthquake, Geological Survey of India 1992)



The Minpui slide is located at milestone 23 on the Lungleh - Tuipang road in Mizoram in the NE region. The landslide was triggered during five days of 140mm of heavy monsoon rains and was preceded by a severe earth tremor (Chatterjee 1975). The slide is activated during the monsoon months.

The landslide-affected area has a longitude of 107m and a transverse width of 150m. The crown of the slide is located at a height of about 100m above road level. The surface is hummocky and has a number of terraces. The layers are folded into a disharmonious overturned fold with a normal limb dip towards the hill and an overturned limb dip away from the hill slope. Although excessive moisture percolation during the monsoon is the immediate causative factor in initiating sliding, lithology and structure are the main controlling factors in the Minpui landslide. The slide area is made of alternating layers of sandstone and shale. Rainwater percolates through the layers and causes slippage along the shale layers (Fig. 7).

Figure 7: Minpui landslide (B. Chatterjee)