The Landslide Issue

Description and Types

The word landslide is used to denote the movement of earth or displaced mass (Lundgren 1986). Various movements of earth are designated in different terms by different authors, for example, rockfall, earth flow, slip, mass movement, subsidence, and so on. They can all be grouped as landslides (Fig. 3a - g).

Zaruba and Mencl (1969) broadly classify landslides as 'recent', 'ancient', and 'fossil' on the basis of their ages. Similarly, slopes have been classified as 'active' or 'inactive' depending on the evidence of movement within the last seasonal cycle. Blyth and deFreitas (1984) point out that landslides or slope movement can occur in the following ways, either separately or together.

i) By detachment of rock as rockfalls and topples
ii) By shear failure on existing large-scale geological surfaces
iii) By shear failure of rock and soil materials often using weak horizons
iv) By gradual adjustments on a microscopic scale as in creep

Figure 1: Road Map of Northern Pakistan

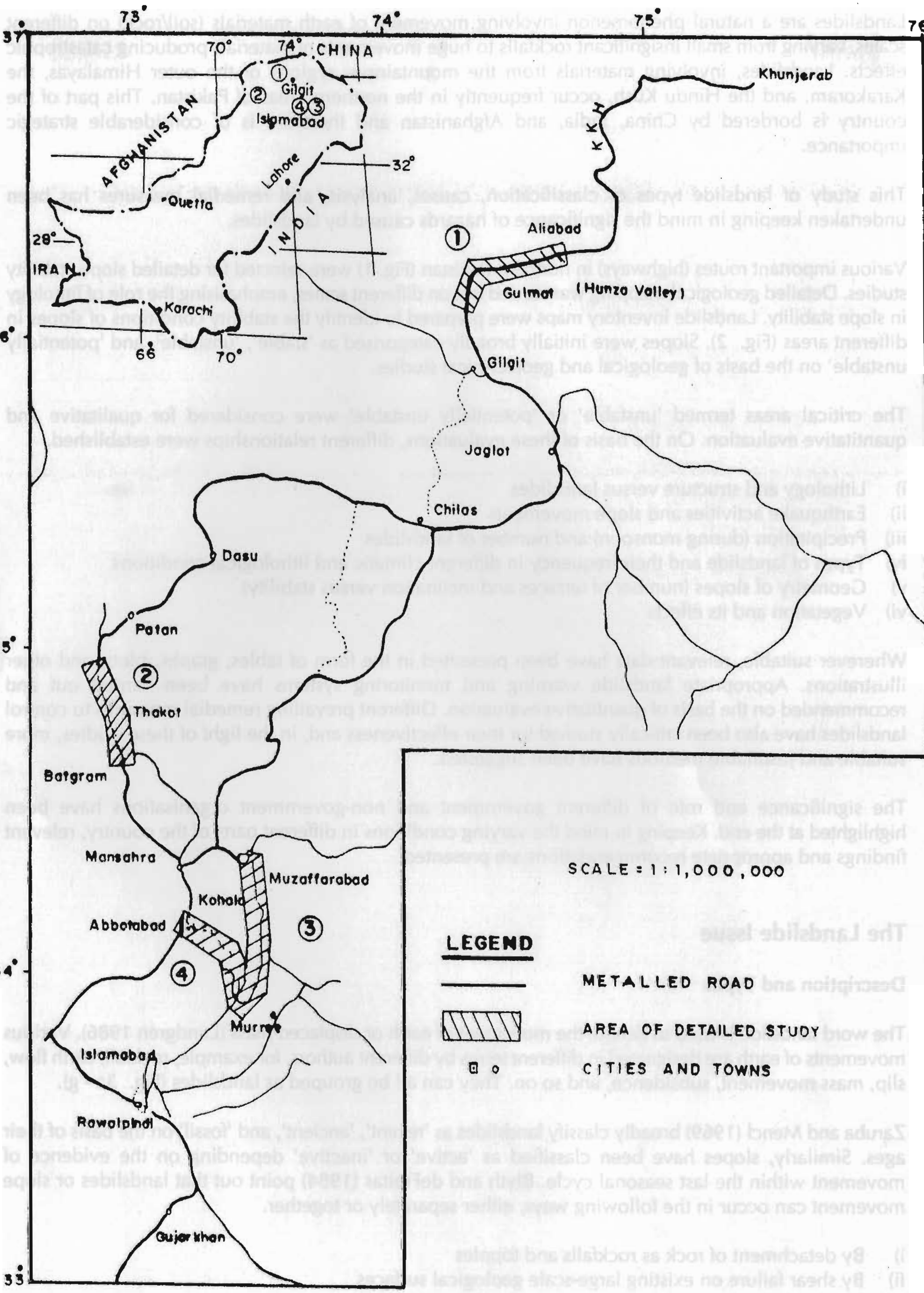


Figure 2: Geological Map of Kohala-Muzaffarabad Area (Kohala to Dulai) Showing Landslide Risk Zones

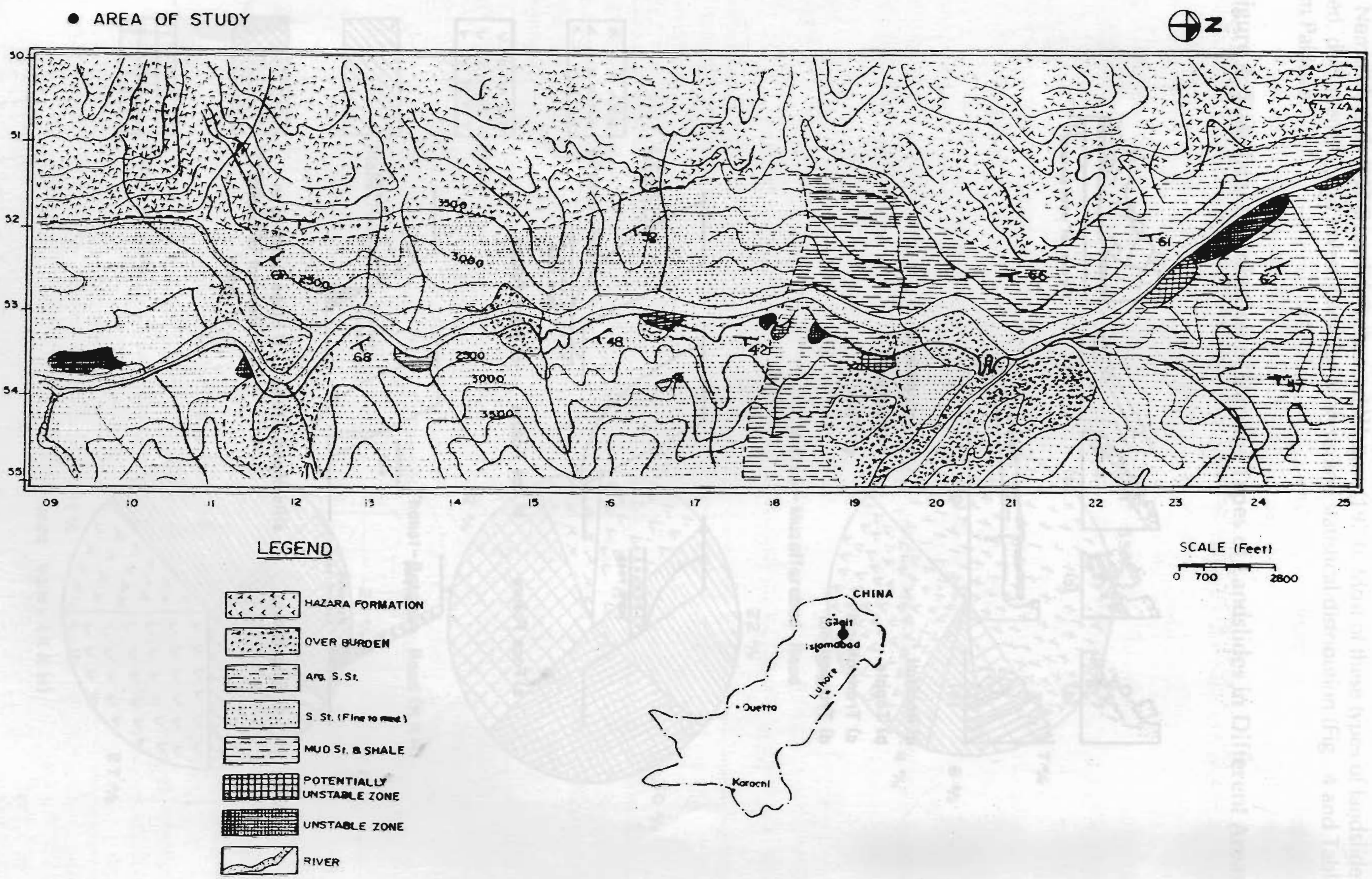
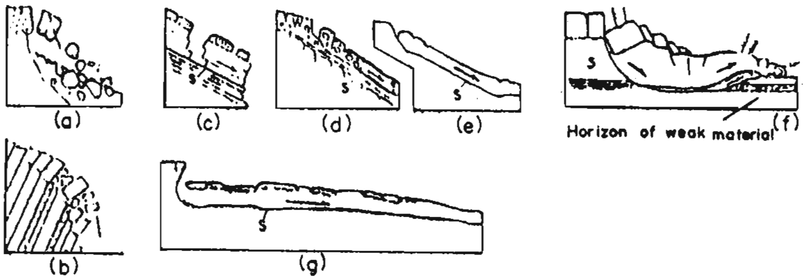
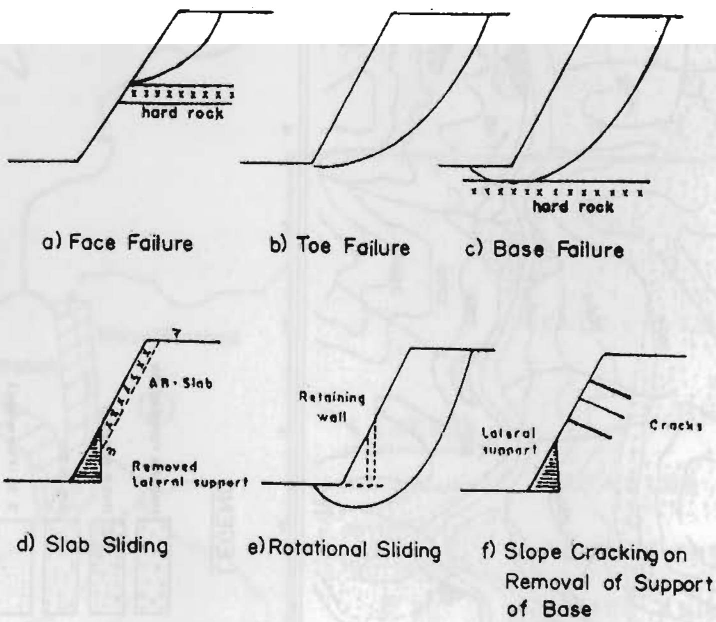


Figure 3: Different Types of Landslides and Slope Failures



a) Rockfall
b) Topple
c) Translational
d) Translational
e) Translational
f) Rotational
g) Flow



Six basic types of slope movement, i.e., falls, topples, slides (translational and rotational), lateral spreads, flows, and complex (combination of two or more principal types of movement) have been referred to by Varnes (1978). This classification is most commonly used (Table 1) and is based on Sharpe (1938), supplemented by other sources Zischinsky (1966), Zaruba and Mencl (1969), Skempton and Hutchinson (1969), Nemcock et al. (1972), and deFreitas and Watters (1973). Most of these types of landslides were identified, documented, and investigated for analysis and statistical distribution (Fig. 4 and Table 2) in northern Pakistan.

Figure 4: Statistical Distribution of Various Types of Landslides in Different Areas

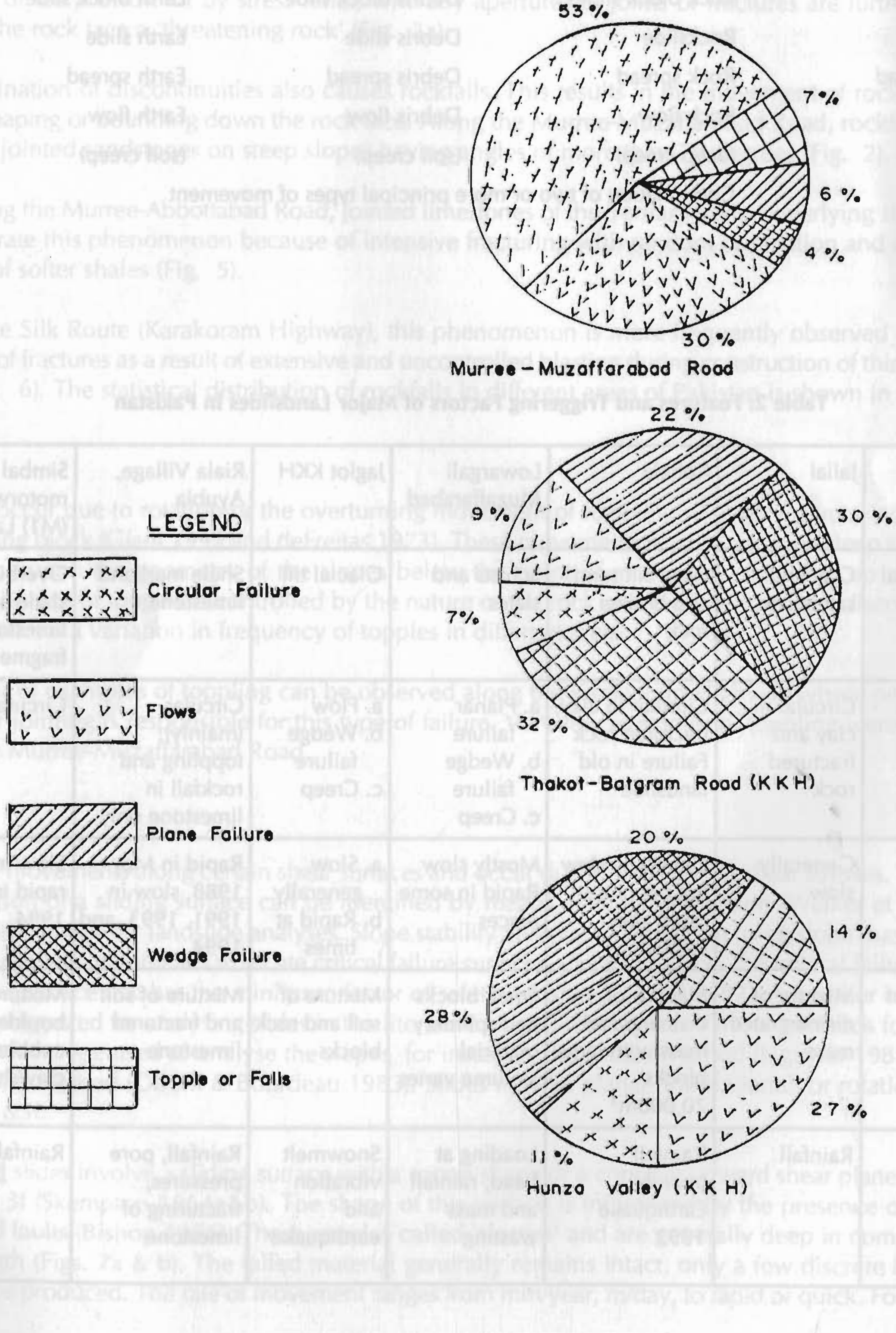


Table 1: Abbreviated Classification of Landslides (After Varnes 1978)

Type of movement	Bedrock	Predominantly coarse	Type of material (Unconsolidated material predominantly fine)
Falls	Rockfalls	Debris fall	Earth fall
Topples	Rock topple	Debris topple	Earth topple
Slides:			
Rotational	Rock slump	Debris slump	Earth slump
Translational	Rock block slides	Debris block slide	Earth block slide
	Rockslide	Debris slide	Earth slide
Lateral spread	Rock spread	Debris spread	Earth spread
Flows	Rock flow	Debris flow	Earth flow
	(deep creep)	(soil creep)	(soil creep)
Complex	Combination of two or more principal types of movement		

Table 2: Features and Triggering Factors of Major Landslides in Pakistan

Features	Jalial	Kohala	Lowargali Muzaffarabad	Jaglot KKH	Riala Village, Ayubia	Simbal motorway (M1) Lahore
Slide material	Clay and sandstone	Clay, silt sand and broken rock	Schists and slates	Glacial till	Shale marl and limestone	Overburden of shale and limestone fragments
Slip surface	Circular in clay and fractured rock	Circular in clay, fractured rock Failure in old landslide	a. Planar failure b. Wedge failure c. Creep	a. Flow b. Wedge failure c. Creep	Circular (mainly), toppling and rockfall in limestone only	Circular
Rate of movement	Generally slow	Generally slow but becomes rapid after rainfall	Mostly slow Rapid in some places	a. Slow generally b. Rapid at times	Rapid in May 1988, slow in 1991, 1993, and 1994	Slow in 1993, rapid in Aug. 1994
Behaviour of mass movement Volume displaced	Mixture of disintegrated mass	Mixture of disintegrated mass with large blocks 70,000m^3	Small blocks and splintery material Volume varies	Mixture of soil and rock blocks	Mixture of soil and fractured limestone	Mixture of boulders, cobbles, and clay/shale
Triggering factors	Rainfall	Rainfall (mainly) Earthquake 1992	Loading at head, rainfall and mass wasting	Snowmelt vibration and earthquake	Rainfall, pore pressures, fracturing of limestone	Rainfall

Brief descriptions of the types of landslide are given below. Figures illustrating the different landslide types are referred in the relevant passages.

Rockfalls

Rockfalls occur due to loss of support, sliding, fracturing, or rotation of small rock units forming a part of the free face. They involve free falling of rock blocks of different sizes detached from rock slopes in the form of rolling or sliding downwards with a velocity of more than 28m/sec. When rock blocks, which are detached but perched on steep slopes, fall, they are categorised as 'secondary falls' (Hutchinson 1988). Rockfalls are small-scale displacements, involving a direct downward movement, resulting from lack of support from below due to differential weathering of softer materials or to physical undercutting of a rock face (Knill 1967). Rock faces marked by vertical or subvertical fractures fall as a result of slab failure due to water or ice pressure or by stress relief, whereby apertures of joints or fractures are further opened leaving the rock face a 'threatening rock' (Fig. 3a).

The inclination of discontinuities also causes rockfalls. This results in the movement of rock debris by freefall leaping or bounding down the rock face. Along the Murree-Muzaffarabad Road, rockfalls mostly occur in jointed sandstones on steep slopes having angles of more than 70 degrees (Fig. 2).

Also along the Murree-Abbottabad Road, jointed limestones of the Tertiary period overlying shales often demonstrate this phenomenon because of intensive fracturing with random orientation and differential erosion of softer shales (Fig. 5).

Along the Silk Route (Karakoram Highway), this phenomenon is more frequently observed due to the opening of fractures as a result of extensive and uncontrolled blasting during construction of this important road (Fig. 6). The statistical distribution of rockfalls in different areas of Pakistan is shown in Figure 4.

Topples

Topples occur due to rotation or the overturning movement of rock (Fig. 3b) on a pivotal point below the toppling block (Giani 1992 and deFreitas 1973). These movements usually occur on steep slopes and, depending upon the geometry of the slopes below the point of movement, may end up as 'falls' or 'slides'. The size of topples is controlled by the nature of the rock and the orientation of discontinuities. Figure 4 shows a variation in frequency of topples in different areas.

A number of examples of toppling can be observed along the Karakoram Highway where near vertical columnar jointing is responsible for this type of failure. Very few examples of toppling were observed along the Murree-Muzaffarabad Road.

Slides

Slides are movements along certain shear surfaces and occur due to unbalanced shear stresses. The shape and position of a sliding surface can be identified by means of site investigation (Walker et al. 1987), which is imperative for landslide analyses. Slope stability analysis is carried out using slope mass strength and pore pressure parameters to locate critical failure surfaces. On a soil slope, the critical failure surface may be the surface that has the minimum factor of safety (Mostyn & Small 1987). A number of methods has been suggested for analysing slides in the literature on soil mechanics. Various methods for locating critical surfaces are used to analyse the slopes, for instance, the Secant Method (Nguyen 1985) and the Probablistic Method (Oboni & Bourdeau 1983). Slides may be planar (translational) or rotational (Figs. 3c,3d,3e &3f).

<u>Rotational</u> slides involve a sliding surface with a spoon shape or a concave upward shear plane as shown in Figure 3f (Skempton 1964a&b). The shape of this surface is influenced by the presence of bedding joints and faults (Bishop 1955). These are also called 'slumps' and are generally deep in comparison to their length (Figs. 7a & b). The failed material generally remains intact, only a few discrete blocks are likely to be produced. The rate of movement ranges from mm/year, m/day, to rapid or quick. For instance,

the rate of movement (54m/day) recorded on 10 August, 1994, at the Simbal Slide in colluvium on Motorway M1 (Lahore to Islamabad) is moderate compared to the Kohala landslide shown in Figure 2, where rapid movements proved hazardous and catastrophic.

Figure 5: Geological and Landslide Inventory Map of Abandoned Road between Khera Gali and Changla Gali (Hazara)

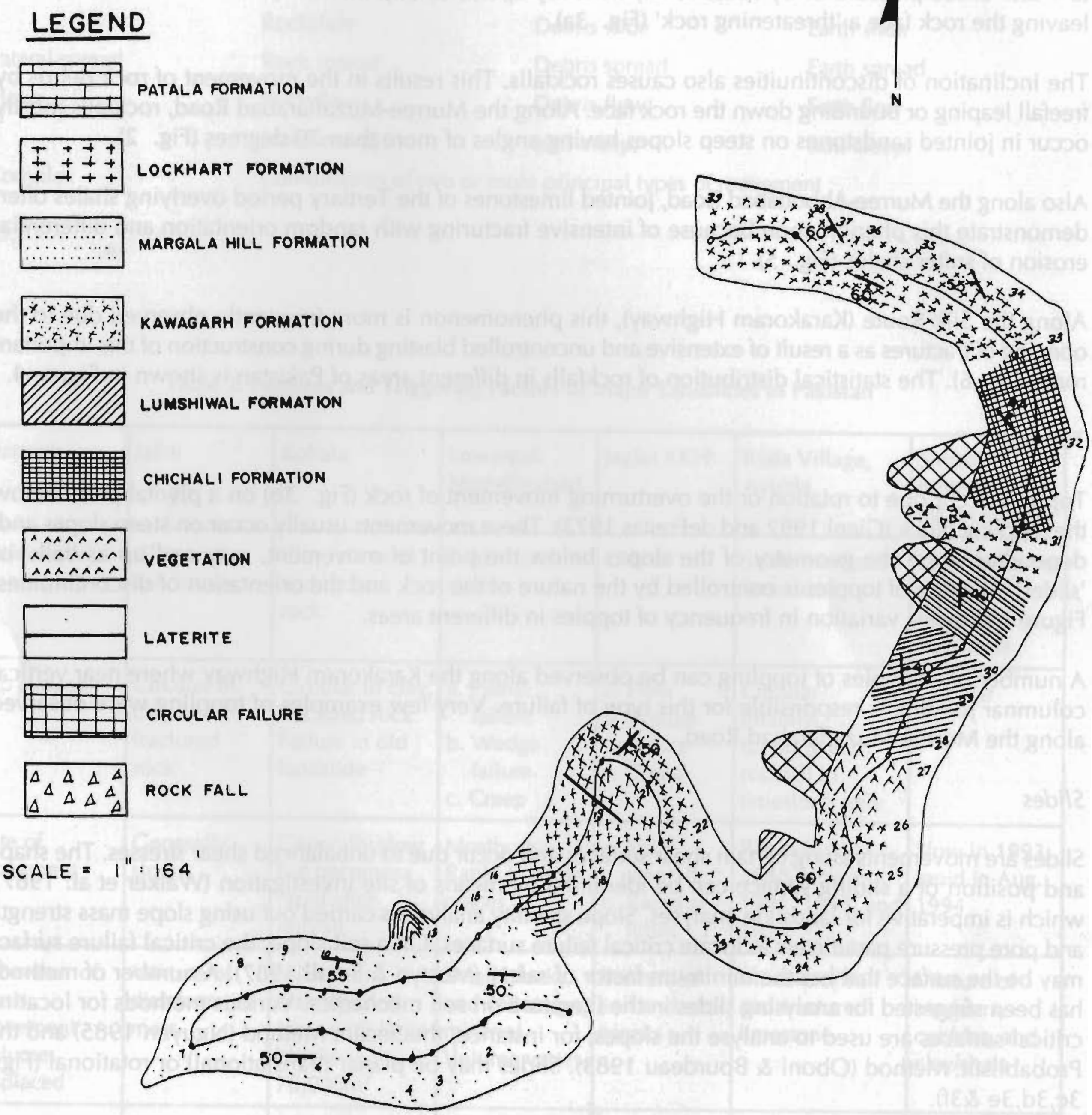


Figure 6: Stability Assessment along part of the Karakoram Highway from Thakot to Batgram (28km) Using the Stereoplotting Technique

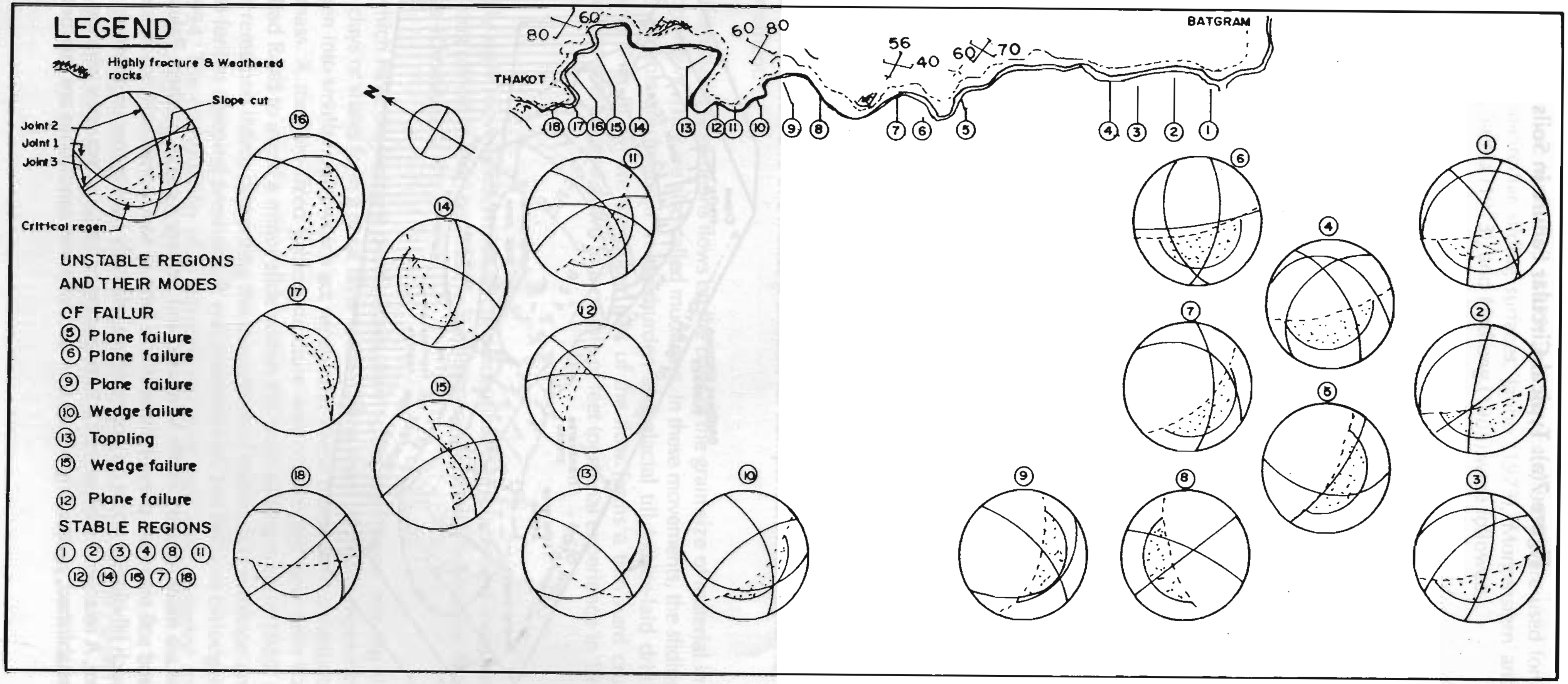


Figure 7(a): Typical Circular Failure in Soils

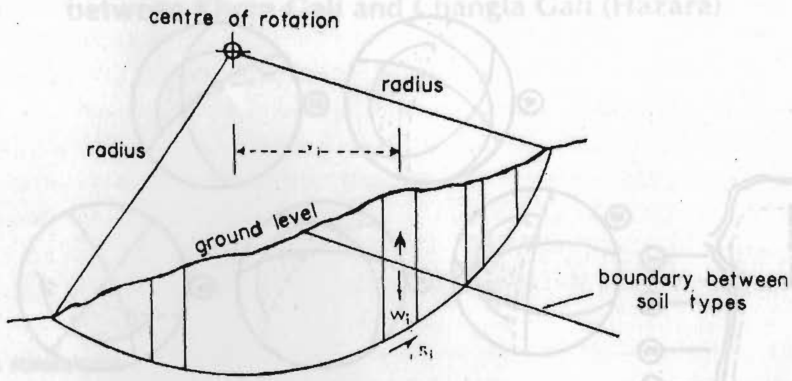
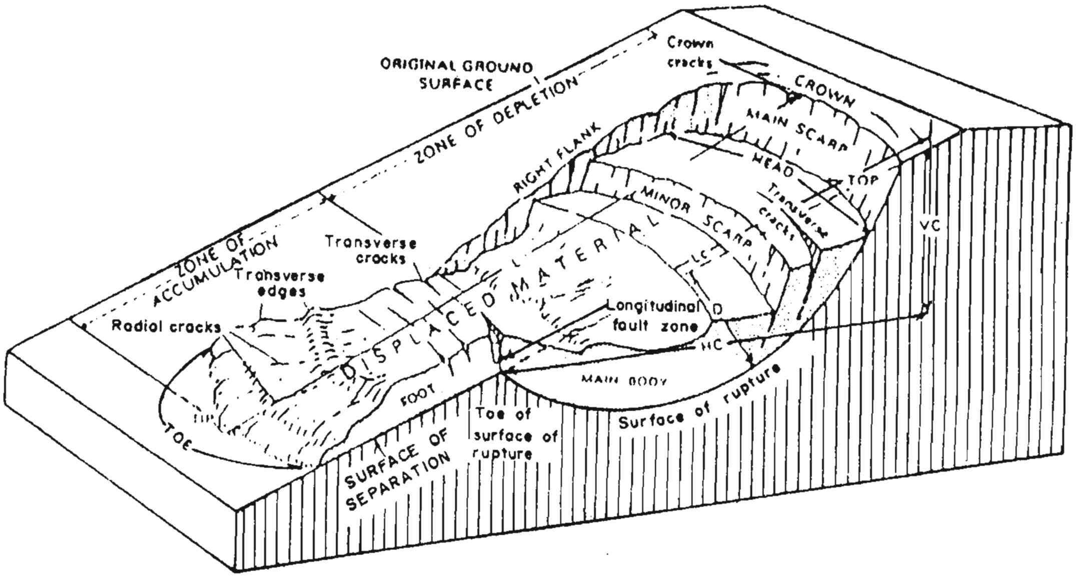


Figure 7(b): Nomenclature Used to Describe Landslides (Varnes 1978)



Rotational slides are more frequent in the Mesozoic and Tertiary rocks of northern Pakistan (Fig. 4) where alternate hard and soft materials prevail either in the form of sandstone/shale or limestone/shale lithologies. Slides in such lithologies occur on slopes where relatively homogeneous materials or closely jointed rocks are present. A relationship between fracture spacing or fracture frequency with the sliding phenomenon has been established, particularly where thin and fractured sandstones are interbedded with shales.

Unit equilibrium methods given by Bishop (1955) and Spencer (1967) were used for circular sliding surface cases, while for non-circular sliding surfaces, Janbu (1973), Morgenstern and Price (1965), Fredlung and Krahn (1977), Sarma (1973), and Fredlung (1984) were followed.

Translational Slides occur when shear failure takes place on a planar surface, or close to bedding planes, joints, faults, or foliation (Hutchinson 1988) and (Morgenstern & Price 1965). These slides were further divided into Plane or Wedge Failures depending upon the discontinuity number and orientation (Hoek and Bray 1981). In northern parts of Pakistan, the frequency of planar or translational slides varies from six to 28 per cent (Figs. 3 & 4).

The effect of pre-existing geological structure as faults or joints is not so prominent in altered, weak, or partly cemented rocks. These may be included in a category known as 'composite slides'.

Debris Slides involve the movement of unconsolidated materials along a bedrock or along more consolidated debris material (Fig. 3g). The movements can lead to a high-velocity flow of rock debris or debris avalanches, which occur more frequently in the upper reaches of the Karakoram Highway than in the rest of the country and which also travel considerable distances. In the lower reaches, i.e., from Mansehra to Thakot (Fig. 1), these slides tend to travel short distances and involve either rockfalls or movement along some discontinuities in the rock.

Flows

This type of movement involves an aspect of flow in unconsolidated materials with low or high rates under saturated or drained conditions. Flows are characteristic features of movement in unstable areas (lying between Kohala and Muzaffarabad) as shown in Figure 2.

Rock Flows refer to displacements due to large or small or even micro-fractures. These movements are usually slow. Flow movements may result in folding, bending, and bulging. It is difficult to assess rock mass parameters in such cases, and this makes it difficult for comparison with numerical results used in other types of movement.

Earth Flows are differentiated from debris flows on the basis of the grain size of material involved, which is finer than in debris flows. They are also called mudflows. In these movements, the sliding surface is not visible. These movements are frequent in overburden and glacial till (or ice-laid drift) near Hunza, Karakoram Highway (Fig. 8), where the upper part of the flow forms a thin hard crust and is very deceptive: a single step gets bogged down to a couple of feet (personal experience in 1974).

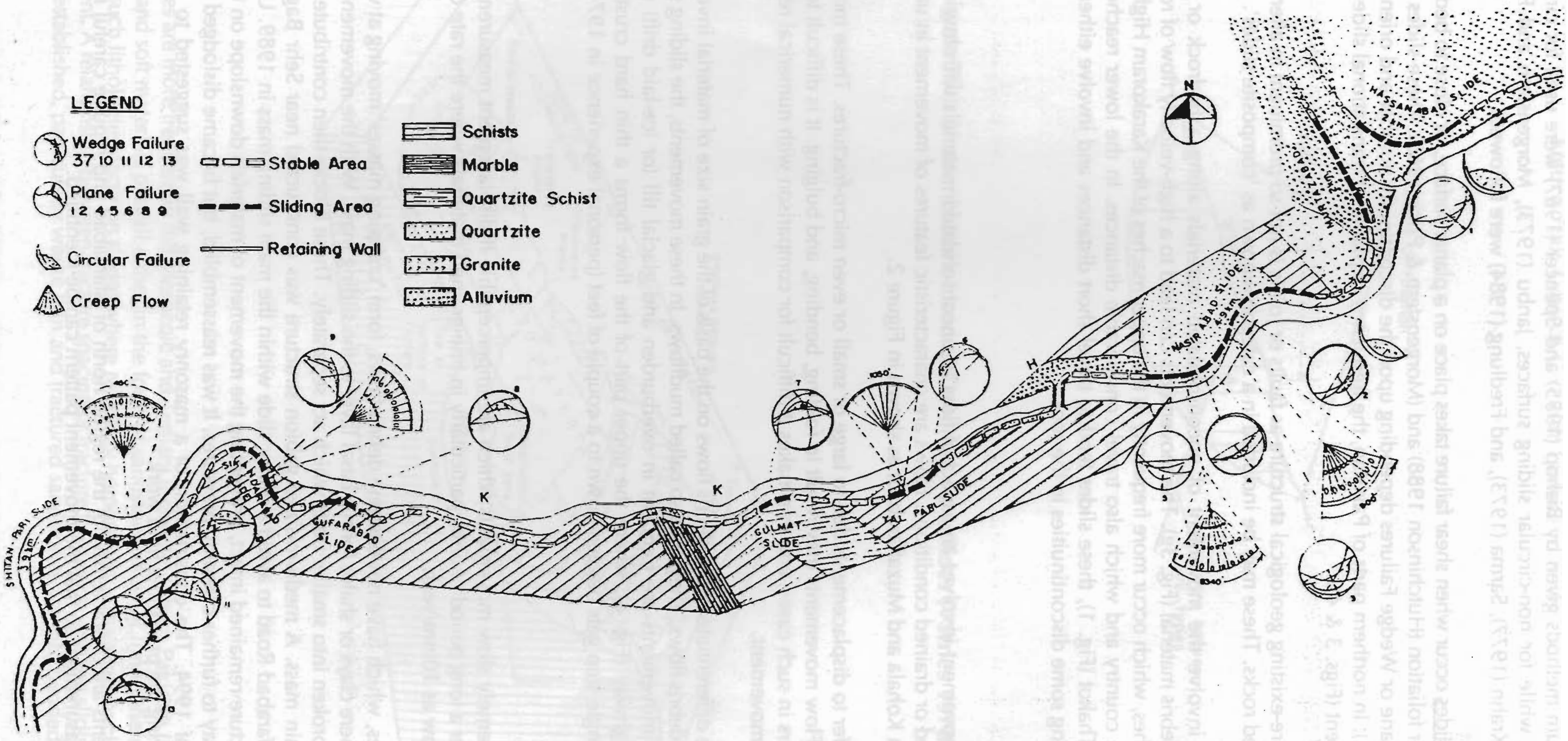
Creep

These are extremely slow movements which are imperceptible if displacement measurements are not carried out over a long period of time, particularly in fine-grained materials where the rate of movement could be as slow as 10mm/year.

Most rockslides, which have not become debris flows, form 'creeping masses' moving at varying rates, particularly where clays or shales form a basal layer to the sliding mass. With the movement, the mass is progressively broken into smaller units which act separately. These blocks then contribute minor slides within the main mass. A medium-sized gabion structure was constructed near Sehr Bagla along the Murree-Muzaffarabad Road to avoid a minor slide within the main sliding mass in 1989. Until October 1993, the structure remained intact, preventing the movement of materials downslope on the highway, then it gave way to further creeping pressures. It was reassembled, but became dislodged again during the summer of 1994. The construction of a masonry retaining wall was suggested to the highway authorities during the prevailing field work.

Such movements are characteristic of the region north of Islamabad and require careful mapping and systematic measurement so that the movement pattern can be identified.

Figure 8: Wedge Failure, Plane Failure, Circular Failure, Creep Flow - Shetan Pari to Aliabad Hunza (65km), Karakoram Highway



Impact of Landslides

The word landslide has been used for a very long time to denote the movement of earth materials varying in origin and magnitude. Landslides also range from near surface disturbances of weathered zones to deep-seated displacements of large rock masses. Their impact, therefore, will depend upon their type, depth of movement, rate of movement, stresses from environments, volume of materials involved, and the proximity of these slides to important structures such as towns, highways, dams, and powerhouses. For instance, movements that are limited to surface layers are generally controlled by stresses produced by surface or near surface environments such as rainfalls or rainstorms and temperature variations, while movements at depth are due to mobilising stresses at depth such as earthquakes and so on. The movements and their effects, therefore, range from slow displacement such as 'creep' to rapid and large catastrophic slides such as the Vajont slide in Italy in 1963, the Jaglot landslide on the Karakoram Highway, the Kohala landslide along the Murree-Kashmir Road, the Riala (Ayubia) landslide in 1988, the landslide near the Powerhouse of the Tarbela Dam, and the Simbal slide on the M1 Motorway in Pakistan. The significance of their impacts is further enhanced if one considers the occurrence of landslide phenomena related to natural or man-made activities, e.g.,valley slides, road cuts, or excavations for engineering work.

As mentioned earlier, landslides range in size from small 'rockfalls' to huge movements involving thousands of cubic metres of earth materials, which may destroy structures, human settlements, and agricultural land; cut off transport and communication systems; block highways of strategic value; and modify landscape. All these points mentioned here are in context with the impact of the landslides occurring in Pakistan. It is appropriate to cite the example of the Riala landslide near Ayubia Pakistan (Malik et al.1989) which occurred in 1988 destroying more than half of the Riala village. An estimated 100 houses and 25 acres of agricultural land were swept down the slope. As a matter of fact, our subsequent visits in 1991, 1993, and 1994 have revealed that the landslide is still active and that more land and houses are being consumed. Already a large number of families has migrated and settled in or around Islamabad, while others have settled in more stable nearby villages. The inhabitants of the remaining so-called stable part of the village apparently feel unaffected temporarily, but they are conscious of the danger that may come in future. This sense of insecurity has led to socioeconomic problems. Developed countries may not have experienced such impacts of landslides to their fullest extent, but it is an absolute reality for the people of affected areas in developing countries like Pakistan.

Small-scale landslides, on the other hand, may affect local structures, individual houses, and small terraced farms in the hills. The magnitude of damage from these landslides, although not catastrophic, should not be underestimated. Landslides lead to serious problems if they are more closely spaced or occur more frequently, as along the Murree-Muzaffarabad (Kashmir) Road. The intensity and frequency of landsliding along this important route, which is a vital link between Pakistan and Independent Kashmir, is a constant problem (even more so during monsoon). The main zones of landslides have been marked, and, on the basis of geotechnical studies, the entire length of this highway is divided into stable, unstable, and potentially unstable regions (Saeed and Malik 1990). Since 1967, these slopes have been studied and documented and, ironically enough, almost every year new slides occur along this route, disrupting transportation, communications, and trade (Malik 1972) and Malik et al. (1989).

Similarly, the impact of landslides on the Karakoram Highway is no less significant. Several landslides (Figs. 5 & 8) have been studied, recorded, and analysed since 1973/74. This route, linking Pakistan with China, is of great national and international importance. Blockage of this strategic route, due to landslides, not only affects settlements and communications but also tourism.

Generally, landslides are considered to be a natural phenomenon triggered by natural factors. However, many landslides are a result of human activities which are initially intended for and oriented towards development of an area for settlement, reclamation of cultivable land, construction of roads, widening of existing roads, or excavation for other civil engineering purposes.

The inevitable pressure of population in mountainous regions in developing countries may indirectly be contributing a great deal to the instability of slopes. There should, therefore, be some balance between the anticipated loss due to induced landslides by human activities and the ultimate achievable goal for development of land use for agriculture or settlements. Farming in northern Pakistan is mainly on terraces, the slopes of which become very steep, particularly in the extreme northern parts. The instability of these slopes affects the cultivated areas and consequently the agricultural produce. For instance, at Jalial landslide on the Murree-Muzaffarabad Road (Fig. 1), agricultural and fruit (apple) farms deteriorate almost every year.

Roads, bridges, transmission lines, and other communication networks are disrupted very frequently in northern Pakistan. For example, the Murree-Muzaffarabad Road remains closed periodically during monsoon because of landslides. Similarly, in the Hunza Valley and on the Thakot-Batgram Section of the Karakoram Highway (Fig. 1), frequent blockage due to landsliding is not very uncommon.

Human settlements are affected gravely by landslides in Pakistan, thus disturbing the socioeconomic patterns of the local population, leading to migration to bigger towns or to the plains. For instance, the occurrence of the Riala landslide near Ayubia in 1988 and the Kohala landslide in 1992 made it essential to shift the bridge location on the Jhelum River.