CHAPTER 6

LANDSLIDES ASSOCIATED WITH THE LUZON EARTQUAKE

6.1 Introduction

The July 16, 1990 earthquake not only caused surface faulting and liquefaction on a regional scale, but also unprecedented slope failure in central and northwestern Luzon with innumerable landslides in the Cordillera Central and Caraballo Mountains (Fig. 6.1). Out of the 1,666 earthquake-induced casualties nearly 450 were due to landslides and an additional 45 to new slope failures and streamflows activated by monsoon rains during the period August-October 1990.

As a secondary short-range effect of the earthquake, numerous shallow-seated slides were triggered in the mountainous provinces of Luzon. In addition to the catastrophic damage and the environmental impact caused by the countless scars, the quake generated an enormous quantity of loosened sediments with further potential for mobilization by monsoon rains. Part of this disaggregated mass, still lying near footslopes, will be a threat to people and a hazard to property, infrastructure and the environment for years to come. The regional reshaping of landforms induced by the quake and by the subsequent rains is one of the most striking examples of rapid geomorphic evolution of this century.

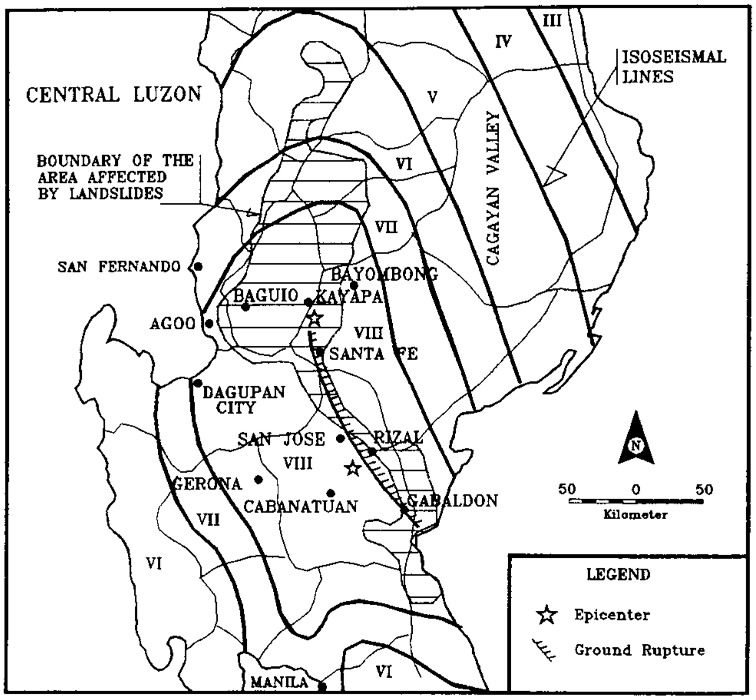

Fig. 6.1 – *Isoseismal Map of Luzon 1990 earthquake and location of the area affected by landslides. Intensities are based on the Rossi-Forel Scale (Punongbayan and Torres, 1990).*

Based on a number of site visits along Dalton Pass Road and in the Baguio region, a preliminary estimate of landslides associated with the quake puts the number at nearly one hundred thousand within the affected area. A detailed inventory of slope instability phenomena is far from complete, due to the vastness of the territory involved and the inaccessibility of some areas. A comparative study of three sets of satellite images taken before and immediately after the quake and at the end of 1990 could help in the identification and mapping of seismically-induced slides and slope failures triggered by the monsoon rains.

Slope destabilization by ground-shaking continued throughout the August-October 1990 rainy season with peaks during the major typhoons. The mass mobilization activated by the quake clogged rivers, created small dams which later washed out, raised river beds, shaped banks and destroyed bridges and minor structures, and finally built up extensive alluvial fans in the flatlands fringing the mountains.

Slides affected roughly 10,000 square kilometers and, due to the variety of local topographic and geological conditions, included nearly all known types of slope failure. Figure 4.11 shows most of the area severely affected by slides (Benguet province, Caraballo Mountains plus the zone along the major ground rupture) and the location of the main roads in Central Luzon.

The area affected by slides (Fig. 6.1) has been estimated on the basis of PHIVOLCS data and information from various other sources, as well as the author's visits to the Caraballo Mountains (along Dalton Pass Road) and Baguio Province (along Kennon and Halsema Roads, Marcos Highway and the road to Ambuklao Dam).

6.2 Tectonic environment

The Cordillera, which is dissected by the splays of the Philippine Fault, is divided into some sub-ranges and interposed valleys, with an approximate, but visible, N-S pattern. The drainage network basically follows the tectonic lineaments as these evolved during Miocene through Quaternary. Thus, the range is characterized by incised valleys and steep sided crests with some undulating plateaus. The core of the chain consists of large granitic and granodioritic batholiths outcropping at various locations.

The slope destabilization process in the Cordillera Central started by the quake was greatly facilitated by the tectonic history of the range. During the emplacement stage, intruding batholiths metamorphosed, intensely fractured, folded and uplifted surrounding earlier formations (shallow marine deposits, mainly limestones, conglomerates, sandstones and shales), partly destroying their original structure.

Volcanic activity during and after the orogenesis further complicated stratigraphic sequences with the overlapping or lateral formation of pyroclastics, basaltic flows, andesitic and dacitic lavas. Rock formations at the periphery of batholiths, already affected by lateral variations and disturbed by tectonics, became highly unstable and prone to accelerated degradation.

Batholith upheaval episodes from Miocene through the Quaternary generally resulted in a marked decline in the mechanical properties of surrounding rocks. Intrusive bodies (granites and granodiorites), which are generally least affected, during the emplacement process were also faulted and fractured with the formation of shear zones and joints. The presence of discontinuities and shear zones heavily contributed to slope destabilization during the quake.

At the present time the evolutionary process of the Cordillera is greatly affected by the deformation induced by the double-sided subduction in Luzon. Part of the subduction-related crustal shortening is converted into strike slip motion along the Philippine Fault; part of it is turned into the uplift of the range, with the consequent rejuvenation of its drainage system, progressive steepening of slopes, accelerated erosion and undercutting at the toe of scarps by the numerous streams. Uplift and deforestation in the mountains of western Luzon markedly contributed to landslide hazards during the earthquake.

The Caraballo Mountains, which are located between the southern terminus of the Cordillera and the Sierra Madre Range, are generally characterized by lower relief contrast and hilly landforms. The range consists of andesitic rocks with intercalations of sandstones and shales, basaltic lavas and dolerites resting on a basement of pre-Tertiary tonalites and schists. Countless shallow-seated landslides occurred there during the quake, particularly in the area along the major ground rupture which also marks the courses of the Talavera and Digdig rivers.

6.3 Landslide distribution, volumes and geometry

Most of the slope failures were concentrated in the mountainous zones south, west and along the major ground rupture and its probable underground extension, namely part of the Central Cordillera, Caraballo Mountains and a small zone of Sierra Madre, near Dingalan Bay. The northern third of Cordillera and the area east of the rupture line (which includes the eastern Cordillera, the Cagayan River Valley and the northern Sierra Madre Range) were marginally affected. The lower quake Intensity, the smaller contrasts in elevation and the presence of a nearly intact rain forest contributed in particular to limiting damage to the slopes of the Sierra Madre.

The concentration of slides along and west of the ruptured fault segment was influenced by the following factors:

a) the uplift history of the Cordillera batholiths, considered responsible for marked geomorphologic contrasts and, hence, for the presence of numerous steep slopes locally topped by shattered rocks.

b) the rigid behavior of the rock basement of Cordillera, made of deep-rooted batholiths;

c) the presence of an intricate system of faults and sub-faults in the most affected zone; relative motion probably occured during the quake along many of these tectonic lineaments;

d) the widespread deforestation in the Cordillera and Caraballo Ranges.

The Caraballo Mountain slopes, in general, behaved the same way as part of the Cordillera, with numerous shallow slides. This can be attributed to the presence of uniformly weathered zones in both ranges, associated with low topographic contrast. Figure 6.1 shows isoseismal lines based on the Rossi-Forel scale (Appendix C), landslide distribution and the location of major ground rupture and epicenters. Slides predominantly occurred in the Intensity VIII and VII zones, though there was a marginal involvement of the zone VI which appears to mark the damage threshold. Zone VIII includes major and minor ground ruptures, the epicenter near Rizal and the probable second epicenter near Kayapa.

The distribution of slope movements in the Cordillera was not homogeneous, being strongly influenced by topographic variations and the local condition of the rock formations both in terms of geology and tectonics. In some areas of this range nearly 60% of the slopes collapsed. In the Caraballo Mountains almost no slope withstood the tremors.

About 100.000 landslides were probably induced by the quake, including those newly triggered and a huge number of old reactivated slides. Largely predominant were shallow-seated slope movements, ranging from small to medium size, with volumes mostly in the 1,000 to 5,000 cubic meter range. Due to the extreme variations in geologic and topographic conditions, landslides were unevenly distributed. Pictures of the strong earthquakes in Guatemala (1976) and New Zealand (1968), from Harp et al., 1981 and, Crozier, 1986, respectively, show a generalized landscape instability similar to that of July 1990 in Luzon.

A very broad estimate has been made of the volume of material mobilized by the quake and by the following rains (second half of 1990). Through a number of site visits to Baguio province and surroundings, to Dalton Pass and the Gabaldon area, about one third of the entire zone affected by landslides was inspected, numerous pictures were taken and available information on inaccessible zones was collected.

Based on the rough figures of 100,000 slides and 4,000 cubic meters per slide (average of small, medium and large ones), about 0.4 cubic kilometers of landscape materials are likely to have moved during the quake. This large volume, which provides some idea as to the vast scale of landscape denudation, was partly mobilized again during the July-September 1990 rains.

Though a number of large deep-seated slides were observed, the great majority consisted of surficial mass movements having a triangular elongated shape and a thickness ranging from 0.5 m to 2 m. In most cases these very shallow failures basically removed the weathered zone composed of tropical residual soils and rock fragments.

With regards to the angle of the natural scarp. no slope steeper than 40 degrees withstood the tremors and several flatter slopes failed as well.

6.4 Seismicity-related effects on slope failures

Relevant effects of the 1990 earthquake in Luzon were:

1) the lowering of cohesion and internal friction of soil materials. The reduction of intergranular bonds by the quake drastically lowered the amount of stability which is the excess of shear strength over shear stress. In rock slopes with a weathered zone the effect of ground shaking was selective. The process of regolith formation generates a weathering front which separates materials with different strength and hydrological properties, namely surficial soils and mother rock. Earth shaking weakened the intergranular cohesion-related bonds and grain-to-grain friction in the surface unconsolidated materials lowering their strength properties and consequently inducing sliding along the weathering front plane. Whenever the shaking intensity was too low to trigger slope failure, it loosened surface soils favoring water penetration. Hence, many dry slopes which withstood the 1990 quake failed during the seasonal rains.

2) the horizontal acceleration caused by the quake led to an increase in shear stress and the consequent failure of numerous slopes. Again, physical separation and different technical properties of the regolith and mother rock played an essential role with their different response potential.

During the quake slopes were mostly dry since the rainy season had not yet started, thus, failures induced by liquefaction did not occur. The distribution, orientation and pattern of faults also interacted with the geology and geometry of the landscape locally enhancing ground shaking intensities and, thus, the occurrence and dimensions of slides.

A remarkable effect of ground shaking in Luzon regarded slopes on bedded rock formations. Joints and fissures were considerably widened, new fractures were initiated and friction properties along major discontinuity planes decreased. Impressive structural failures occurred along Halsema and Kennon roads, north and south of Baguio respectively, due to sliding along the daylighting planes.

6.5 Shallow and deep-seated slides

The extensive failure of slopes in Luzon can be broadly divided into two groups: shallow-seated landslides involving the removal of the thin alteration cover and deep-seated landslides in which part of the bedrock with its weathered zone moves down the hillside.

The first group is typical of moderate to steep slopes with limited differences in elevation (Fig. 6.2). The height of the slope has no influence, failure being basically controlled by the slope angle. Sliding occurs along the contact plane between the 0.5 to 2 m thick weathered zone and the bedrock.

The joint pattern of the mother rock is marginally involved in slides of this type. Shallow-seated slides occurred extensively in the Caraballo Mountains (Dalton Pass Road) and in large areas of the Central Cordillera.

In the second group, deep-seated landslides, the failure involved the weathered zone and the bedrock (Fig. 6.3). Critical slope height, in general, is a major controlling factor together with the joint pattern, probably combined with the degree of weathering of the bedrock. Numerous slope failures of this type were observed in Cordillera Central and a few cases in the Caraballo Mountains.

Figure 6.4 shows in sequence the ridge opposite the slope along which the road leading from Agoo to Baguio (Marcos Highway) is located. The two pictures clearly illustrate that the steep slope has failed for kilometers. Debris slides, debris flows and avalanches, rock falls and rock slides in this area were associated with large-scale accelerated erosion.

Of the types of movement defined in the Varnes (1978) classification, slides were dominant, followed by flows and to a lesser extent by falls and complex types. Flows were abundant in the Cordillera Central but limited in the Caraballo Mountains. Slides were mostly translational, but cases of rotational types were also observed.

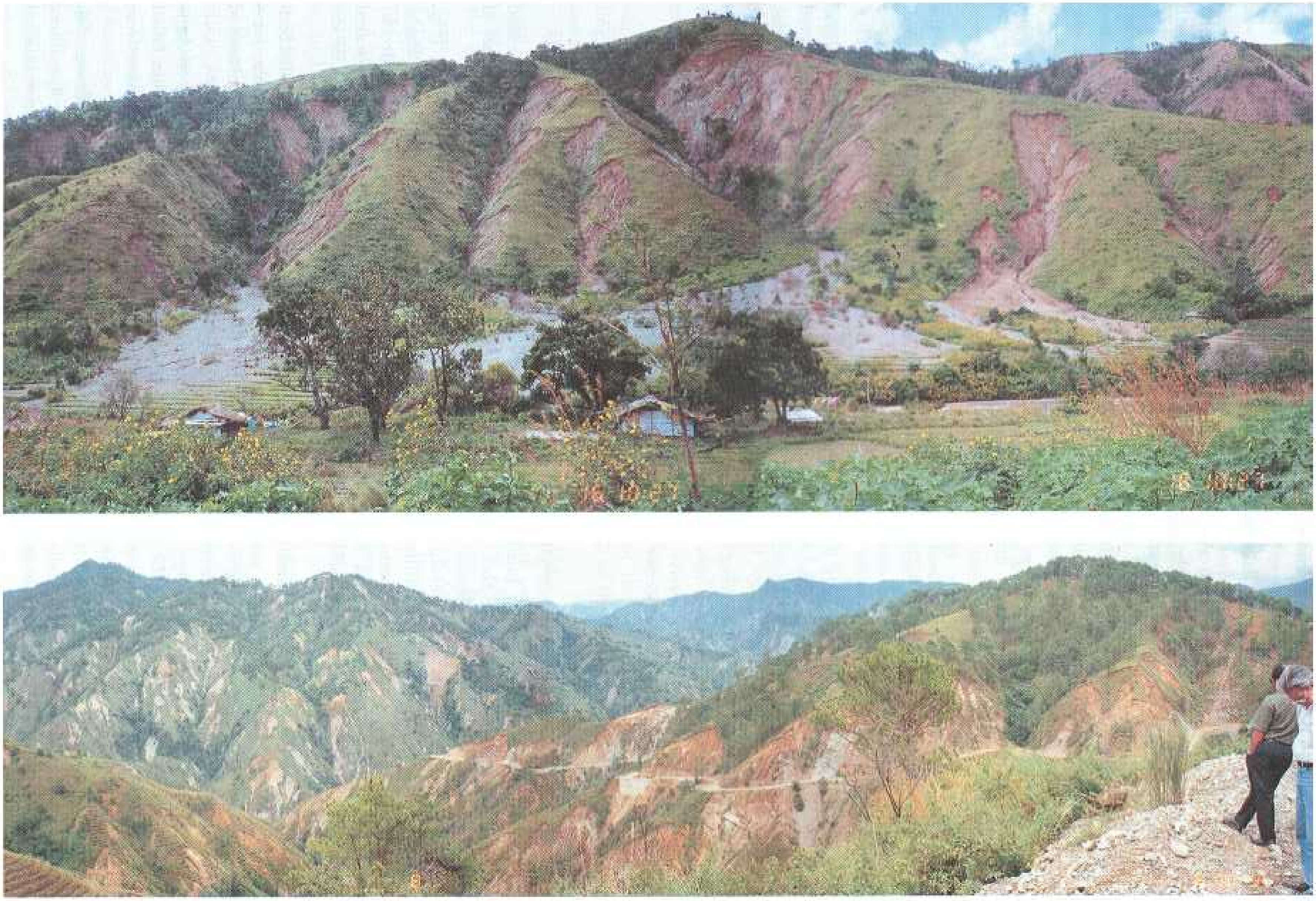

Fig. 6.2 *Hilly landforms of the Caraballo Mountains with the typical shallow-seated landslides (debris slides) along the Dalton Pass Road (top). Shallow debris slides near the road leading to Ambuklao Dam (Cordillera Central), NE of Baguio (bottom).*

Fig. 6.3 – *Huge deep-seated complex landslide (debris avalanche and rock slide) in the Caraballo Mountains. The failure involved the weathered zone and the bedrock.*

Fig. 6.4 – *Generalized failure of very steep slopes across the valley with debris flows, debris slides, debris avalanches, and many rock flows and some rock slides, seen from the Marcos Highway near Baguio. The two pictures are in sequence.*

The slide materials included large quantities of rock fragments, which is an indication of the presence of mainly young weathered soils in the Luzon mountains. Coarse granular material was predominant in the deeply incised valleys in the Cordillera Central. In the high-topographic contrast area of the Caraballo Mountains, along Dalton Pass, some huge earth slides occurred (Fig. 6.11, top left). A few slides near Santa Fe' (Fig. 6.1) were characterized by a whitish color due to the failure of the coarse-graded quartz blanket covering granodiorites.

The abundant material which accumulated on the footslopes, was systematically eroded and transported by the heavy rains during the monsoon season.

6.6 Landscape evolution and environmental impact

In mountainous regions quakes can easily generate landslides, produce new cracks which can later develop into slope failures, and loosen surface materials, thus enhancing the erosive action of rain and flowing water. The July 1990 earthquake in this respect represents a major step in the evolution of the landscape in the Cordillera and Caraballo Mountains and an example of seismically induced enveronmental impact on a regional scale. In both ranges slides marked the landscape from the lowest elevations up to the farthest visible crests.

It is likely that a Magnitude comparable to that of the 1990 Luzon earthquake and intensities of VI to VIII on the Rossi-Forel scale were also reached in this area during previous strong tremors. The quakes of 1645, 1796 and 1892, with epicenters along the Philippine Fault segment between Dingalan Bay and the Gulf of Lingayen (Fig. 4.9), probably had the potential for producing an environmental impact similar to that induced by the July 1990 ground shaking.

According to Spanish chroniclers these events were highly destructive and caused considerable property damage. However, no systematic data were provided on what is now called the environmental impact. There are three reasons for this, *a*) Mountain Provinces were still widely covered by primeval forest, which attenuated slope instability and most certainly enabled disaggregated slope materials to progressively recover part of their original shear strength, *b*) there were very few access roads and the population was smaller and concentrated in coastal areas (thus, the information available mainly concerned inhabited flatlands), *c*) human action on vegetation and topography was minimal. The July 1990 quake, by contrast, and the following rainy season hit a quite, although not uniformly, populated region which had undergone deforestation and was widely farmed.

An active erosion cycle, in general, affects Luzon mountains due to the combination of heavy rains, tectonic uplift. river rejuvenation and deforestation. Fluvial downcutting is also very active and a marked slope retreat can be attributed to the combined effects of quakes and erosion. The erosive power of streams was evident for instance along Dalton Pass Road at the end of the 1990 rainy season. River sediments, transported and deposited between San Josè and Dalton Pass (Fig. 4.11), after the quake and seasonal rains, were deeply re-eroded down to a depth of 1 to 3 m.

The scars induced in Luzon mountains will probably remain visible for decades since deforestation and present erosion rate prevent rapid growth of a new vegetation cover. This will have an adverse effect on the fauna in general, increase runoff and reduce water seepage which is fundamental for the recharge of aquifers. The huge landslide-related impact already assessed in the latter part of 1990, was followed by additional devastation due to rain-induced slides and flow of sediments down rivers during the monsoon season of 1991.

6.7 Casualties, property and infrastructure damage

6.7.1 Death toll

Four hundred fifty lives were lost due to seismically-induced landslides and an additional forty casualties were reported due to later rainfall-triggered slope failures. In some of the most affected areas and remote zones landslides hampered search and rescue (SAR). The repeated traffic interruptions along

Dalton Pass Road due to rain-triggered slides not only damaged the economy but also delayed efforts by the SAR teams to provide medical supplies and help to remote villages.

6.7.2 Damage to property and roads

Property damage occurred in villages and on cultivated lands close to landslide prone areas. A number of small villages were reportedly abandoned or evacuated because of landslide hazard. People living along Dalton Pass Road, in particular, had to cope with repeated interruptions of traffic. There were over 100 small to medium sized slides and around 25 large slides, with an estimated overall volume of about 2 million cubic meters of debris along the 40 kilometers of the Dalton Pass Road between San Josè and Santa Fe' (Fig. 4.11).

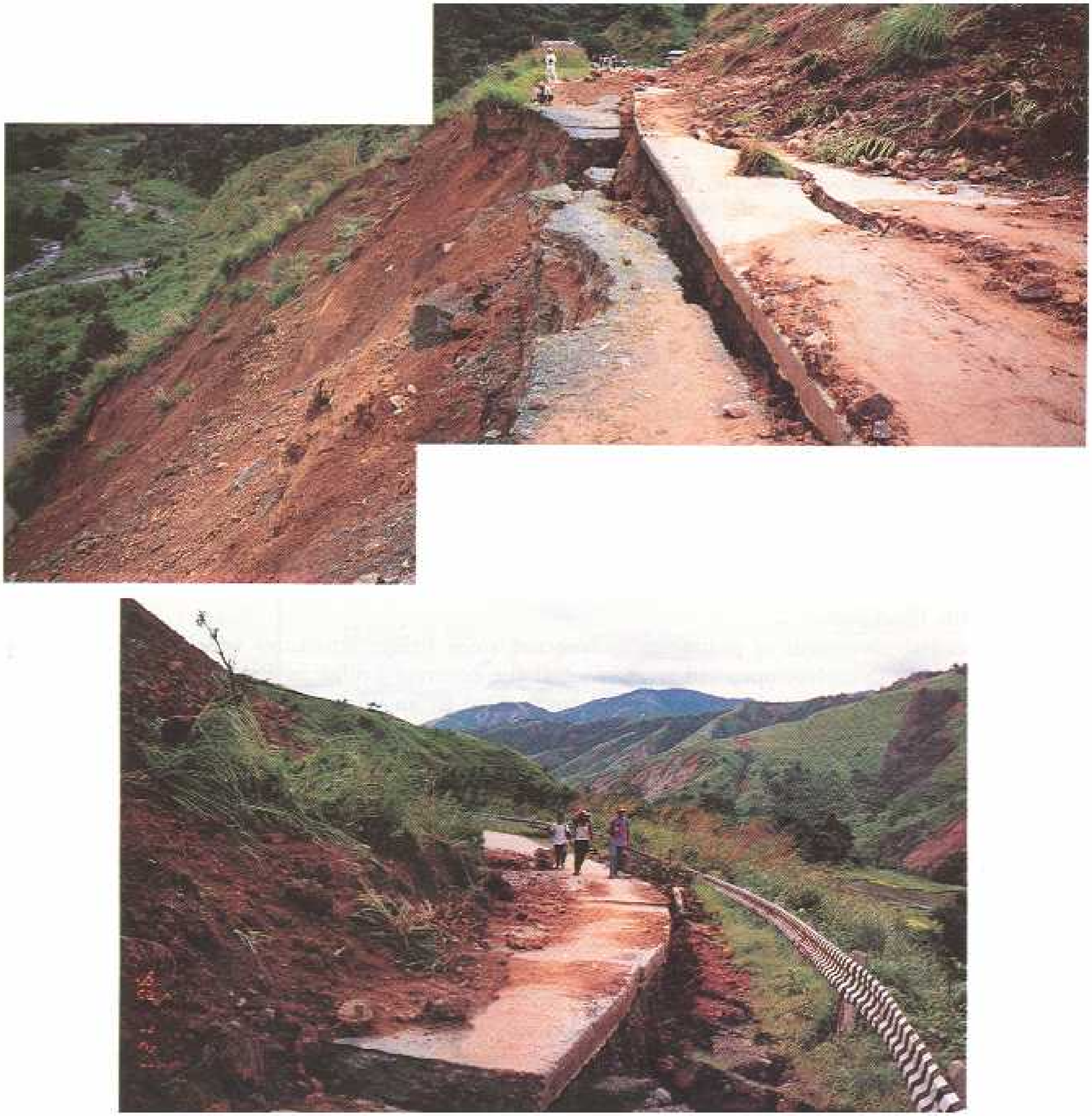

Fig. 6.5 – *Debris slides along the Dalton Pass Road. Pavement, side slopes, drainage and often the entire road platform were badly damaged. Fissures induced by the quake affected the rigid pavement (top) and the shoulder (bottom), often with irreparable damage of the road surface. (Courtesy of DPWH and Katahira).*

A huge slide accompanied the earthquake in Bateria (Ligaya, Nueva Ecija Province), near the southern terminus of the major ground rupture (Wieczorek et al., 1990) close to Gabaldon (Fig 6.1). Along a very gentle slope angled at only a few degrees a huge quantity of sandy gravel and some boulders started to move slowly during the quake and traversed several hundred meters in the form of a semi-liquid mass. The translational movement was favored by the water-saturated condition of the mass.

Landslides contributed largely to structural damage in Baguio City. The airport runway and terminal, city buildings and houses suffered various types of damage due to soil movement and associated cracks. In a number of cases, however, rather than sliding, the soil underneath foundations was compacted by the tremors thus initiating foundation failure. According to Wieczorek (1990), landslides in Trinidad Valley (Baguio) swept some homes downslope.

Roads were affected by an enormous number of shallow debris slides (Fig. 6.5) and some rock falls, with consequent damage to cut slopes, retaining walls, side drainage, pipes and culverts, as well as to road surface.

Marcos Highway (Fig. 4.11) between Agoo and Baguio City was closed to traffic for some weeks after the quake. The most impressive landslide zone on this road is located a few kilometers before Baguio where very steep slopes (Fig. 6.4) along a deeply incised river valley dominate the landscape. In this case the entire slope was affected over several km.

In addition to shallow slides there were also deep joint-controlled plane failures on the Halsema and Kennon Roads (Fig. 4.11), respectively leading north and south of Baguio. The Naguillian Road, N-E of Baguio, also suffered damage from slope failures, while the road connecting Bagabag to Banawe (the village with the famous rice terraces) was closed for several weeks due to numerous landslides (Fig. 4.11 top).

The gravel road leading to Ambuklao Dam, northeast of Baguio, did not suffer major damage, but the surrounding landscape close to the damsite was badly affected by numerous debris slides. As in the case of Caraballo Mountains, contiguous surficial slope failures marked the landscape everywhere. A considerable volume of materials reworked by the monsoon rains filled up the reservoir of Ambuklao Dam in a few weeks, thus ending the electricity production.

Equally consistent was the downward movement of sediments along tributaries and major river beds during the August through October rainy season. The mass movements, which included rock fragments, plants, trees and debris, blocked or damaged bridges and drainage structures. After a month sediments transported along the natural drainage system reached the foothills and then started spreading out in the floodplains.

This natural movement of sediments endangered some bridge structures which had safely withstood the tremor. Countless uprooted trees blocked the concrete bridge in Puncan (along the Dalton Pass Road, Fig. 4.22), where the river bed had been raised by an unprecedented accumulation of sediments, which had also buried rice fields upstream. The Talavera and Digdig rivers along Dalton Pass Road (Fig. 4.11), were also choked by a major accumulation of debris. The sediments blocking the natural drainage in some cases caused rivers to overflow their banks.

6.8 Landslides in the Cordillera Central and Caraballo Mountains

6.8.1 General

The classification of landslides proposed by Varnes (1978) has been adopted (Fig. 6.6) top and terms are based primarily on the type of movement and secondarily on the type of material. The figure in brackets, which follows each landslide class in the next sections, represents a percentage of total landslides by type of material. The value is an indicative estimate derived from visual inspection of a number of sites covering about 280 sq. km in Southern Cordillera and 150 sq. km in Caraballo Range. Considering that the latter range is smaller and morphologically more uniform, the percentages of slope movements are comparatively more representative for the Caraballo Mountains. The most common types of landslides are illustrated in the lower part of Figure 6.6.

6.8.2 Types of slope failure in the Southern Cordillera

The distribution of landslides in shown in Fig. 6.1 which also includes isoseismal lines. Slide types in the Southern Cordillera mountains were classified as follows:

a) debris slides (33%) and debris flows (14%). Debris slides in hilly landforms are shown in Figures 6.2 (bottom) and 6.7, while Figures 6.8 and 6.9 illustrate debris flows and some debris slides in shattered rocks forming steep-sided slopes near Baguio.

b) rock flows (6%) and debris avalanches (7%). A number of rock flows and debris avalanches associated with other types and accelerated erosion occurred on steep slopes in the Central Cordillera (Fig. 6.4).

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL		Rock block slide	Debris block slide	Earth block slide
		MANY UNITS	Rock slide	Debris slide	
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (Deep creep)	Debris flow Debris avalanche (soil creep)	Earth flow
COMPLEX			Combination of two or more principal types of movement		

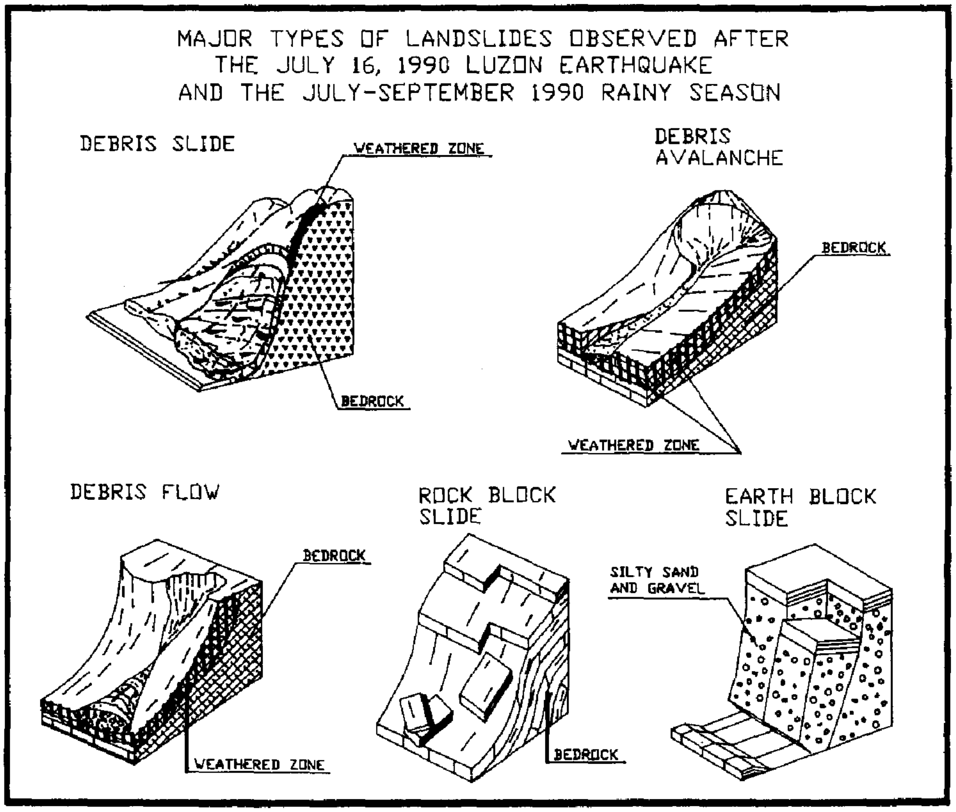

Fig. 6.6 – *Varnes classification (1978) of slope movements (top) and most common types of slope instability phenomena in Luzon (bottom) triggered by the earthquake and the rainy season which followed soon after.*

Fig. 6.7 – *Shallow-seated landslides (mainly debris slides) along the road leading to Ambuklao damsite.*

Fig. 6.8 – *Debris flows, debris slides and accelerated erosion along the steep slopes of the Marcos Highway near Baguio.*

Fig. 6.9 – *Debris flows, some debris slides and accelerated erosion along the Marcos Highway, near Baguio. The deep-seated slide on the far right is interpreted as a complex type of movement combining falling, sliding and flowing.*

c) rock slides (10%). Slope failure controlled by joints and other discontinuities of the rock mass occurred along Halsema and Kennon Roads.

d) rock falls (7%). This type of instability was common on steep slopes but the quantity of material mobilized was usually minimal.

e) rock block slides (5%). Typical cases of plane failure along bedding planes occurred along the Halsema and Kennon Roads. This joint-controlled type of slide involving the bedrock is quite common in folded sedimentary rocks. Figure 6.10 shows an example of sliding along inclined sandstone layers near Baguio (Halsema Road). The angle of the natural slope coincided in this case with the dip of bedding planes. The construction of the road, however, contributed to the sliding by bringing the bedding planes to daylight through the slope face.

f) complex (9%). Figure 6.9 (Marcos Highway near Baguio) shows a complex slide on the right due to the combination of rock fall, rock flow and some cutting through the intact rock material.

g) others (9%).

6.8.3 Types of slope failure in the Caraballo Mountains

Over 400 slides of different types were counted along the Dalton Pass Road (Maharlika Highway); construction, repair and drainage works in this case heavily influenced the behavior of slopes during the quake. More uniformity, instead, was observed in the slope failures at a distance from the road and generally in the southern part of Caraballo Mountains.

Fig. 6.10 – *Plane failure along the Halsema Road north of Baguio in sandstone rocks. Beyond the ground shaking, the two factors that affected the pulling force were the angle of slope and the daylighting of the bedding planes*

Fig 6 11 *Typical area of debris and earth slides along very steep slopes near Dalton Pass (top left). Earth block slides induced by undercutting along Digdig river (top right). Debris slides along the Digdig River (near Capintalan) and the huge fan created during the 1990 rainy season (bottom).*

Slope failures were classified as follows:

a) debris slides (55%). Shallow debris slides are dominant and their main characteristics are (Figs. 6.2 top and 6.11 bottom):

  - moderate to steep slopes (35 - 55 degrees). The critical slope angle above which failure occurred is in the 35 to 38 degree range, depending on the type of regolith, bedrock, and the quantity and type of fines; slope height is usually moderate and the topography is predominantly hilly. The thickness of the slides is between 0.5 and 2.0 m.
  - the most common type of slide material is a light-brown mixture of partly weathered angular rock fragments, ranging from 2 to 15 cm in size, sand and silt; some large debris slides with a predominant light-gray fine matrix occurred south of the Dalton Pass (Fig. 6.11 top left);
  - the detachment area is variously shaped depending on local geological and topographic conditions, but generally marked by a sharp line.

b) debris flows (15%) and debris avalanches (3%). Some occurrences were observed along the Dalton Pass Road. The huge debris avalanche (and rock slide) in Figure 6.3 is thought to have been reactivated by the quake.

c) rock slides (4%). The slides of instability was not very common. A number of cases vere observed along the road leading from Sta. Fe to Imugan (Fig. 4.11).

d) earth block slides (4%). The slides of this type along undercut banks of streams were mainly activated by the rains which followed soon after the quake. Examples of downcutting along the Digdig river are shown in Figure 6.11 (top right). The material is composed mainly of sandy gravel.

e) rock fall (3%). Very few rock falls were observed along the Dalton Pass Road.

f) complex (7%). A number of slides combining two or more types of movement were observed along the Dalton Pass Road (Fig. 6.3).

g) others (9%).

The slide material reworked and transported during the July-November 1990 rainy season created spectacular alluvial fans (Fig. 6.11 top right and bottom) near the Dalton Pass road.