2. The role of geology

The cause of the landslide in Puriscal is a combination of the geology, the topography and the climate of the area. In this thesis the aim is not to describe the geological properties of the area in detail, but only briefly for the reader to understand the cause of the problems. This chapter is divided into three main sections, the first one covering regional geology of Costa Rica and its neighbour countries, the second slope instability in Costa Rica. The third part covers the local geology of the Puriscal region and the Puriscal landslide.

2.1. Regional geology of Costa Rica

From a plate tectonic perspective Costa Rica is situated at the junction of three continental plates; the North American, the Caribbean and the Cocos Plate. The Cocos Plate is being subducted under the North American Plate and the Caribbean Plate. The relative motion between the North American and the Caribbean Plate is estimated to 40 mm/year. According to scientists at OVSICORI, this movement and the plate boundaries might even be more

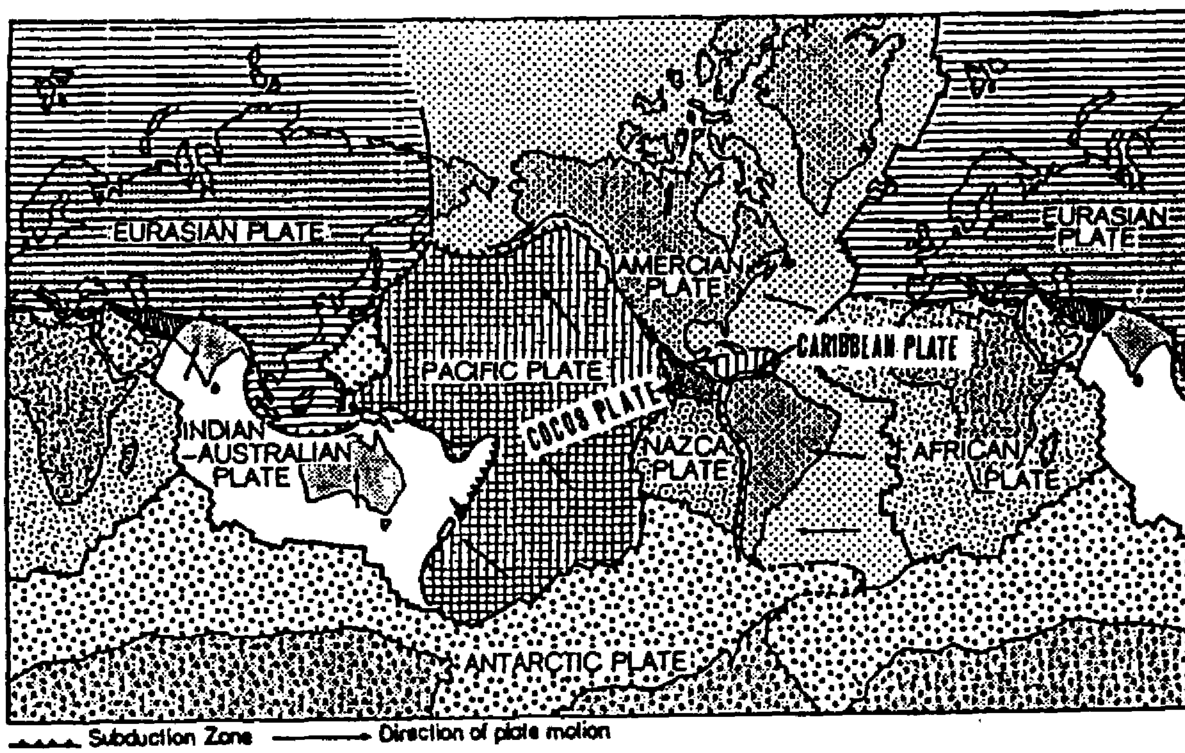

Figure 2.2. Tectonic map of the world, showing the biggest plates and the movement direction of each plate (Dowric, 1987).

complicated, i.e. more plate boundaries may be involved. This complicated movement generates a complex system of faults all over the country and in fact over most of Central America. This tectonic activity proves its existence through major earthquakes, active volcanoes, high mountains and hydrothermal activity.

2.1.1. Seismic activity

Most of the worlds seismic activity is concentrated along the boundaries of the continental plates. In the Central American subduction zone this activity is very intensive. Every year earthquakes cause major destruction of infrastructures and the loss of human lives. In Costa Rica at least two types of damaging earthquakes occur; major events, probably related to the subduction of the Cocos Plate under the Caribbean Plate, and more moderate shallow ones probably generated by deformations in the upper crust. Of those the latter ones induce bigger damage as they are closer to the surface, and therefore stronger in intensity.

In Costa Rica another phenomenon is common, the seismic swarm. The seismic swarm is characterised by high seismic activity during a short period of time, usually several days. The earthquakes of the seismic swarm are moderate or low in magnitude, less than 4.5 on the Richter scale. It is most common in the inner volcanic arc, the Central and Guanacaste mountain ranges. Two types of seismic swarms can be distinguished in Costa Rica; tectonic and volcanic. The tectonic ones occur in areas with a lot of fractures and faults, where the tectonic stress gradually liberates. Often a bigger earthquake is the trigger of a sequence of many smaller earthquakes. This phenomena could be seen on the 26th March 1990, one day after the Cóbano earthquake, magnitude of 6.5. Then lots of smaller earthquakes where observed around Puriscal (Wolgé, 1992).
The volcanic ones are related to magmatic processes within volcanoes and not to tectonic movements.

2.1.2. Topography

In all subduction zones in the world high mountains or islands are created when the two plates come together. The Himalayas, the Alps, Japan etc. are examples of mountain building in those active zones. In the Americas this phenomenon can be seen on the West coast of the American Continent *from Tierra del Fuego in Chile to Alaska in the north, although it is not continuos. The major part of Costa Rica is in this mountain range, with the highest peak Mount Chirripó reaching 3819m altitude. Approximately 70% of the area of the country consists of volcano ranges. All ranges in Costa Rica have steep slopes; 40°-50° and even more. An estimated 90-95% of the population lives close to steep slopes (Mora, 1989).

2.2. Slope instability in Costa Rica

Slope instability has a major influence on the social and economic life in Costa Rica. The cost of damages due to slope instability is high, though no secure figures could been found for Costa Rica. In the USA it is estimated that 15-25% of the total cost of geological damages is due to slope instability (Schuster et al, 1978). In Costa Rica this proportion might even be higher, as very many areas are affected. In former days earthquake and rainfall-triggered landslides were found to be sensational, whereas nowadays the population has got used to the landslides and they have become a part of daily life.

Slope instability in Costa Rica can be divided into several groups depending on its characteristics.

- **Solifluction (Creep) :** Occurs in slopes of moderate inclination (5°-30°). The speed is in the order of metres per year. The depth of the soil involved is rarely thicker than 5m. It is widespread in Costa Rica, particularly in areas where the drainage is poor, e.g. along roads with inadequate drainage. Deeply rooted trees can be useful in preventing solifluction (Mora, 1989).

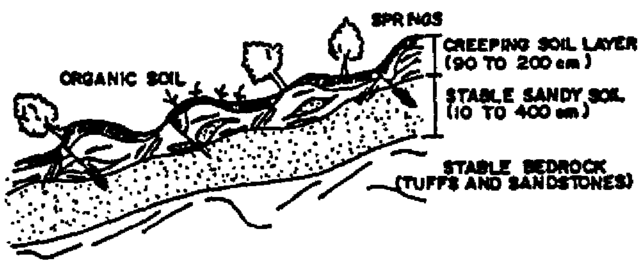

Figure 2.3. Solifluction (Mora, 1989).

- **Sheet erosion :** Occurs in moderately steep slopes that have been overgrazed, deforested or damaged in other way. The soil is removed during periods of intensive rainfall (Mora, 1989).

- **Concentrated erosion :** Is created by the erosion of rivers or streams that remove the soil and erode the land by generating e.g. ravines. This type is often in combination with human activity (Mora, 1989).

Figure 2.4. Erosion in Costa Rica (Mora, 1989).

- **Landslides :** In Costa Rica landslides are most common in residual soils. Mostly susceptible are lateric-bauxitic and montmorillonitic-bentonitic soils. The landslides are mostly shallow. To the mobilisation contribute seismic activity and/or heavy rainfall. Slopes from 35°-80° are the most vulnerable to landslides. Differences in the soil, hydrodynamic behaviour of the slope and the geology define the shape of the failure surface. This shape is mostly semi-circular, semi-elliptical or irregular (Mora, 1989).

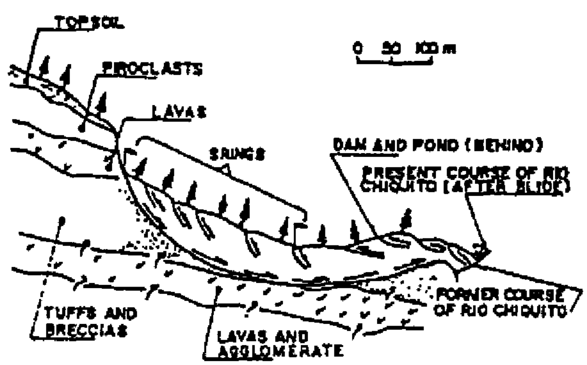

Figure 2.5. A typical profile of a landslide (Mora, 1989).

In Costa Rica eighteen large landslides, involving at least a million cubic meters of soil and rock, have been identified. Among those is the landslide of Puriscal.

2.3. Local geology of Puriscal

Puriscal is situated in a mountainous region, with valleys of 'V'-type with steep slopes of inclinations of 45° and more. Thus it is easy to come to the conclusion that this region is in the first phase of the geomorphic cycle. This cycle is permanently renewed by the tectonic activity of the area. In the whole area evidence of the intensive activity can be seen. Deep and shallow landslides, mud flows and land creep can be seen all over. The area affected by those is estimated to be about 44% of the total area of the region of Puriscal.

The area is surrounded by several systems of faults. Many of them are active, which could be seen in a recent seismic swarm in the area. It is estimated that three different systems of faults lie around Santiago de Puriscal, derived from satellite images and aerial photographs. The main axis of the fault system is estimated as:

- W-E for the system north of Santiago
- NW-SE for the system of north and north-east of Santiago
- NE-SW for the system north-west of Santiago (Wolgé, 1992).

This fault system can even be seen in seismic data from the area. Along the fault lines, intensive seismic activity occurs. On the 25th of March 1990, a seismic swarm began in Puriscal. It was the consequence of the Cóbano earthquake the day before, just south of the Nicoya Peninsula. Smaller earthquakes could be observed in all three faults around Santiago de Puriscal. Almost all earthquakes were shallow, i.e. originated from less than 25 km depth. Most of the earthquakes were of magnitudes between 1 and 4, but some events where bigger, the biggest one of 5.0 in magnitude and at only 8 km depth. The seismic swarm caused severe damages in the Puriscal area. According to Comisión Local de Emergencía (Local Emergency Commission) in Santiago de Puriscal more than 600 houses were damaged and 137 of those had to be demolished. The seismic swarm is estimated to have ended the 11th of July 1990. The number of earthquakes perceptible by the population during the whole period was at least 500 (Wolgé, 1992).

The bedding rock of the Puriscal region principally consists of volcanic material; tuff, breccia, agglomerates and basaltic-andesitic lavas. This rock originates from the Mio-Pliocen age (5-3 million years old). These materials have been exposed to alternating influences, such as hydrothermal activity and the humid tropical climate. The rocks of the region are in an advanced weathered stadium, resulting from both mechanical weathering and hydrothermalism.

The soils are of residual-regolithic type called Ultisol. The structure of the soils are in general silty and clayey-silty, a less part silty-sandy. The soil can reach a thickness of 60m of highly weathered bedrock (Wolgé, 1992).

2.4. The Puriscal landslide

The landslide on which Santiago de Puriscal is founded, can actually be divided into two parts; the Cirri-Carit part and the principal part below and around the town. The estimated area of the total landslide is 4-5 km^2 and its thickness 30-60m. The total volume is estimated to 195 000 000 m^3 (Wolgé, 1992). It is the biggest ever known landslide in the Americas and maybe in the whole world.

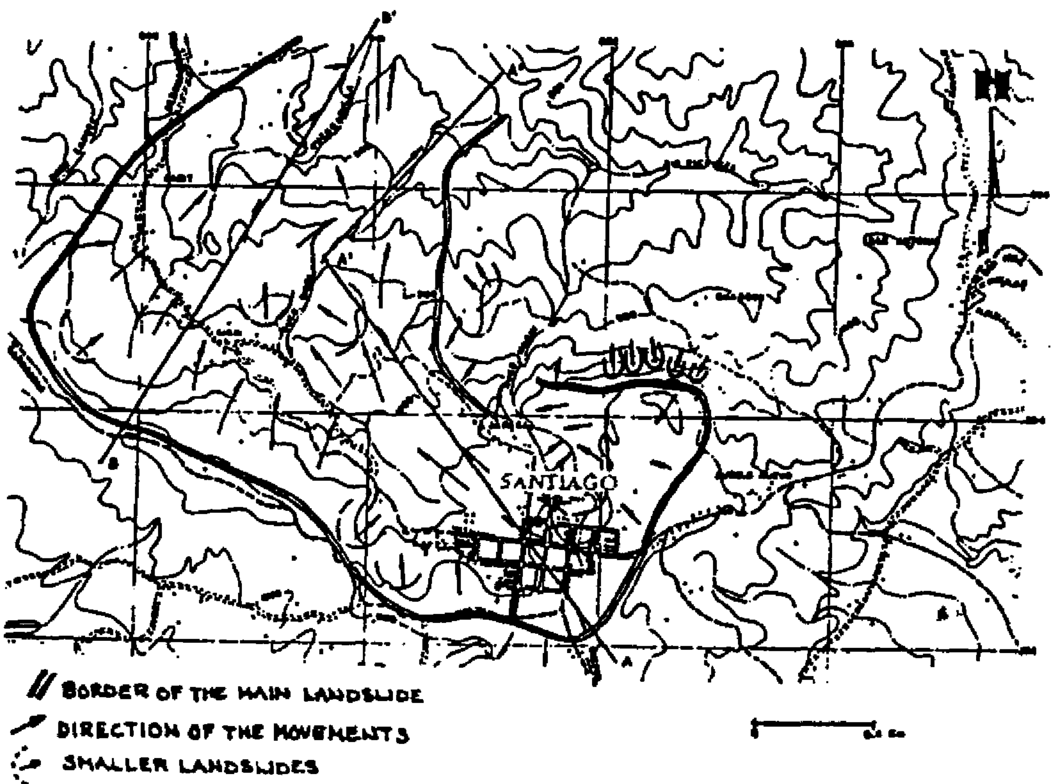

Figure 2.6. The extension and movements of the Puriscal landslide (Wolgé, 1992).

The history of the landslide is known to range back to 1918, according to old local people. Though there are indices that the landslide is not a young feature but possibly the consequence of natural cataclysm that occurred more than 200 years ago (Mora, 1992). The landslide has caused severe damages in the area, mostly on infrastructures like roads and buildings

The size and borders of the landslide have been verified in aerial photographs since 1945. It is believed to expand with 10-20 cm every year and to move with approximately 5-15 cm per year downhill.

Year	Active area (Ha)
1945	86,7
1956	70,8
1961	112,0
1965	145,8
1970	156,0
1974	161,1
1981	165,3
1984	169,7
1989	194,3

Table 1.3. Active areas within the landslide of Puriscal (total of 450 Ha). Interpretation of aerial photographs (Mora, 1992).

The surface of the landslide is covered by fractures, 5-80 m long and 0.5-10 mm wide. These cracks can be seen on the roads, in the houses and in the terrain.

A very important factor for the mobilisation of the landslide of Puriscal is the annual mean rainfall of 2 451 mm, mostly concentrated to the rain period between may and November. The rains are at times very intensive. The rains are most intensive in September and October. In October the average rainfall is 400 mm.

From a geodetic point of view this area is complicated to measure, as it is very difficult to establish any control points that are stable, easily accessible and with sight between each other. For the time being those conditions seem impossible to fulfil. In the future observations by GPS technique, or other similar system, might solve a part the problems encountered in Puriscal.