Mass Movements in the Loja Basin – Ecuador, South America

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ABSTRACT: The Loja Basin comprises a north south elongate valley, bounded by the Cordilleras Real and Occidental of the Ecuadorian Andes. Most part of the area is inhabited and includes the city of Loja (4°002' S, 79°12.5'W). Geologically it comprises metamorphic rocks from Paleozoic age overlied by sedimentary rocks, from Miocene/Pliocene age, in faulted and discordant contact. The Loja Basin is subject to mass movement processes with different mechanisms, volumes and movement rates. The biggest landslides involve almost the entire margins of the city. They are complex, extremely slow and are continuously active. The grade of instability may have increased by the construction of infrastructure like houses, roads and irrigation channels. Considering the hazard and vulnerability grade of the zone, the Multinational Andean Project-Geosciences for the Andean Communities MAP-GAC chosen the ciudadela Reinaldo Espinosa, like a Pilot Area for developing a detailed investigation, which is being carried out by the Direccion Nacional de Geologia DINAGE in cooperation with the Universidad Tecnica Particular de Loja UTPL and the Programa Regional de Desarrollo del Sur PREDESUR. This investigation comprises, detailed topographic and geological mapping, control and monitoring using Differential GPS, Geophysical surveys and Geotechnical analysis.

LOCATION

The Loja Basin is located in the southern part of Ecuador, corresponding to the Loja Province, adjacent to the Peruvian border and comprises an elongated valley N-S forming the Basin of the same name, bounded to the east by the Real Cordillera (3000m) and to the west by the Occidental Cordillera (3000m). The most part of the area comprises the city of Loja and is located on the topographic maps sheets of Loja Norte and Sabanilla at a scale of 1:50.000 (Figure 1)

TOPOGRAPHY AND HYDROGEOLOGY

In the Loja intermontane valley the Andes consist of two parallel ranges, broken up into an irregular system of mountains called as the southern Interandean mountain system (Sauer, 1965).

The zone shows an irregular relief with moderate slopes at the valley bottom increasing to steep slopes in the border of the basin along the flanks of the Cordilleras.

The main hydrographic system is the Zamora River, which flows from the south to the north crossing the city of Loja. It is fed by streams from the Real and Occidental Cordilleras.

The morphology of the basin is changing rapidly because of urban expansion. New construction along the flanks of the cordilleras are increasing the grade of instability of areas susceptible to landslides because of undercutting slopes. Many of these areas have been identified by air photograph interpretation and field observations (Figure 2).

The city of Loja gets its drinking water from the streams of the Occidental Cordillera but it is insufficient for satisfying all the population and for this reason the Municipality is constructing a new water supply pipe line from the Real Cordillera.

Figure 2: Panorama of Loja from E to W

POPULATION AND ACCESS

Loja is the capital and the largest city of the province, with a population about 130,000 inhabitants.

Loja is about a 10 hour drive from Quito along the Panamerican Highway by the mountain range, and can also be accessed via a longer route along the coast. The area can also be reached by air from Quito to La Toma, which involves a 45 minutes. Flight. From La Toma to Loja driving by car takes about 30 minutes.

GEOLOGY

Geologically, sedimentary rocks varying from conglomerates to shales of Miocene/Pliocene age are prevalent in the zone and correspond to Quillollaco formation. According to Kennerley (1973), the Quillollaco formation outcrops principally along the eastern side of the basin, immediately west of the city of Loja and extends southwards to Nudo de Cajanuma. It comprises well-rounded pebbles and cobbles of phyllite, quartzite, sericite schist, volcanic rocks and vein quartz in a sandy matrix. This sedimentary sequence is in reverse faulted contact and in some parts unconformable with metamorphic rocks of Paleozoic age. Black phyllites and quarzites outcrop in the border east in faulted contact with conglomerates, while to the southwest along the road connecting Loja and Malacatos it is possible to see an unconformity between the metamorphic and sedimentary rocks.

According the BGS and CODIGEM (1994), the metamorphic rocks are from the Chiguinda Unit, comprising semipelites, quarzites and black phyllites from Loja Terrain and Paleozoic age.

The Loja Basin is a sedimentary clastic transitional inter montane basin marine-continental located in the south extension of the Cordillera Real. Other authors include it with the basins of Nabon, Cuenca, Malacatos, Catamayo and Zumba of the same age. The sedimentology and evolution of some of these basins have been investigated in detail recently and are considered to represent structural depressions generated during dextral oblique transpression during the Middle Miocene to the Pliocene (Shaw, 2003)

The structure within the basin is not fully understood, and faulting is probably more extensive than recorded. In general the sediments are folded into an asymmetrical syncline with its N-S trending axis lying near the eastern side of the basin within the Quillollaco Formation. The layers in the western side of the basin dip to the east; or are only slightly flexed forming conspicuous scarps and dip slopes.

The Quillollaco Group comprises the Trigal, La Banda, San Cayetano, Quillollaco and Salapa formations, which make up the Loja Basin (Hungerbuhler, 1997).

Within the basin an important N-S fault is inferred to extend more or less the full length of the basin but to be concealed beneath the alluvium of the Rio Zamora and along the Road between Loja and Malacatos. Several E-W faults displace the contacts and fold axes on the east side of the basin, and probably extend into the metamorphic, causing prominent river alignments (Kennerley, 1973).

One NW-SE fault is observed 8 Km to the south of Loja along the road to Malacatos. It cuts the metamorphic and sedimentary rocks and there is evidence that it is active.

MASS MOVEMENT PROCESSES

The zone is subject to numerous mass movement processes exhibiting different mechanisms, volumes, and movement rates. The largest landslides are extremely large (greater than 1,000,000 m^3 in volume) and extend from the valley bottom to the upper margins of the Loja Basin (Figure 3). The mechanism of failure is not fully understood but appears complex; involving a combination of structurally controlled translational sliding, as well as rotational sliding and some flow-type behavior in the disturbed colluvium. The base of translational sliding probably corresponds to a clay-rich shale, but could also involve deformation along relict thrust faults.

Upon first inspection, many of the extremely large landslides appear dormant or extremely slow moving (less than 16 mm/yr). The landslides were probably more active during the late epoch of the Loja Basin construction. Detailed inspection along the upper margins of the basin, however, shows that many of the landslides continue to be active and move at rates exceeding 16 mm/yr (Figure 3). The instability of these landslides may be increasing as a result of urbanization, drainage alteration and, potentially, climate change.

Large to medium size landslides tend to be more active and move at slow rates (1.6 m/yr to 13 m/year). They are present along most slopes that have been over-steepened as a result of stream downcutting near the valley botton, as well as on blocks rotated by the extremely large landslides (Figure 3)

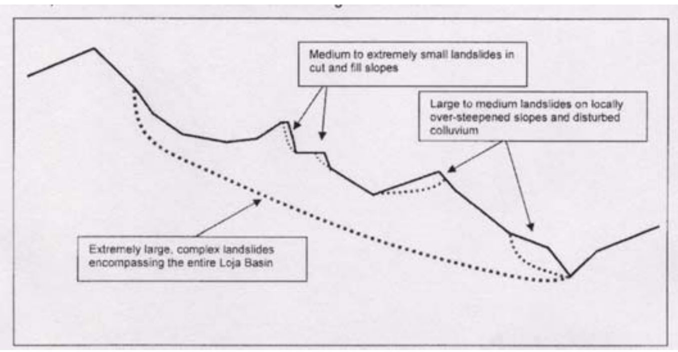


Figure 3: Schematic illustration of landslide mechanisms in Loja Basin

Medium to extremely small landslides are common where the topography is steep, and where retaining walls have been constructed without proper design of support and drainage measures.

The high density of landslides is a result of the regional geology, stream downcutting causing the over-steeping of slopes, moderate seismicity, high precipitation, and anthropogenic activity.

Regional geology is contributing to the instability of Loja basin because of the faults located in the margins and across the area cutting the sedimentary rocks. Additionally the metamorphic rocks located in the borders of the basin are very sheared and fractured, which increase the instability of the slopes.

Rainfall is very high in the mountainous eastern part of the basin and it decreases gradually westwards and a very long dry season occurs from May to November. The rainy season is between December to April and most of landslides in Loja Basin occur during this time. According the data provided by INAMHI (Instituto Nacional de Meteorologia e Hidrologia) of Ecuador, the maximum precipitation registered in the station of La Argelia located in Loja city during the period between 1965 and 1999 was 113.9mm in March.

Anthropogenic activity in some cases increase the instability of the slopes, when some infrastructure is constructed without any prevention or mitigation measures, mainly along the borders of the basin where urban expansion is increasing very fast (Figure 4)

Figure 4: Unstable area along the margin of Loja Basin

LANDSLIDE VULNERABILITY

The vulnerability of the city of Loja and its inhabitants to economic losses and loss of life caused by landslides is considered high because most of the constructions are placed in unstable areas and is expected to increase with ongoing urbanization.

The city´s infrastructure is vulnerable to all types of mass movement processes described above. At risks are houses, schools and other buildings, roads, water supply pipelines, waste water collection facilities and electrical and telecommunication towers. Facilities constructed above and below poorly designed retaining walls are especially vulnerable to rapid slope failures.

Ongoing landslides in surficial deposits, which have produced cracks along roads and buildings in sectors including Colegio Adolfo Valarezo, Universidad Tecnica Particular de Loja, Cuartel Cabo Minacho, and Ciudadela Reinaldo Espinosa.

CASE STUDY OF REINALDO ESPINOSA AREA

INTRODUCTION

Considering the high likelihood of future landslides and the vulnerability of people and infrastructure to be impacted by these landslides, the Multinational Andean Project-Geosciences for the Andean Communities (MAP-GAC) chose the Ciudadela Reinaldo Espinosa, as a Pilot Area for developing detailed landslide investigation. There was a complex landslide in the year 2001 at the location, which damaged infrastructure but fortunately did not result in injuries or fatalities.

The Direccion Nacional de Geologia (DINAGE) in cooperation with the Universidad Tecnica Particular de Loja (UTPL) and the Programa Regional de Desarrollo del Sur (PREDESUR) are carrying out monitoring and control of some sites located in the Loja Basin using Differential GPS, including the Ciudadela Reinaldo Espinosa site. Detailed topographic and geological mapping, and landslide monitoring are proposed and will be completed by geophysical surveys, drilling and geotechnical investigations.

LOCATION

The investigation area (Figure 5) is located in the southwest portion of the Loja Basin and within the city of Loja. The coordinates are:

REFERENCE	UTM COORDINATES	
POINT 1	9556441.81 N	697840.85 E
POINT 2	9556591.76 N	698510.24 E
POINT 3	9556682.79 N	698719.08 E
POINT 4	9556661.37 N	698965.42 E
POINT 5	9556479.30 N	698922.57 E
POINT 6	9556265.10 N	698488.81 E
POINT 7	9556441.82 N	697776.59 E

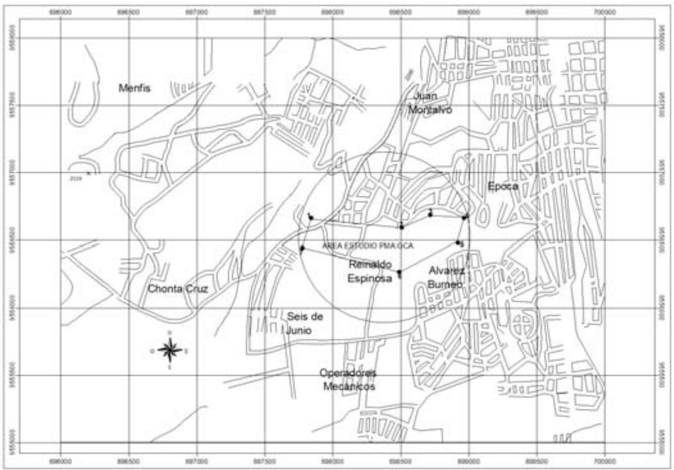


Figure 5: Location of Reinaldo Espinosa area

HISTORY

According the people living in the area, approximately in May of 1999, the Ciudadela Reinaldo Espinosa was affected by a landslide at the top of the slope where there are water supply reservoirs. Between March and April of 2001 a second landslide occurred, which affected some houses in the area (Figure 6).

According the observations it seems that there are some cracks at the base of the tanks and water is filtering in the soil contributing in the instability of the area.

The residents describe that part of their houses were separated approximately 1 meter during a period of 2 months, corresponding to a slow rate of movement (1.6m/yr to 13m/yr).

It is still possible to see cracks in the walls of some houses, deformed structures, and walls totally destroyed by slope movements (Figure 7).

Preliminary evaluation suggests that the onset of movement corresponds with the end of the rainy season, at which time the soil is likely saturated and the slope is no longer in a state of limit equilibrium. The community is considering installing a drainage system to prevent movements in the future, but further evaluation is required to determine if this solution will be effective and will provide the greatest cost-benefit. It is no clear if it is the best solution or if is going to work.

Figure 6: Damaged House in Reinaldo Espinosa area

Figure 7: Cracks in the wall of a house in Reinaldo Espinosa area

GEOLOGY AND GEOMORPHOLOGY

Geomorphology

Two blocks of conglomerate dipping to the NE define the geomorphology of the area. One of them is located at the border of Las Paltas Avenue, which shows a uniform slope in its upper part and steep cliffs along its margin.

The second block in the border of Eugenio Espejo Avenue shows a gentle slope with some hummocks and elongated forms in the central part as a result of slope movement to the Southwest

The stream valleys have an asymmetric V-shaped as a result of the geological faults (Figure 8).

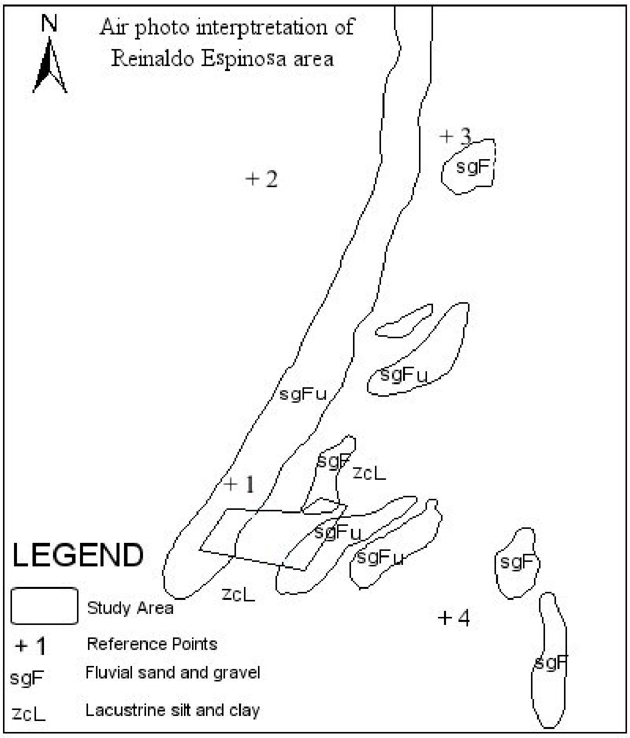


Figure 8: Air photo interpretation of Reinaldo Espinosa Area

Bedrock and Surficial Geology

Bedrock geology comprises conglomerates, which outcrop through out of the area. They contain poorly sorted clasts of schist, quartzite, and quartz veins within clayey sand matrix. The thickness of the conglomerates in this area is over 45 meters (Figure 9).

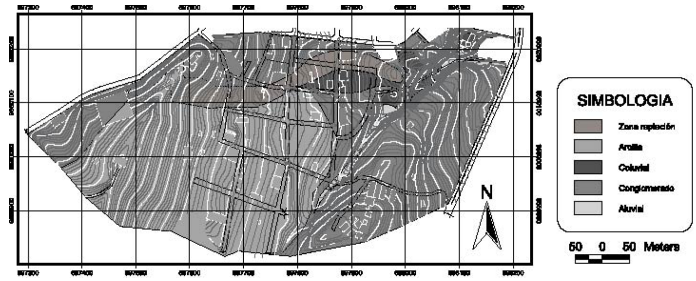


Figure 9: Geology of Reinaldo Espinosa Area

There are some intercalations of shale and siltstone within the conglomerates, varying in thickness between 1 and 2 meters.

A clay-rich shale lens may form the base of the landslide.

There are some surficial colluvial deposits restricted to the depressions of the lower part of the area, comprising fragments of phyllites, schist and quartz.

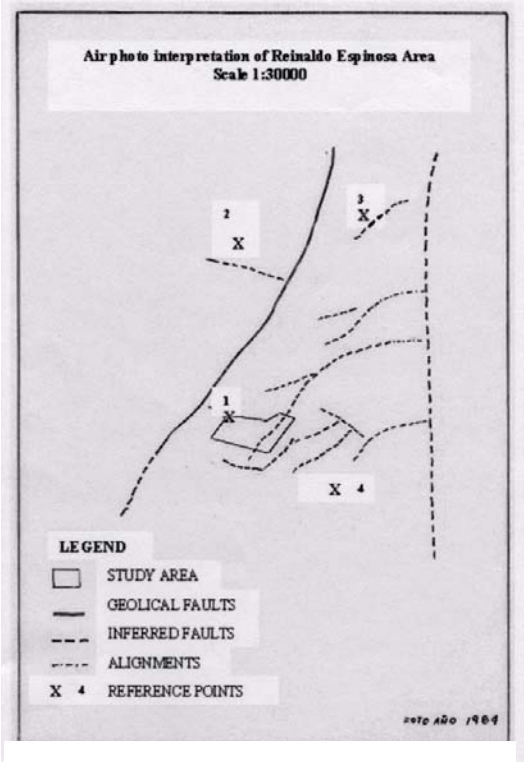
Clays cover a large portion of the central and southern part of the area. They are stiff and contain organic material and shows grey colour with brown and black mottles. They exhibit moderate plasticity and their moisture content is medium and they could be the result of highly weathered colluvium.

Structural Geology

The area exhibits some alignment structurally-controlled: the principal corresponds to a stream, which flows N33E, bordering the two conglomerate blocks described before and likely caused by a vertical displacement between them; the second alignment corresponds to the landslide with preferential direction NE-SW, which is cutting the other alignment forming a wedge (Figure 10)

These blocks form a depression of the terrain, which has been infilled by sandy colluvium and washed material with slight lithification and high permeability.

They could be the result of tectonic activity of the faults in the past.



LANDSLIDE MORPHOLOGY

The Reinaldo Espinosa landslide has a length of 367 m. The wide at the top of the slope is 53 m, at the middle part is 15 m and at the foot is 56 m. The total area is 15415.3 m^2, its perimeter is 910 m and the average slope from the middle part to the top is 13% and from the middle part to the foot is 7%.

Considering the parameters described before and assuming that the landslide plane is at depth about 20 m, the volume estimated would be 308,306 m^3.

Taking into account the landslides classification according Varnes (1978), Reinaldo Espinosa landslide is slow with a velocity of 6 m/yr.

It is active, medium large landslide with a volume of 308,306 m^3. It can be classified as an earth landslide involving sand, clay and silt.

RISK MANAGEMENT

Some monitoring and control points were established in Loja Basin, mainly in the Reinaldo Espinosa area, to gain a better understanding of the movement of unstable areas using Differential GPS. The first monitoring campaign was made in May 2004, the second in June and the third in September (Figure 11). The obtained data reveals that there is not any change between each monitoring campaign.

This work will be to be carried out on regular basis by DINAGE staff and members of other regional institutions to investigate temporal and spatial variations between each campaign of monitoring and to help minimize the risk to people living in the Reinaldo Espinosa area.

Figure 11: Control and monitoring points

PLANNED ACTIVITIES

Additional investigation is required to develop a full understanding of the mechanisms controlling Reinaldo Espinosa landslide and other landslides in the region, to assess risk to people and infrastructure and to evaluate risk control options.

Air photo interpretation of the basin in scale 1:20.000, to get a detailed inventory of unstable areas and topographic map could help to identify and characterize landslides located within the Loja basin.

Proposed activities at the Reinaldo Espinosa Landslide include:

- Underground investigations:
    - Test pits
    - Geophysic surveys
    - Drilling and instrumentation
- Geotechnical analysis
- Meteorological analysis
- Socioeconomic Investigation
- Risk assessment
- Evaluation of landslide stabilization options, and.
- Contingency and emergency response

CONCLUSIONS

- The type of landslides occurring in the Loja Basin is very complex.
- Many of the extremely large landslides appear dormant or extremely slow moving (less than 16 mm/yr).
- The landslides were probably more active during the late epoch of the Loja Basin construction. Detailed inspection along the upper margins of

the basin, however, shows that many of the landslides continue to be active and move at rates exceeding 16 mm/yr.

- The instability of landslides may be increasing as a result of urbanization, drainage alteration and, potentially, climate change.
- Large to medium size landslides tend to be more active and move at slow rates (1.6 m/yr to 13 m/yr). They are present along most slopes that have been over-steepened as a result of stream downcutting near the valley bottom, as well as on blocks rotated by the extremely large landslides.
- Medium to extremely small landslides are common where the topography is steep, and where retaining walls have been constructed without proper design of support and drainage measures.
- The high density of landslides is a result of the regional geology, stream downcutting causing the over-steeping of slopes, moderate seismicity, high precipitation, and anthropogenic activity.
- Most of the area of Loja Basin is susceptible for different type of mass movements and one of them is the landslide occurred in Reinaldo Espinosa in the year 2001.
- Preliminary evaluation in Reinaldo Espinosa Landslide suggests that the onset of movement corresponds with the end of the rainy season, at which time the soil is likely saturated and the slope is no longer in a state of limit equilibrium.
- The plane of failure in Reinaldo Espinosa landslide could be related to a highly clayey layer of shale.
- Further research is proposed in order to characterize Loja Basin landslides and mitigate future losses.

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