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OVERVIEW OF RECENT LANDSLIDES IN BARRIO RETAMANI, LA PAZ, BOLIVIA

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INTRODUCTION

Landslides are common throughout the city of La Paz, Bolivia and include a wide variety of types and sizes (Dobrovolny, 1963; BRGM, 1977); small damaging events occur almost every year (O'Hare and Rivas, 2005). Rapid growth and development of the city has resulted in increased exposure of the population and infrastructure to landslides, and the landslide risk has been exacerbated by human modification of the natural landscape.

Barrio Retamani in the San Antonio district of La Paz has a long history of slope instability, including many damaging failures in the past few years (Table 1). Retamani is centrally located in La Paz and thus is subject to extreme development pressure fueled by a scarcity of developable land. Given these pressures and the likelihood of future landslides, we have examined the history and style of recent mass movements in the barrio and the factors contributing to the instability.

SETTING

NATURAL ENVIROMENT

The valley in which La Paz is situated formed during the late Pleistocene by incision of a thick fill of poorly consolidated Plio-Pleistocene sediments that extend up to the surface of the Altiplano (Dobrovolny, 1963). The lowest unit in the sequence is the Pliocene La Paz formation; it comprises more than 500 m of weakly lithified, fluvial and lacustrine mudstone and conglomerate (Dobrovolny, 1963). The overlying Pleistocene deposits consist of a series of thick glacial diamictons and gravels separated by unconformities. This dissected Plio-Pleistocene filll is unconformably overlain by colluvium, including extensive landslide deposits (Dobrovolny, 1963; BRGM, 1977). Landslides range from frequent small shallow translational and rotational failures (Guzmán, 2007; Quenta et al. 2007) to prehistoric (1.5-10 ka) earth flows or flow-slides several tens of square kilometres in area (Dobrovolny, 1962; Hermanns et al., 2008).

Table 1. Recent landslides in barrio Retamani.

Year	Date	Material	Area (m^2)	Families displaced	Houses damaged	Infrastructure damage
2007	25 September	La Paz Fm., fill	6,540	22	ca. 20	Buried culverts of Río Orkojahuira
2009	17 February	Landslide deposit, La Paz Fm., fill	27,700	72	60	Road blockage, road destruction, buried culverts
2010	3/4 February	Landslide deposit	8,200	18	16	Utility poles, power lines, road blockage, buried culverts

Barrio Retamani is located on the east, outer bank of Río Orkojahuira, a tributary of Río Choqueyapu. The slope is covered by prehistoric and recent landslide deposits, upon which small rotational landslides have occurred in recent decades (Guzmán, 2007). The landslide deposits overlie poorly cemented mudstones and conglomerates of the La Paz formation. Terraced remnants of late Pleistocene Miraflores outwash gravels occur beneath terraces along this section of the Río Orkojahuira, and the valley floor is underlain by modern

alluvial deposits (BRGM, 1977) and fill (cf. Guzmán 2007) (Fig. 1). Prior to development, the slope on which Retamani is now located, was dissected by several gullies that supported small ephemeral streams tributary to the Río Orkojahuira.

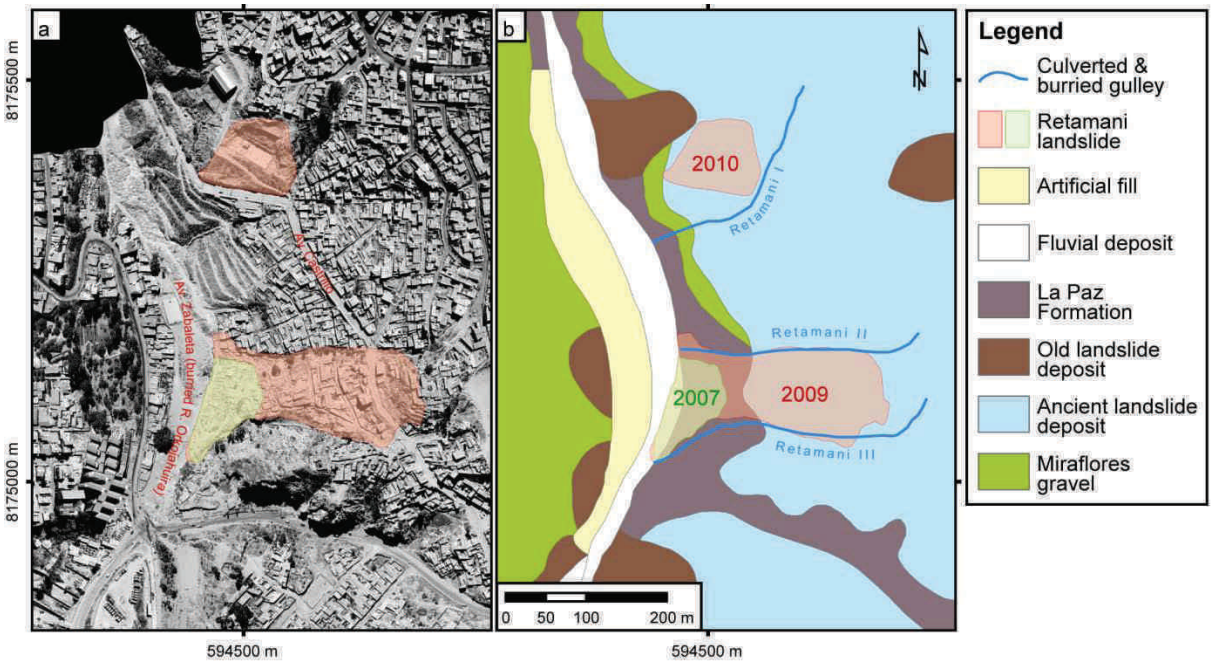

Fig. 1. Overview of barrio Retamani showing (a) development and infrastructure in 2006, and (b) geology (after BRGM, 1977) and buried gullies.

ANTHROPOGENIC LANDSCAPE MODIFICATION

La Paz has tripled in population since the early 1940s, fueled largely by migration of Bolivians from rural areas. The increase in population has resulted in the spread of the city up the valley walls bordering the original city and into adjacent valleys; these areas are steep and locally unstable.

Development of the Retamani area can be traced using historic air photos. The area supported mainly agriculture through the first half of the twentieth century. By the mid-1970s, much of the modern road network was established and much of the land had been urbanized at moderate densities, except for the gullies. By the mid-1990s, the area had been developed to? nearly its current extent. Almost all vegetation had been removed, and the gullies had been either diverted into culverts or buried (Fig. 1; Retamani I, II, and III). Slopes, including those that had previously failed, had been regraded, commonly into terraces (Fig. 2). About ten years ago, the Río Orkojahuira was channelized and covered with a thick layer of fill, on which Avenida Zabaleta is now located (Guzman, 2007).

RECENT LANDSLIDES

2007 LANDSLIDE

A destructive landslide occurred in Retamani on 25 September 2007. It extended from the buried Río Orkojahuira about 70 m up-slope. The landslide had a maximum width of 130 m, bounded by the buried Retamani II and Retamani III gullies. The failure occurred in the La Paz formation, although the toe of the failure likely involved Río Orkojahuira fluvial deposits and overlying fill (Fig. 1).

Although there were no fatalities, about 20 homes were destroyed and 22 families were left homeless, (La Razón, 2009). The affected site had minimal infrastructure at the time of the landslide; no major roads or utility lines are visible on the 2006 orthophotos. It is likely, however, that buried culverts in the lower portions of the Retamani II and Retamani III gullies were damaged.

Engineering work for the Río Orkojahuira channelization project and construction of Avenida Zabaleta was taking place during 2007 and may have contributed to instability. Rainfall preceding the landslide may also have weakened the slope (La Razón, 2009). Following the failure, the slope was terraced into seven treds, but this did not improve the stability of the slope.

2009 LANDSLIDE

On 17 February 2009, another landslide occurred at the location of the 2007 failure. It had a width of 165 m and extended 535 m up the slope, much farther than the 2007 landslide. The lower portion of the landslide occurred mainly in the La Paz formation, including parts that had been mobilized during the 2007 event, but the upper portion involved older landslide deposits, mainly diamicton (Fig. 1). The landslide was just slow enough to allow residents to escape on foot. On the morning of 17 February, the debris extended to the centre of the north-bound lane of Avenida Zabaleta; by noon on the 18th, it completely buried the north-bound lane and extended to the centre of the south-bound lane.

The landslide destroyed 60 homes, leaving 72 families homeless. Two heavily trafficked roads, Avenida Zavaleta and Avenida Castrillo, were covered by debris or destroyed, limiting access to neighborhoods to the north. Several minor roads, utility lines and poles, and buried culverts were destroyed.

Poorly built, leaky drainage and sewer systems in the area and heavy rains likely contributed to failure (La Razón, 2009). The municipal government reported after the landslide that many of the affected houses were unauthorized, which likely contributed water to the slope. Unloading of the toe of the slope by the 2007 failure also may have been a factor. The steeper, upper portion of the 2009 landslide, above Avenida Castrillo, terminates in a scarp, above which are buildings that are still in use.

2010 LANDSLIDE

The most recent landslide in Retamani began on the night of 3 February 2010 and continued into the early morning of the following day. The failure occurred directly above Avenida Castrillo in previously remobilized deposits, similar to those involved in the upper part of the 2009 failure (Fig. 1).

Sixteen homes were destroyed, displacing 18 families. The fate of four homes directly above the headscarp is uncertain. The landslide also destroyed street lights, electrical lines, and a sports field (La Razón, 2010).

About 60 m of buried culverts in the Retamani I drainage were destroyed, and over 100 m of Avenida Castrillo were buried. A cloth factory located at top of slope and was slipping after the landslide (La Razón, 2010).

Media reports attribute failure to saturation of soil by heavy rain in the previous week, although a local resident stated later in 2010 that rainfall before the landslide was not unusually heavy. A concavity with steep lateral margins is visible on pre-failure air photos, suggesting that the 2010 landslide may have been a reactivation of a previous failure.

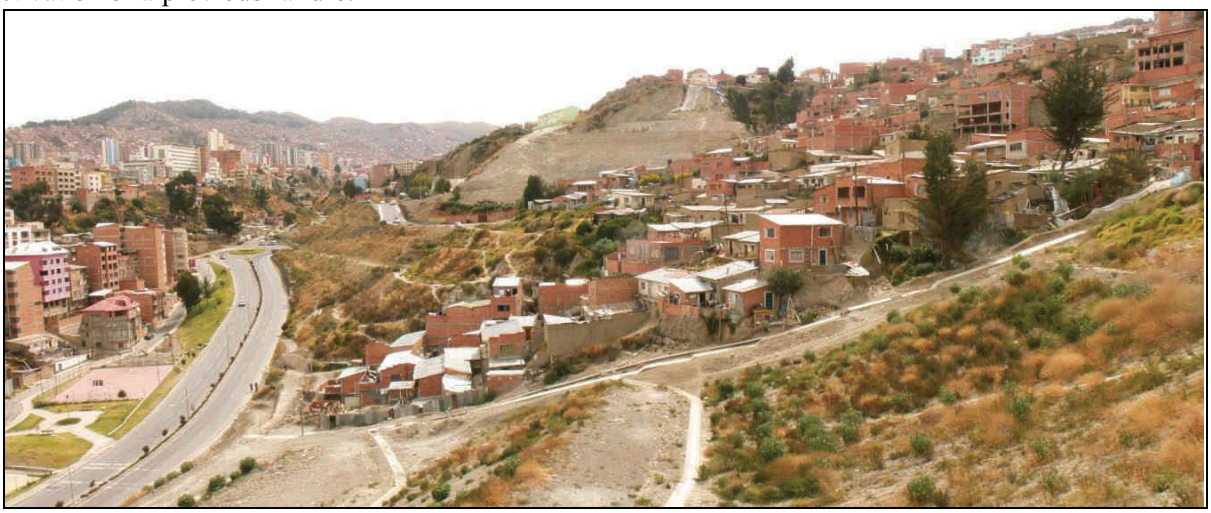

Fig. 2. View of 2010 landslide (center background) from the lower portion of the 2009 failure (foreground). Note terracing of landslides deposits and Avenida Zabaleta (lower left).

SUMMARY

The three slope failures at Retamani have several commonalities. All three involve artificial fill, old landslide deposits, or both. Similar reactivation of previously failed material has been noted elsewhere in La Paz by O'Hare and Rivas (2005) and just south of barrio Retamani by Guzmán (2007). Water channeled in in-filled gullies and culverts seems to have been a contributory factor. Toe release was facilitated by stream burial and road construction along Río Orkojahuira.

Development in the Retamani area may have increased the susceptibility of the slope to mass movements. Human activities that perhaps contributed to the failures include slope loading and introduction of water via leaky sewer lines, as occurred at the Cuarto Centenario landslide just to the south (Guzmán, 2007). The 2009 and 2010 failures occurred during the wet season following rains, although the amounts of precipitation were not unusual. Casualties were avoided because the rate of movement of the landslides was slow enough, probably of the order of decimetres per second, to allow residents time to escape before their homes collapsed.

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