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Slope movements in Callejón de Huaylas, Peru

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ABSTRACT

Slope movements in Callejón de Huaylas (the Santa River valley) are of different origin according to the variety of their causes. This paper is describing the area of Huascarán Mt. and Cañón del Pato. Rock and ice falls belong to the most well known, but also debris flows and slumps occurred in this area. The high dynamic of the relief in connection with seismic shaking and local heavy rains are the main triggering factors. The slope movements are also of different sizes from huge catastrophes which belong to the most serious in the western hemisphere to local ones which influence daily life in densely populated areas of Peru.

Key words: slope movements, natural hazards, Cordillera Blanca, Huascarán, Peru

1. Introduction

Callejón de Huaylas (Santa River – Rio Santa) which is situated between two parallel mountain ranges in the Cordillera Occidental in the northern part of the Peruvian Andes is densely inhabited (Fig. 1). Both ranges – Cordillera Blanca and Cordillera Negra – are relatively young mountains with a high degree of seismic activity, steep slopes and an intensive valley erosion resulting locally in slope instability. The area has been affected by several natural catastrophes; slope movements belong to the main ones. Apart from the most catastrophic rock and ice avalanche of 1970, triggered by an earthquake (e.g. Cluff 1971, Plafker et al. 1971), there are other hazardous processes. Most of them are connected with slope movements (Zamora, Zapata 1982, Reynolds 1989, Vilímek 1995).

From the geological point of view the Santa River valley is formed by Tertiary – Quaternary sediments which infilled the depression located between two parallel mountain ranges – Cordillera Blanca in the East and Cordillera Negra in the West. The range of Cordillera Blanca consist of granites of Miocene age. The slopes inclined into the valley bottom are covered by remnants of Quaternary glacio-fluvial sediments and they follow the right bank of the Santa River along the main Cordillera Blanca fault. The valley bottom is formed by alluvial sediments and glacio-fluvial sediments of Holocene age. From the grid of longitudinal and transversal faults, the normal Cordillera Blanca fault (longitudinal) forming the border between batholith and sediments, is of main importance. In the area of Cordillera Negra the anticlinal – synclinal deformations prevail. The axis of deformations follow the direction of Cordillera Blanca fault too.

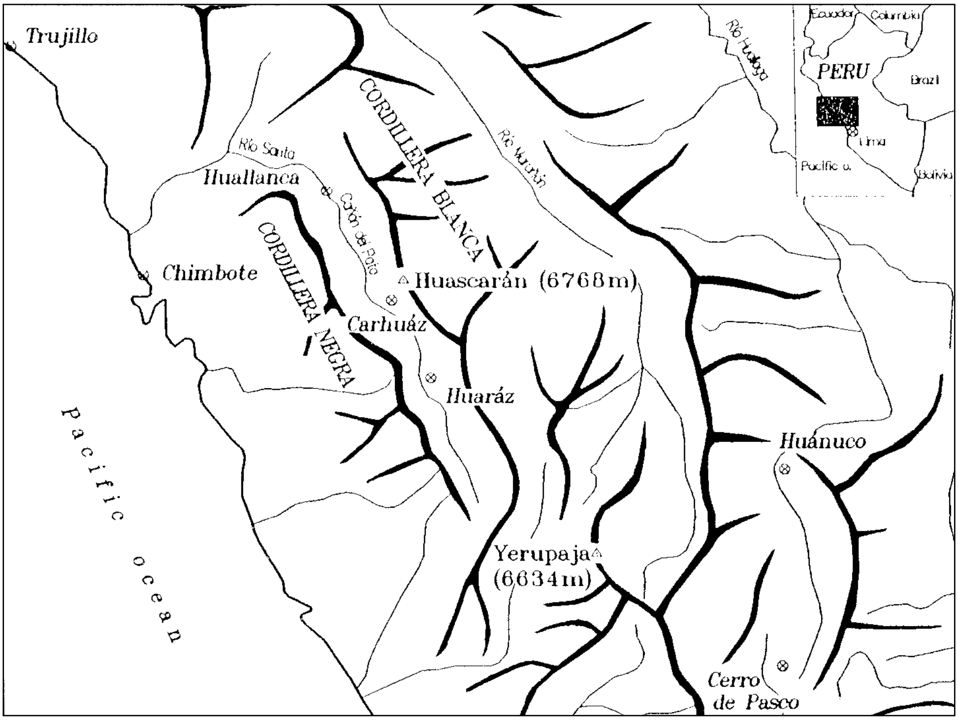

Fig. 1: Callejón de Huaylas.

Generally, we can distinguish the two main processes strongly influencing slope stability – recent earthquakes and climatic abnormalities like the El Niño effects. The earthquake effect was strongly manifested during 1970 event when the Yungay was completely destroyed (e.g. Plafker et al. 1971, Cluff 1971).

Strong El Niño effects are registered and described by Wells (1987), from the northern coastal region of Peru as well. She presented stacked sequences of flood deposits throughout the Late Pleistocene (a minimum of 21 events) and Holocene (a minimum of 15 events). A relative chronology of the deposits is based on terrace and soil stratigraphy and on the degree of preservation of surficial features. Episodic El Niño events usually bring torrential flooding to the northern coast. Such a record is missing from Callejón de Huaylas, but due to the regional effect of El Niño it could be supposed.

2. The Huascarán Mt. area

On January 10, 1962, rock and ice avalanche on the western face of the northern summit produced a debris flow which devastated Ranrahirca village and several smaller settlements (9 in total). Another disaster came in 1970, this time following an earthquake. On May 31, at 3:23 local time, an earthquake occurred with its epicentre some 25 km west of the coastal town Chimbote. Almost all towns in Callejón de Huaylas were damaged, Yungay among them. Both the events were described many times (e.g. Cluff 1971, Lomnitz 1971, Plafker et al. 1971, Plafker – Ericksen 1978).

The possibility of huge pre-Columbian avalanche was discussed by Plafker - Ericksen (1978). They mentioned that any such event occurred after the Spaniards arrival. In our opinion the extent of such a large avalanche remains a question. The presented upper limit is marked on the western site 260 m above the limit of the 1970 event (!). It seems to be rather high up the slope. The other site (eastern) was not marked. In fact there also exist huge blocks of granodiorites like the ones described by Plafker – Ericksen (1978). Fig. 2 shows the extent of such blocks near Musho village. But the question of origin remains. The other explanation could be secondary transport from morainic deposits which are spread all over the upper part of the studied area. It is possible to see similar blocks in lateral moraines on the right hand bank of Lagoons Llanganuco valley. In this case we would not like to make conclusions about the extent of an pre-Columbian avalanche.

On the other hand there exists an area, where the limit of debris flow is marked undoubtedly. The rock- and ice avalanche continued as a debris flow. The area is situated at the foothill of the Cordillera Negra, on the slope opposite the Huascarán Mt. It is already the left hand bank of the Santa River. The advantage of this locality is that the Huascarán origin of debris flow deposits can not be mixed with other influences because the Cordillera Negra consists in the large surrounding of this area of volcanic material. The locality does not bear any traces of glacial modelling.

According to Plafker – Ericksen (1978) debris runs up to a vertical distance of 123 m, 40 m higher than the 1970 deposit. They describe blocks several meters across which contrast with the much smaller size of the rocks that make up the 1970 deposit at this location. According to our field investigation the limit is at a level of 2, 540 m a.s.l., close to Matacoto village. It means 150 m above the river water level.

Two boulders (30 x 50 cm) were found in a small, shallow stream channel under approximately 20 cm of local slope debris and pure soil. About 3 m down stream was another block found, partly rounded. This could mean that boulders might have been partly transported after deposition from an upper locality. Also the above mentioned fact that only larger blocks from a pre-Columbian avalanche were found, compared with that of 1970, could suggest that the extent was in fact larger and small stones could not have survived on the steep slope up to now. The rather coherent cover of pre-Columbian deposits is developed at a level of 2, 525 m a.s.l. The blocks measure up to 1,5 m in diameter. In the river bed it is possible to see huge blocks from the pre-Columbian deposits. They were exhumed by the river action. In contrary, the large blocks described by Plafker – Ericksen (1978) at the slope of the Huascarán Mt. and similar ones registered by authors on the opposite site of the 1970 event are at the surface, only party buried in slope deposits due to their weight. We know that this huge avalanche occurred somehow before the Spaniards arrived and due to the 20 cm thick cover of local debris and soil it was not „just before“.

The youngest event took place in December 1987 (Ames 1987), but was not risky for the inhabitants settled below. The mixture of ice, snow and rocks accumulated relatively high up slope of the Huascarán Mt. this time at an altitude of 2, 950 – 3, 000 m a.s.l. at

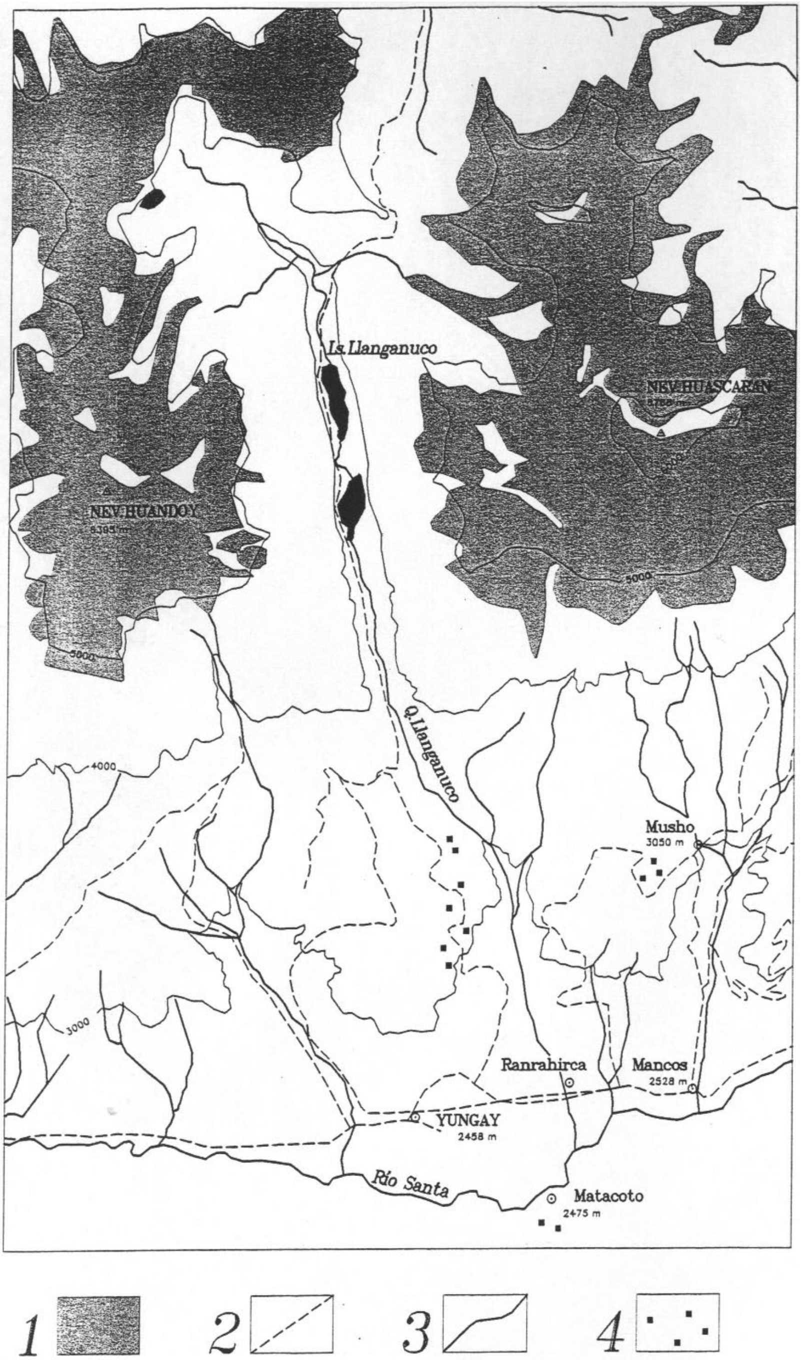

Fig. 2: The Huascarán Mt. area
1. recent glaciation, 2. roads, 3. rivers, 4. supposed remnants of pre-Columbian rockfall.

the crossing of the Armapampa and Shacsha (Llanganuco River) valleys. According to Plafker – Ericksen (1978), fresh linear cracks in the summit ice cap that extended far from the avalanche source were observed. Their continuity and vertical offsets suggest that they may have reached bedrock and produced instability of the peak for future.

The origin of the lakes in Quebrada Llanganuco (Llanganuco valley), between Nevados Huascarán and Huandoy, is also partly associated with slope movements. The lakes are dammed by dejection cones coming from both the above mentioned mountains. Slope material from the lateral walls of the "U" shaped valley is partly involved, partly glacio-fluvial material from frontal moraine of tributaries, and, during the 1970 earthquake, some deposition took place from northern summit of Huascarán (but the total volume of rocks and ice can not be compared with that which buried Yungay).

From its issue to the broader Callejón de Huaylas the general character of the Llanganuco valley is changing towards the upper parts (behind Llanganuco lakes). Most rockfalls from steep walls are in the lower part of the valley close to the main Cordillera Blanca fault. This area is also much more dissected by fissures parallel to the longitudinal fault system and the valley is in this part rather narrow. The primary jointing in this area is 81° and due to the exfoliation 59°. The process of exfoliation is known to play a significant role in creating suitable conditions for rockfalls. Higher, in the upper and broader part of the Llanganuco valley (above the lakes), the bottom is flat due to fluvial accumulation and lateral walls do not suffer from significant slope movements. Continuous accumulation of debris only takes place at the foot of steep slopes. But the intensive support of material from the lateral slopes or from the crest above slopes is ending at the level of dammed Llanganuco lakes.

Between Yungay and Yanama, on 11 January 1995 after 3-days rains the road was destroyed for a total length of 300 meters. The material was washed out from the young unconsolidated frontal moraine (4,700 m a.s.l.) situated under the southern peak of Huandoy (6,166 m a.s.l.). The frontal part of the debris flow reached one of the Llanganuco lakes (between Huascarán and Huandoy Mts.) According to the airphotos this area is endangered by the melting tongue of the Huandoy glacier. Its water is breaking through the moraine. The retreat of the glaciation in Cordillera Blanca is very clear in last 30 years.

3. Cañón del Pato

The Santa River eroded the deep and narrow Cañón del Pato on its crossing of the Cordillera Negra. The water level of the Santa River is 1,813 m a.s.l. at the beginning of the canyon. The main fault separates Plio-Pleistocene volcanics and, slightly to north, Mesozoic sediments from the Pliocene granodioritic batholith to the east (Dalmayrac 1974). The 1970 earthquake left the area highly unstable. There are reactivated normal faults, rock slides, detached slabs creeping under gravity and perched alluvium on steep rock slabs (Reynolds 1989). At the very beginning of the canyon several types of instability were registered and mapped by Zapata (1987). The main plant at Cañón del

Photo 1: A blockslide in the right tributary of the Santa River (below the village of Monterrey. (Photo by V. Vilímek)

Photo 2. Transported material from the above mentioned blockslide (Photo 1) which changed the cross profile of the valley (close to the main road going through Callejón de Huaylas). (Photo by V. Vilímek)

Photo 3: Non-consolidated material was transported by a debris flow from Cordillera Negra. Small slides from lateral slopes are well visible. (Photo by V. Vilímek)

Photo 4: The airport by Marcará (close to Carhuaz) was blocked by a debris flow coming from Cordillera Negra. (Photo by V. Vilímek)

Photo 5: Cañón del Pato could be blocked by a rock slide especially during an earthquake. Detached slabs are creeping under gravity. (Photo by V. Vilímek)

Photo 6: The upper part of the rockslide (Photo 5) is heavily disturbed with large open trenches between separate blocks. (Photo by V. Vilímek)

Photo 7: Large blocks of granodiorites are spread on the SW slope of Huascarán Mt., due to ice- and rockfalls. (Photo by V. Vilímek)

Photo 8: Some blocks of granodiorites reached the lower part of the Cordillera Negra slope, which consists of volcanic material in this area, after the rockslide from Huascarán Mt. It means that these blocks went across the Santa River up into the opposite slope of Huascarán. (Photo by V. Vilímek)

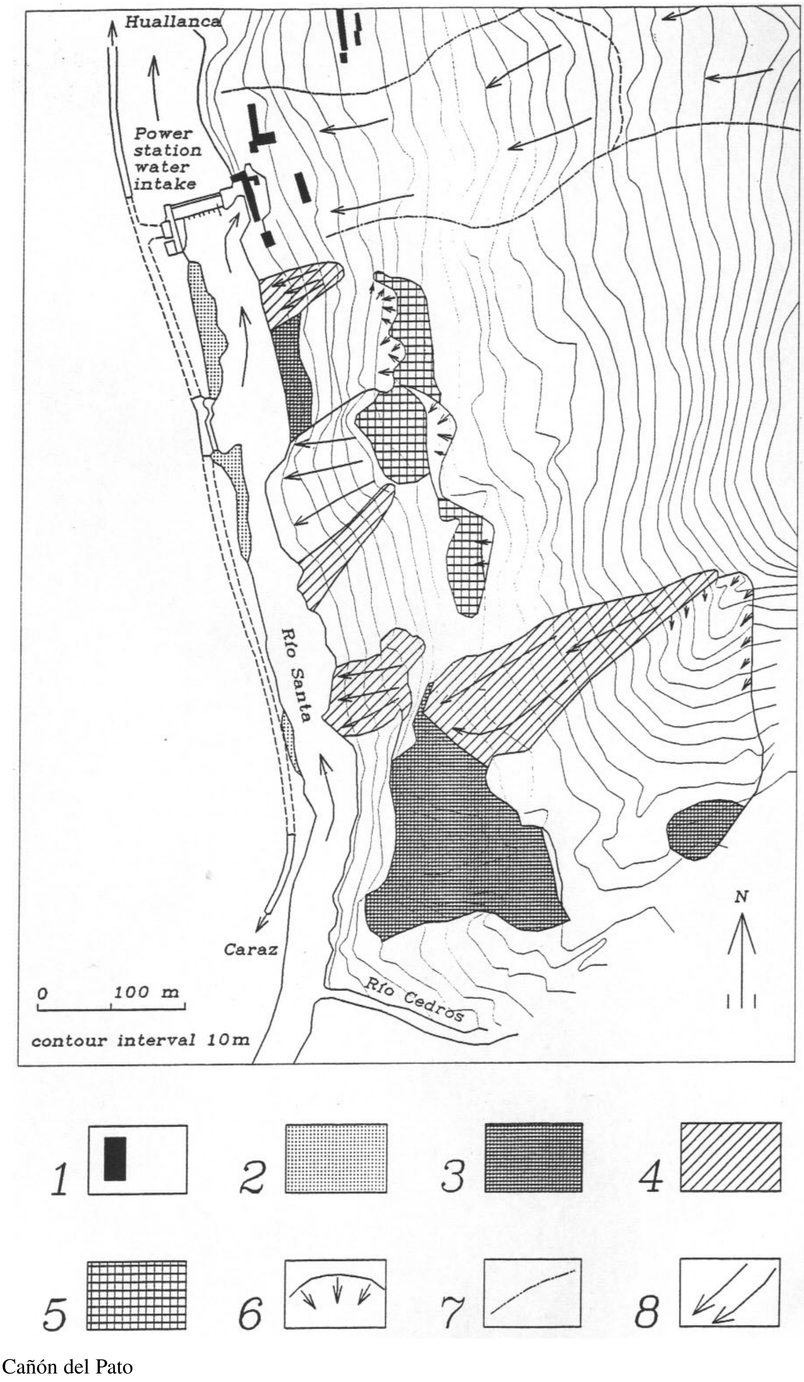

Fig. 3: Cañón del Pato
1. buildings, 2. fluvial deposits, 3. alluvial deposits, 4. rock slides, 5. rock platforms, 6. slip directions, 7. supposed fault, 8. direction of slope movements.

Pato is threatened by general slippage of a zone 900 m long and about 360 m wide from an altitude of about 2,320 m. The volume of potentially unstable huge main blocks is about 600,000 m^3 in area about 315,000 m^2. The metamorphic rocks occurred in slabs of different thickness and other parts are covered by debris. In the case of the slabs, natural stratification (foliation) prevails. For understanding the intensive fracturing, it is important to study the mechanism of batholith intrusion. Due to both the steepness of the slope and the inclination of stratification down the slope, gravitational processes play an important role in slope movement development.

It is possible to divide the area of sliding into different parts according to the type and intensity of process (Fig. 3). A rockslide of about 86,000 m^2 (Zapata 1987) is situated on the right bank of the Santa River. In the lower part, the slabs are partly sitting in the river bed supporting the upper part of the hanging rocks. The blocks were moved and they found temporary equilibrium. The general inclination of the mass which slid is 42°. In addition the rock slide narrowed the river bed and the flowing water must produce considerable stress on rocks. Visible lateral erosion was not seen. But the locality could be under strong pressure during a high water level, especially at the time of carrying debris from some local tributary debris flow. The other process which could trigger a slide is the seismic shaking. Seismic hazards are rather strong in this area.

There is a step like crest at the confluence of Rio Cedros (a fault based valley) and Rio Santa, which consists again of a triangular block. The influence of crossing faults is supposed. The area is also significant by enormous accumulation of transported material from the tributary (Rio Cedros) which is presented by a dissected fan and moreover remnants of this material coming from a huge debris flow are hanging up in the opposite wall – the left hand bank of the Santa River valley.

Rock platforms are situated at a level of 1880–1900 m. Some of their blocks have signs of rotation and some are chaotically distributed. They are also source of potential hazard, especially in the case of an earthquake.

The sliding area in general was influenced by contact metamorphism and, moreover, is situated at a fault crossing (the main Cordillera Blanca fault and the perpendicular fault of the Los Cedros valley). The intensity of fracturing could coincide with the intensity of faulting. The weathered material does not contain clay – this is not the reason for sliding.

Apart from the described rocksliding, there are, in the upper zone, open trenches which comprise a considerable hazard during an earthquake. Any significant slope movement could totally block the Santa River and form a lake, which after sudden break would produce a flooding situation. The present equilibrium, determined only from visual observations, is only a temporary state.

4. Conclusions

There are different types of slope movements in Callejón de Huaylas according to variability of geological and tectonical setting. Most of them were triggered by intensive rains or earthquakes. The anthropological factor does not belong to the main ones. Apart from local investigations, no inventory of slope movements exists. The youngest fault zone is also accompanied by small landslides.

Using a combination of geological, geomorphological and recent geodynamical investigations we are able to distinguish 3 basic engineering geological zones with different conditions and types of slope deformation. The first one is the mountain range of the Cordillera Blanca, formed predominantly by Miocene granitic rocks disrupted by tectonic ruptures and affected by recent exogenous geodynamic processes like glaciers. The geological setting is appropriate for huge rockfalls.

The second one is the mountain range of the Cordillera Negra formed previously by Cretaceous formation with volcanic rocks and sediments. Volcanic rocks weather relatively quickly and produce material for debris flows of different volume.

The third one is a zone of Tertiary-Quaternary filling sediments of the Santa River valley, formed by slightly or not cemented fluvio-glacial sediments. There, it is possible to observe different types of slope deformations from rotational slides, block slope deformations or debris flows.

About 93 slope movements with propriety damage or lives lost were observed during the first half of 1998 due to the El Niño effect. Some other slope movements did not cause any damage and therefore were not registered by regional offices. In the Santa River valley (between Huaraz and Yungay towns) we observed some tens of such landslides. The main road along the Santa River was constructed previously in the fluvial and glacio-fluvial sediments. During February 1998 the road was damaged in 4 places between Huaraz and Yungay by debris flows from the west side, from the Cordillera Negra mountain range.

In these registered landslides 25 people died, 856 houses were destroyed and 2,917 damaged. Some 62 bridges were destroyed, 56 of them damaged and 4.8 km of roads were totally destroyed (83.7 km were damaged) by flood and slope movements

Using a detailed field investigation, the reach of pre-Columbian rockfall has been identified at a level of 2,540 m a.s.l. It means 150 m above the water level of Santa River near Matacoto village, higher than has been mentioned in previous works. On the other hand, it is not possible to distinguish so precisely the description of the remnants of pre-Columbian rockfall on the slopes of the Huascarán Mt.

The area of considerable slope movements on the right bank of Santa River in Cañón del Pato consists of different parts (Fig. 3). A rockslide of about 86,000 m^2 moved down to the river bed, but a lot of slabs are still hanging higher in the slope under temporary equilibrium which could be disrupted by any stronger earthquake. Another potential hazard results from rock platforms situated at a level of 1,880–1,900 m a. s. l. They are chaotically distributed and some of them bear signs of rotation.

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References

AMES A. M. (1987): Informe de la inspeccion del alud del Nevado Huascaran producido el 16 de Diciembre de 1987. Report Hidrandia s.a., Glaciologia e Hidrologia, 4 p., Huaraz, Peru.

CLUFF L. S. (1971): Peru earthquake of May 31, 1970; Engineering geology observations. Bulletin of the Seismological Society of America, 61 (3), June, 511–533.

DALMAYRAC B. (1974): Un exemple de tectonique vivante: les failles subactuelles du pied de la Cordillére Blanche (Pérou). Cahier ORSTOM, sér. Géologique, 7 (1), 19–27.

LOMNITZ C. (1971): The Peru earthquake of May 31, 1970: Some preliminary seismological results. Bulletin of the Seismological Society of America, 61 (3), June, 535–542.

PLAFKER G., ERICKSEN G. E., CONCHA J. F. (1971): Geological aspects of the May 31, 1970, Perú earthquake. Bulletin of the Seismological Society of America, 61 (3), June, 543–578.

PLAFKER G., ERICKSEN G. E. (1978): Nevados Huascarán avalanches, Peru. In Rockslides and avalanches, Natural Phenomena, 277–314, Voight B. ed., Elsevier. Amsterdam – Oxford – New York.

REYNOLDS J. M. (1989): Hazards assessment in the Callejón de Huaylas, Cordillera Blanca, Peru. Report for Hidrandia S. A., Glaciología e Hidrología, No. 857, 71 p., Huaraz, Peru.

VILÍMEK V., ZAPATA M. L. (1998): Geomorphological response of neotectonic activity along the Cordillera Blanca fault zone, Peru. In: J. Kalvoda, Ch. Rosenfeld eds., Geomorphological Hazards in High Mountains Areas, 1998, 245–262, Kluwer Academic Publishers, 314 p., London.

WELLS L. E. (1987): An alluvial record of El Niño events from northern coastal Peru. Journal of Geophysical Research, 92, C13, 14 643–14 470.

ZAPATA M. L. (1987): Estudio geologico definitivo sobre deslizamientos y derrumbes de roca en la zona de Bocatoma de la central hidroelectrica Canon del Pato. Report for Hidrandia s.a., Glaciologia e Hidrologia, Huaraz, 31 p., Peru.

SVAHOVÉ POHYBY V CALLEJÓN DE HUAYLAS V PERU

R é s u m é

Cordillera Blanca je budována především z granitických hornin, byla porušena tektonickými pohyby a údolí jsou přehloubena ledovci. Strmé skalní stěny porušené exfoliací podléhají skalním řícením. Některá skalní či ledová řícení jsou podmíněna výskytem zemětřesení. Cordillera Negra je tvořena především z vulkanických a sedimentárních hornin. V důsledku intenzivního zvětrávání je na svazích velké množství nesoudržného materiálu pro různé typy svahových pohybů (např. bahnotoky, přívalové proudy). Sedimenty v údolí řeky Santy mají charakter fluvio-glaciální, místy s vulkanickými sedimenty. Většinou se jedná o nezpevněné materiály, ve kterých vznikají rotační sesuvy, svahové pohyby blokového typu či kamenné proudy.

Terénní výzkum a studium leteckých snímků z oblasti Huascaránu byly zaměřeny na upřesnění rozsahu starého skalního řícení, ke kterému došlo v prehistorickém období. Na jeho existenci upozornili již Plafker, Ericksen (1978). Při našem detailním terénním průzkumu protilehlého svahu Huascaránu byly identifikovány zřícené hmoty v nadmořské výšce až 2540 m n.m., a to 150 m nad úrovní řeky u obce Matacoto. Relativně-souvislejší výskyt těchto zřícených hmot, který je odkryt říční erozí, leží v nadmořské výšce 2525 m n. m., tedy 135 m nad hladinou řeky. Mohutné balvany, kterými zmínění autoři dokládají rozsah prehistorického řícení na svazích Huascaránu, mohly být přemístěny ledovcem a nelze je tedy jednoznačně považovat za důkaz. Obdobné bloky se vyskytují také v boční moréně na pravém břehu řeky Shacsha (vytéká z jezer Llanganuco); tedy zde již prokazatelně mimo akumulační oblast dávného skalního řícení ze severního vrcholu Huascaránu.

Svahové pohyby v kaňonu del Pato jsou převážně blokové skalní sesuvy, které ohrožují ústí vodního přivaděče podzemní hydroelektrárny, včetně doprovodných staveb. Spodní část porušené zóny dosahuje okraje řečiště a při zemětřesení či větší povodni hrozí další aktivace svahového pohybu. Vzhledem k úzkému korytu řeky Santy může při rozsáhlejším svahovém pohybu dojít k úplnému přehrazení toku akumulační haldou sesuvu, jejíž protržení by mělo katastrofické následky.