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NATURAL HAZARDS IN THE CORDILLERA BLANCA MTS., PERU

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ABSTRACT. The Cordillera Blanca Mts., as a part of the Peruvian Andes, is a young mountain range with a high degree of seismic activity, an intensive valley and highly developed erosion network, connected with slope instability. The Callejón de Huaylas (Santa River Valley) and adjacent slopes of the Cordillera Blanca Mts. have been affected by several natural catastrophes, the most important of them taking place in 1970 (an earthquake and consequent slope movements). As the whole region is relatively densely populated, the problems of risk assessment levels gains in importance, especially when proofs exist that in the period before the arrival of the Spanish, the Huascarán was the cause of a much larger rockfall than those registered during this century.

KEY WORDS: geomorphology, natural hazards, earthquake, Huascaran Mt.

1. INTRODUCTION

The western part of South America is an example of an active continental margin with Cordillera tectonics [Frutos, 1981]. That margin has developed, in addition to a deep marginal trench, a belt of coastal sea terraces and an elevation zone under the form of the Andes. According to the theory of lithospheric plates, the Andes were generated during a collision of the South American lithospheric plate with the Cocoz, Nazca and Antarctic Block [Mísař, 1987]. A belt of young mountains ranges with a high tectonic activity spreads for a length of 7,000 km. The western limit of the South American continent represents the boundary between the oceanic and the continental plates. The model of subduction of the Pacific plate is generally valid also for its part – the Nazca plate. Specific features nevertheless appear in a more detailed study.

According to Barazangi and Isacks (1976), two out of five relatively independent segments of the Nazca plate are slowly and parallelly to the lower margin of the South American plate (subhorizontal character of subduction) immerging under South America. At their contact zone, asthenosphere material is either scarse or lacking, which is manifested by insufficient Quaternary volcanism. According to L. Ocola's estimations (oral communication), the Nazca plate moves on average 7 cm per year. In the northern and central part of Peru, slower movements are supposed, while 7 cm per year are indicated for the southern part of Peru. One of the two above-described segments is also the region including the central and the northern part of Peru. However, this part manifests Miocene and Pliocene volcanism [Giletti, Day 1968]. The overthrust geometry is probably variable in time. Volcanism and seismic activity in the western part of South America depend on the tectonic development of oceanic plates. For instance, impulsion of the Upper Eocene volcanism can be correlated in time with the change of speed and of expansion and with the sense of rotation of the Pacific plate [Mísař, 1987].

Earthquakes foci in Peru are situated at a depth inferior to 640 km. A number of them are linked closely to the subduction zone and by that, the depths of the different foci grow with increasing distance eastwards from the coast. According to L. Ocola (oral communication), earthquakes with their foci at depths superior to 400 km are not dangerous in their intensity. Besides these so-called subduction earthquakes, there are, in the Andes, also shallower earthquakes connected with faults in the Earth's crust. In the case of Callejón de Huaylas (Santa River Valley), the so-called subduction earthquakes should originate at depths of about 80 to 90 km, in fact however, their foci are situated relatively shallowly below the surface (10 to 20 km), which influences their destructive effects.

Tab. 1. Survey of earthquakes in the Ancash region (1948–1974)
(elaborated according to Silgado E.F., 1978).

1956, October 29
Carhuaz – both old and new houses damaged
Ancash region I_0 =V – VII

1961, July 3
mainly Trujillo affected
Huaraz I_0 =VI

1962, April 18
Huaraz – church tower fallen
Ancash region – landslides
(I_0 not indicated)

1963, September 17
epicentre at the coast (Trujillo)
only registered in Callejón de Huaylas
(I_0 not indicated)

1963, September 24
Ancash region, Cordillera Negra – canals damaged, landslides
Huaraz – houses damaged
(I_0 not indicated)

1970, May 30
the whole Ancash region strongly affected
aluvial regions I_0 =VIII (by high level of underground water up to I_0 =IX)
Callejón de Huaylas I_0 =VII to VIII

The intensity of endogenic processes also influences the high activity of hazardous geomorphological processes. The Cordillera Blanca (White Cordillera) and Callejón de Huaylas, separating the Cordillera Blanca and Negra, were affected by natural catastrophes many times in the past. These were earthquakes (see Tab. 1), landslides, debris flows, inundations or mud flows from broken glacial lakes.

2. Destructive Mud Flows Called Alluviones

Glacial lakes in the Cordillera Blanca region are relatively young, which is associated with a rapid retreat of glaciers. In the last fifty years, a number of new lakes were constituted and older lakes grew. According to C.R. Portocarrera (oral communication), a perceptible warm spell occurred during the last forty years: it was at its most intense during the fifties and then since the middle seventies up to now.

Water in the glacial lakes is usually retained by moraines. Avalanches and landslides falling into lakes put pressure on these natural dams which may cause them to break. Water, together with washed up moraine material, is thus transported into the valley, dragging with it on its way soil and weathered rocks. The so-called alluvion (local name) is formed, representing a great danger for settlements situated in the lower parts of the valley. Water from lakes may also soak through the moraine dam, washing away more fine-grained material and by that progressively weaken the solidity of the dam.

The most destructive alluvion in that region occurred on the 13th of December 1941. A big avalanche fell into the Palcacocha lake situated above Huaraz in the upper part of the Cojup Valley. This caused the frontal moraine which had been retaining water in the lake to break. The water streamed down into another lake, situated below (non-existent nowadays). It broke up, too, and water rushed down the valley into the town of Huaraz and further on into the Santa River Valley. The alluvion covered a distance of 20 km causing the death of 5,000 persons. The town was reconstructed and there are no traces left to remind of the catastrophe. Today Palcacocha is only a shallow lake beneath steep walls of a lateral moraine. The oldest recorded catastrophe of this type is dated 1702.

The pyramid in Chavin originating from the period of about 1,500 B.C. was buried by an alluvion in 1945. That alluvion was due to an ice avalanche which fell down to the lake from the Nevado Huantsán ("nevado" is a mountain covered by perpetual snow). Other alluvions devastated the Valley de los Cedros (in 1950) with the water coming from the Lake Jancarurish. Fifteen years later (in 1965), the situation repeated itself in the Carhuascancha Valley after the emptying of the water from Lake Tumarino.

3. Avalanches and Ice and Rock Falls

Various types of slope movements are a frequent phenomenon in the Cordillera Blanca. They are most frequently due to extreme rainfalls or to earthquakes. Due to the relatively low age of the mountains and to intensive erosion development in the valleys, a number of slopes are unstable and because of that predisposed to mass movements. One of the most significant natural catastrophes occurred directly below the Huascarán, the highest mountain of the Cordillera Blanca (6,746 m – southern summit) and at the same time in the Peruvian part of the Andes.

On the 10th of January 1962, an avalanche on the western wall of the northern summit of the Huascarán (6,655 m) devastated the town of Ranrahirca and several smaller settlements (9 in total; according to Plafker and Ericksen 1978). This catastrophe, as well as another one in 1970, is often called by different names, as it was composed conjointly by several types of processes. It is classified either as an avalanche, because it started as a snow and ice avalanche [Bolt et al., 1975], or as a debris flow (also a mud flow – Lomnitz, 1971). Sometimes it is classified as a landslide [Bolt et al., 1975] or as a rock slide [Browning, 1973]. It killed some 4,000 people. Záruba and Mencl (1982) affirm that it was caused by an earthquake, but neither any other do confirm their statements. In any case, the avalanche contained a great part of snow and ice. It was succeeded by a rockfall from lower parts of the wall than during a similar rockfall in 1970 (according to eye–witnesses in Plafker and Ericksen, 1978). The rock loosening was probably due to a lower consistency of the rock massif caused by an incessant repetition of the freeze – melt process. These regelation processes are largely dependent on latitude (9° of southern latitude) and on altitude (up to 6,655 m). In this case, during the day it is warm even in the high altitudes with frost at night. The temperature oscillations are high. Ranrahirca has been reconstructed, but moved southwards. The avalanche was much smaller than the one which occurred eight years later from the same summit (see Fig. 1) down to the level of the small ridge (Cerro de Aira) that protected Yungay at the time. The 1970 catastrophe is much better known and for that reason it is compared to the older event.

On the 31st of May 1970 at 15:23 local time, an earthquake with an epicentre situated about 25 km west of the coastal town of Chimbote occurred (see Fig. 2). Its hypocentre was situated at a depth of about 50 km, its magnitude was 7.75. Some 80,000 people died on that occasion (according to other data, there were more than 50,000 dead and more than 50,000 injured in an area of 75,000 km^2 – Bolt et al., 1975), which is the most serious seismic catastrophe in the western hemisphere from the point of view of numbers of victims. In the historic period, other earthquakes with significantly greater quantities of released energy have occurred in South America (see Tab. 2). In 1970, almost all the towns in Callejón de Huaylas were destroyed. About 1 million persons (800,000 according to Bolt et al., 1985) lost their homes. The extent of the catastrophe was not entirely known for several weeks, as landslides and rockfalls caused by the earthquake blocked roads and a number of places were inaccessible which complicated rescue works.

The earthquake started with feeble oscillations, then the vibrations became more intensive lasting about 50 s (30 to 50 s according to Bolt et al., 1975). Aftershocks went on during the entire night, 64 in total. The proper rockfall occurred, according to eye–witnesses (in Voigt, 1978) immediately
phases: the second one being the more intensive. The quantity of dust in the atmosphere was so great that helicopters could not land in some places even after two days. Ninety per cent of the town of Huaraz in the Santa River Valley were

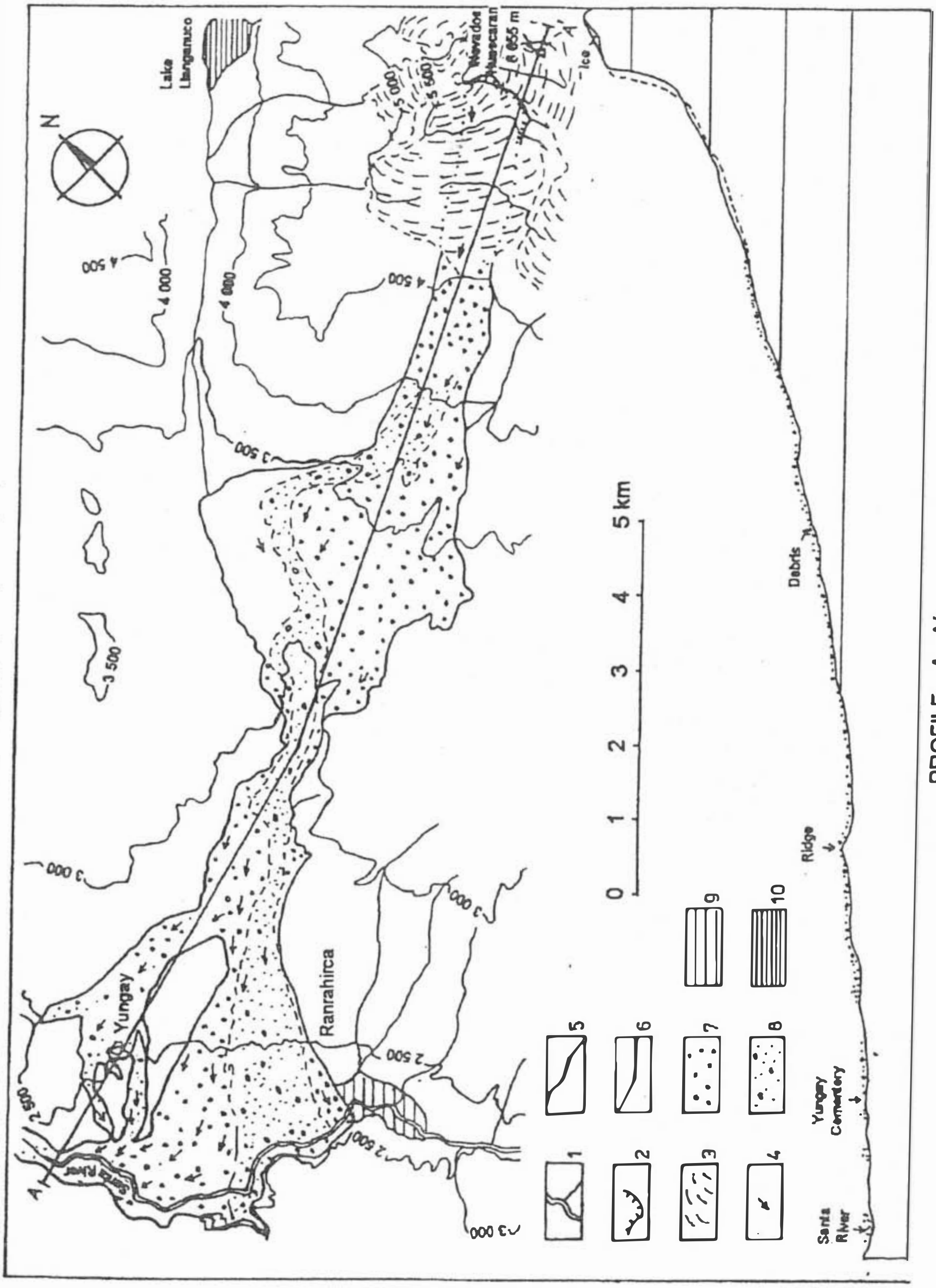

FIG. 1. Map scheme and lengthwise profile of the avalanche from the Huascarán (according to Plafker, Ericksen, Concha 1971). 1) rivers; 2) rockfall dissociable region; 3) glacier; 4) direction of the fallen matter movement; 5) limit of the debris flow; 6) profile A – Á; 7) region affected only in 1970; 8) region affected both in 1962 and 1970; 9) temporarily dammed lakes; and 10) present-day lake.

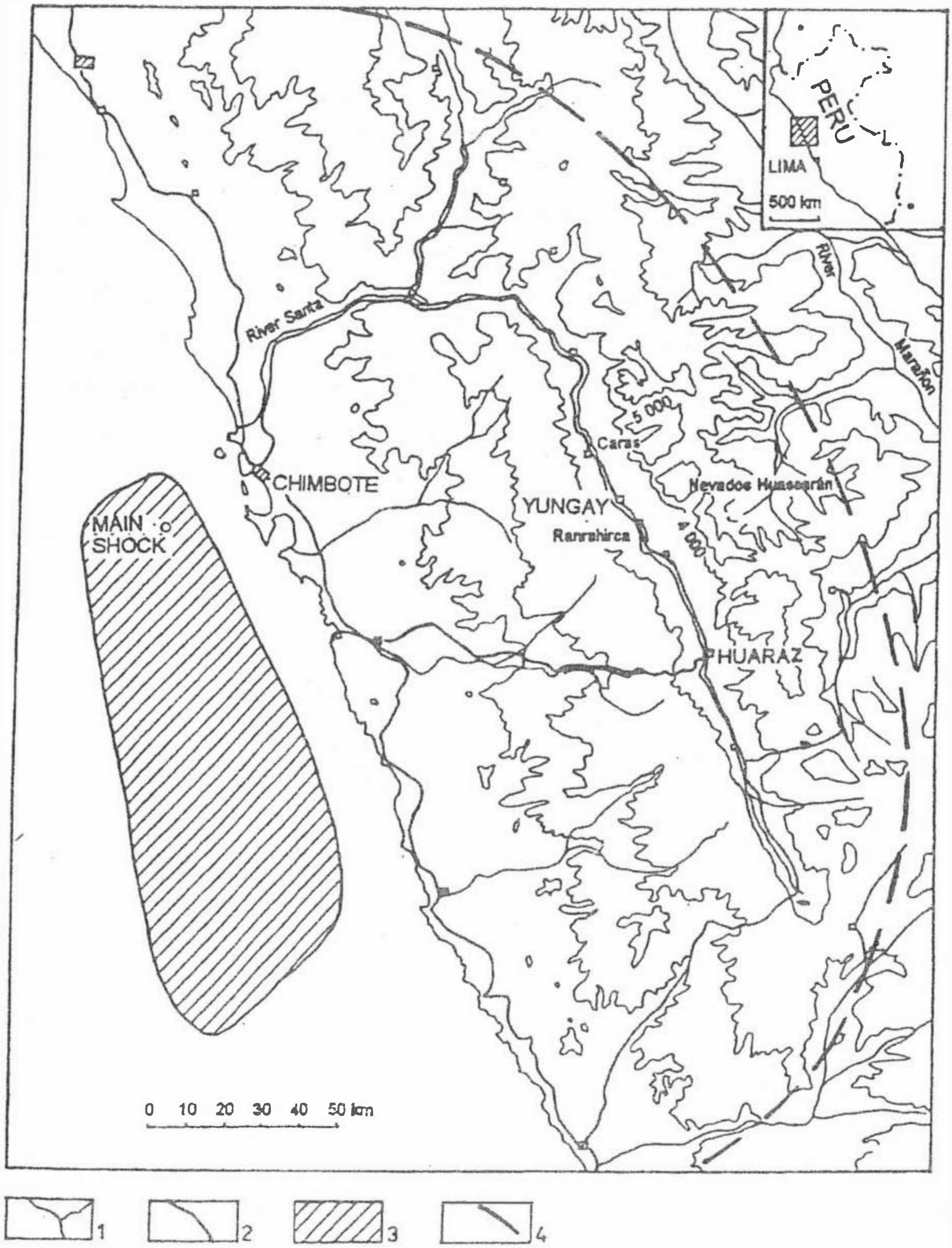

FIG. 2. Map scheme of that part of Peru affected by the earthquake of 1970 (according to Plafker, Ericksen 1978).
1) rivers; 2) roads; 3) region of the epicentre (point) and of aftershocks (hatched); and 4) approximative limit of the affected region.

TAB. 2. Earthquakes in Peru (with $M \geq 7.5$)
(elaborated according to Silgado E.F. and Oshiro F.H.)

place	date	magnitudo
Lima	July 9, 1586	8.1
Moquegua	November 24, 1604	8.4
Lima	October 20, 1687	8.2
Lima	October 28, 1746	8.4
Arequipa	May 13, 1784	8.0
Tacna	August 13, 1868	8.6
Piura	July 24, 1912	7.9
Caravelí	August 6, 1913	7.75
Lima	May 24, 1940	8.2
Nazca	August 24, 1942	8.4
Satipo	November 1, 1947	7.5
Tumbes	December 12, 1953	7.7
–	July 26, 1958	7.5 (?)
Arequipa	January 13, 1960	7.5
N of Lima	October 17, 1966	7.5
Chimbote	May 31, 1970	7.75
Lima and more southwards	October 3, 1974	7.5 (or 7.6)

destroyed and more than one half of its 30,000 inhabitants died. Another damaged town in Callejón de Huaylas was Caraz (see Fig. 2). The numbers of destroyed buildings were very high because they were not constructed with a view to the possibility of earthquakes. In the majority of cases, mainly in villages, they were simple houses from unburnt bricks simply laid one on a top the other without any reinforcement. The same way of building is used there still now.

Granite blocks broke off the northern summit of the Huascarán (6,655 m), and that again from the western wall. They took with them 3 million m^2 of ice and snow and later on an even greater quantity of soil on their way downhill. After the granite blocks and ice fell on the glacier, they caused a partial melting of ice and snow and a rather great quantity of water appeared. The catastrophe occurred at the end of the humid period (in May), that is, in the period of the greatest accumulation of snow in the course of the year. The quantity of water in the avalanche could also have been influenced by the fact that the earthquake occurred after noon, that is, at that time of day with the highest relative temperatures and with the best melt conditions. On the contrary, Plafker and Ericksen (1978) affirm that the water in the mud flow only partially originated from the ice, as non-melted ice blocks were found in the Santa River Valley accumulations. They assume that the water came mainly from the water courses of valleys into which the avalanche had fallen, from damaged water canals bringing water from mountains to artificially irrigated fields and finally from underground water. Nevertheless, if we compare the immense quantity of the transported material and its liquidity with the Ranrahirca River flow, the river water would not seem to be the main source (when not mentioning the role of the underground water). In total, Bolt et al. (1975) estimate the quantity of the transported matter to reach 50 million m^2, while Plafker et al (1971) 50–100 million m^2 (Tab. 3). The avalanche route was 14 km (16 km according to Záruba and Mencl, 1982) with a vertical elevation of 4,000 m. The supposed speeds largely differ, from 280 km/h to 320 km/h (Tab. 3) and in exceptions up to 400 km/h. The avalanche took a route similar to that of 1962 (see Fig. 1).

Tab. 3. Comparison of volumes of rockfalls and consequent debris flows from the Huascarán.

year	rockfall volume (m^3)	speed (km/h)	source
1970	50 mil.	3	Bolt et al. (1975)
	50–100 mil.	280	Plafker and Ericksen (1978)
		280–335	Plafker et al. (1971)
1962	13 mil.	—	Bolt et al. (1975)
	—	170	Plafker and Ericksen (1978)

The world was shocked mainly by the disaster in the town of Yungay (at the foot of the Huascarán), where 18,000 inhabitants were buried under an immense debris flow (Photo 1). The difference with a similar catastrophe in 1962 is in the fact that this time the avalanche
which until that time has protected the town of Yungay. The rushing mass had no difficulty overcoming the ridge, as in this place the matter rose up to the height of 230 m above the Ranrahirca River bottom. The relative height of this ridge is sometimes indicated as 200 m, but it is not that high at the point where it was surmounted by the avalanche.

The question as to why Yungay was not preserved even this time has often been discussed. Considering the quantity of fallen matter (including the material gathered on the way downhill) and the fact that in 1962 the Ranrahirca Valley was almost entirely filled in, it follows that the quantity of material rushing down in 1970 from the Huascarán slope simply had to affect Yungay (Tab. 3). By 1962 it had been registered that the centrifugal force lifted the material at the outer sides of the valley bends into considerably greater heights than at the inner sides. In 1970 a part of the transported material flew into the air due to a moraine mound on the Huascarán slope situated across the avalanche route. The mound acted as a sort of springboard and immense boulders fell onto the area above Yungay – it was later testified by findings of boulder "craters" [Plafker et al., 1971].

The Ranrahirca River Valley narrows markedly 4 km before it opens into the main Santa River Valley (about 2.5 km from the road Huaraz – Caraz) and forms

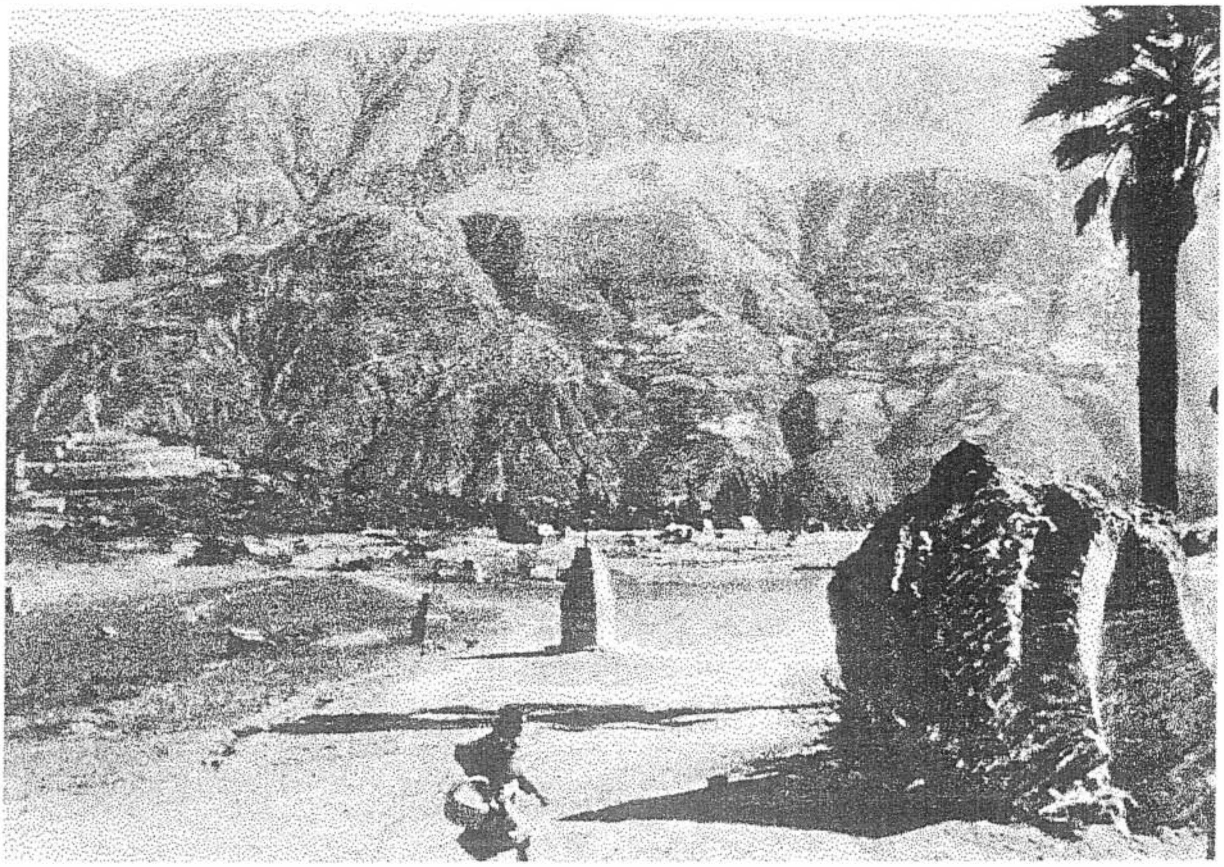

PHOTO 1. The region of former Yungay – on the right side, remnants of a church, on the left side the hill with the cemetery to which it was possible to run to save one's life in 1970. The Cordillera Negra in the background.

a sort of narrow gorge. The critical point for the genesis of a catastrophic event is probably located on the ESE margin of the Shillcop Village. Thanks to inertia (already mentioned above), in the laevorotatory bend, the falling mass reached a relatively high position on the right–side slope. After reaching the shallow col dividing the little ridge (Cerro de Aira) and a steep slope, it only had to surmount a height difference of 50 m. When considering the Ranrahirca Valley morphology and when taking into account the quantity of transported material, a hypothesis can be deduced that the narrow gorge of the above–mentioned defile jammed and the material was forced to find another way across the Cerro de Aira. (This fact was also confirmed by local inhabitants 25 years after the event, but the reliability of such information is questionable). In the middle part of the little ridge, crossed by the avalanche, too, the height difference is already considerably greater (about 140 to 200 m) and in the steepest place the slope inclination reaches 30 to 35°.

Downstream the water course below this narrow place, the valley considerably broadens and river sediments appear on slopes slightly above the present river bed (including abandoned relics up to a thickness of 20 m). Today, in the river bed, mostly terrace sediments (boulders) can be found. The material from the avalanche

PHOTO 2. View from the upper margin of the former Yungay towards the Huascarán (the northern summit is on the left).

has already been transported away. Boulders accumulated from the avalanche can be found on the talus cone and on the slopes where they are outside of the reach of the present river activity.

The Peruvian geophysicist M. Casaverde, who was by chance exactly in the affected region at the Yungay margin, describes how his car skipped during the earthquake and that it was not possible to entirely control it (Bolt et al., 1975). He also registered fissures in the road and damaged bridges and houses. He estimated that the height of the frontal wave of the avalanche (debris flow) affecting Yungay reached about 60 m. Further on, he described how one wave reached as high as the second "terrace" of the artificial hill with the cemetery (an old Inka sacred place) – the only place in Yungay which remained intact.

The avalanche route began under the northern summit of the Huascarán (Photo 2), followed the present river network, and dragged a part of the moraine material downward from the Huascarán slope. The major part of the material sedimentated in the former Yungay region is not of river origin though it has passed through the river network. The transport of material from the Huascarán had to be immense. In the accumulation region, numerous huge blocks originating not from the moraine sediments or from the debris mantle, but directly from the Huascarán rock wall are scattered.

In the centre of the former Yungay, the debris flow spread and its present surface is only slightly vaulted. While higher in the slope, in the direction from which the flow had come, the vaulting of the central part is greater and elongated in the direction of the longitudinal axis (that is in the direction of the avalanche movement). Palms were growing on the square of the destroyed Yungay, and some of them remained as they were partly protected by the hugest building of the town, the church. Although, the thickness of deposits in this relatively protected place reached 5 m. The church building, however, was unable to resist and it also fell down. At present, it is the only ruin apparent above the flat surface of the accumulation. The thickness of the deposits in the Yungay area, which is not the same in different places, is estimated by Browning (1973) to reach up to 33 m. The main road through the Callejón de Huaylas Valley has been newly constructed on the surface of the accumulation region. The height difference between the new segment and the original part reaches about 35 m on one margin of the avalanche accumulation, and about 25 m on the other one.

At the Ranrahirca mouthing, there is a huge talus cone, the source region of which was the northern summit of the Huascarán. Several generations of debris flows can be distinguished. Nowadays, scattered houses are mostly built higher on the slopes outside the accumulation area. The territory, menaced by flows of material from the Huascarán slope, is either left unused and grown over by a scarse wood, or small fields which have been created in some places. The tendency to progressively settle the damaged region is seen on its margins.

In the nearest proximity of Yungay, several other localities were affected by avalanches and landslides (for instance at the Parón lake). A smaller avalanche fell from the northern wall of the northern Huascarán summit into the lateral valley (a Czechoslovak mountaineering expedition perished there – Photo 3 and 4). The morphology of the valley shows that debris flows are frequent in those places, and that not only those coming from the Huascarán, but also those from the opposite group of summits (Nevados Huandoy – 6,342 m). In that place, the Llanganuco River Valley is practically blocked by accumulations from steep lateral slopes (Photo 4) and a new small

upper Llanganuco Lake (Oron Cocha) and the lower lake. The lower of these two lakes (Chiman Cocha) is also dammed by a huge debris cone from the Huascarán slope. Since 1970, two other smaller debris flows have fallen from the northern wall of the Huascarán, which is evident from the surface and the vegetation character on the main debris cone under which the Czechoslovak expedition is buried (Photo 3). At the foot of the opposite slope where a memorial to victims of the mountains is situated, a new huge debris flow appeared on 5th of January 1995 after strong rains (Photo 5 and 4) by-passing the above mentioned memorial by only centimetres. When taking into consideration both opposite slopes, nowhere in the Llanganuco River Valley are debris flows so frequent and have such a quantity of material accumulated than in this relatively short segment.

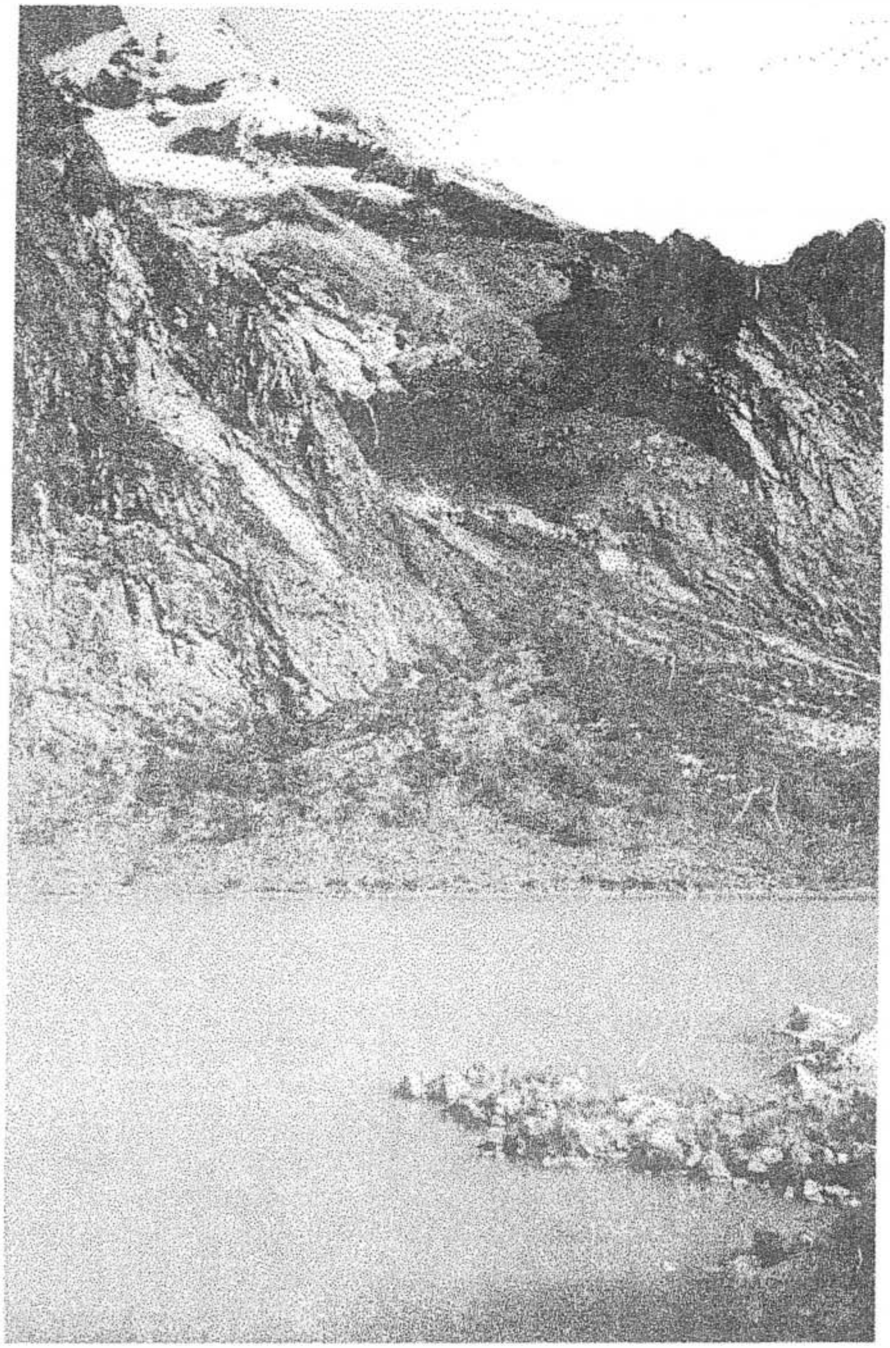

PHOTO 3. A debris cone under the northern summit of the Huascarán (between the upper and the lower Llanganuco lakes). A Czechoslovak mountaineering expedition perished here in 1970 during a smaller rock and ice fall.

4. CONCLUSION

In the place where the Ranrahirca is mouthing into the Callejón de Huaylas, the Santa River markedly turns to the opposite side (south–east) against the neighbouring mountain ridge called Cordillera Negra. Probably for a long time, the Santa River has been "pushed" away (by a huge amount of sediments) from the Huascarán which rests against its left river bank. It has already affected the straight course

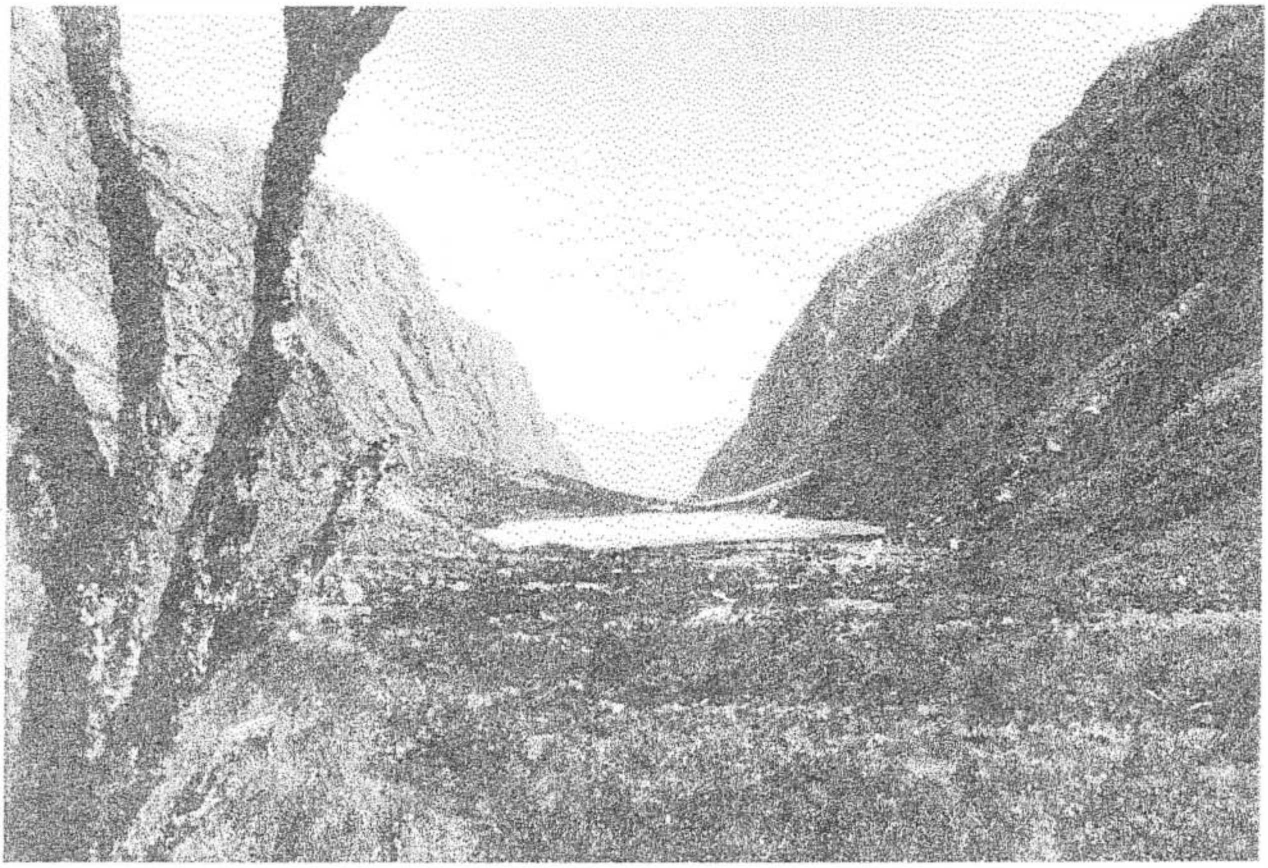

PHOTO 4. The upper Llanganuco Lake; in the left part a talus cone from the Huascarám Mts. is visible. The light belt on the right–hand bank is a new debris flow dating from 1995.

of the Cordillera Negra foot. A pronounced depression is evident on the western slope of the northern summit of the Huascarán. This place was the source of rock and ice falls in 1962 and in 1970. The possibility of a huge prehistoric rockfall from the Huascarán is mentioned for instance by Cluff (1971), albeit without precise evidence, and by Plafker and Ericksen (1978) who present a map scheme comparing the extent of that older rockfall with both more recent events.

The centre of the new Yungay seems to be situated outside the reach of possible avalanches from the Huascarán. The town spreads about 2 km north–westwards from the former town and is protected by a smaller hill situated in the foreground of the Huandoy Mt. Nevertheless, the south–eastern margin of Yungay could be menaced by a considerably larger rockfall from the Huascarán and in addition, the population in the expanding Yungay has continued to progressively settle at the margin of the once destroyed region. In 1995, a new school building was opened directly on the mud flow accumulation of 1970. It occurred exactly on the occasion of the 25th anniversary of the largest natural catastrophe in Peru's recorded history.

The slope above the new Yungay presents the danger of landslides even though the risk is lower in comparison with the avalanche of 1970. In the spring of 1994 (probably in March), a part of the slope slid (Photo 6) after a relatively intensive rainfall and burying fields and a small road at the northern margin of Yungay

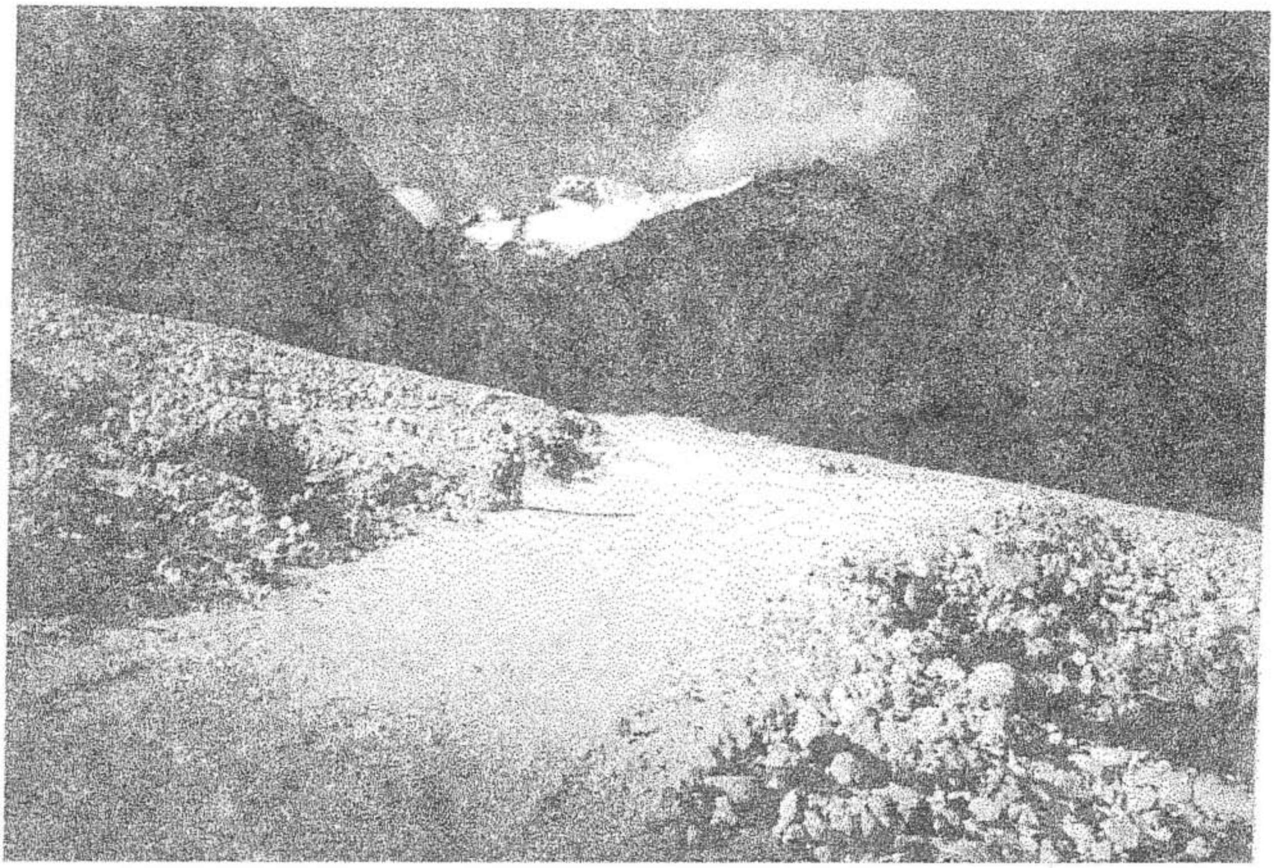

PHOTO 5. In January 1995 a debris flow went down the Huandoy slope towards the Llanganuco lakes.

(houses were not immediately menaced). The slope is furrowed by deeply cut river valleys and ravines, the lateral slopes of which are possible landslide regions. In comparison with rockfalls and avalanches from the Huascarán, this type of process poses only local risk and cannot menace the whole town (only some houses on its upper margin).

Further geomorphological research could be aimed at the elaboration of a detailed map of the menaced region by mass movements under the Huascarán. This could include the maximal extent of prehistoric avalanches and more importantly consider the possible risks for the Santa River Valley as the majority of the fallen material comes to rest there and the area is being settled yet again.

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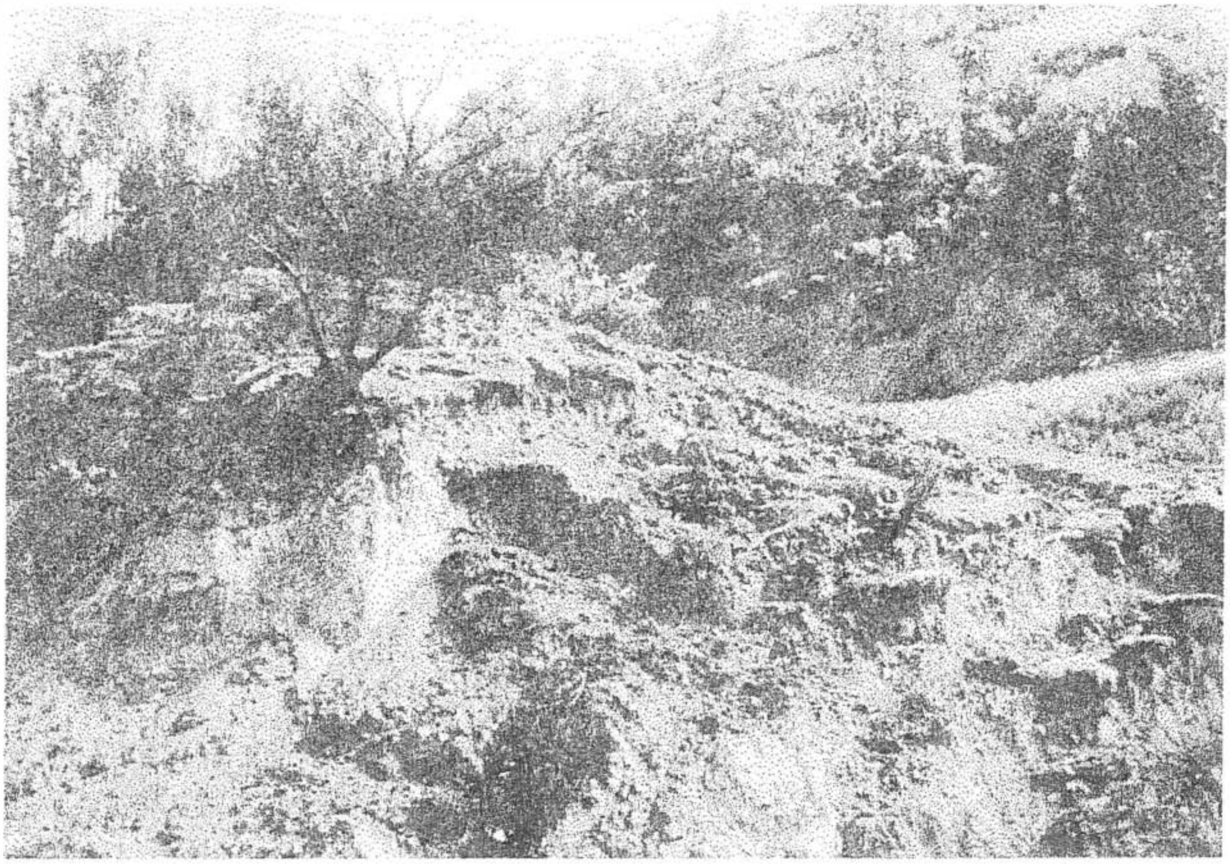

Photo 6. The landslide of 1994 above the present Yungay.

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PŘÍRODNÍ RIZIKOVÉ PROCESY V POHOŘÍ CORDILLERA BLANCA, PERU

Vít VILÍMEK

Cordillera Blanca v Peru patří k pásmu mladých pohoří s vysokou tektonickou aktivitou, které se táhne při západním okraji jihoamerického kontinentu. Horský systém And vznikl při kolizi jihoamerické litosférické desky s deskami cocoskou, nazckou a antarktickou. Intenzita endogenních procesů má též vliv na vysokou aktivitu rizikových geomorfologických procesů.

Cordillera Blanca (Bílé Kordiléry) a Callejón de Huaylas (údolí řeky Santy) byly v minulosti mnohokráte postiženy přírodními katastrofami (sesuvy, skalní a ledová řícení, laviny, kamenné proudy, bahnotoky, povodně apod.). Nejvýznamnější přírodní katastrofa se odehrála v roce 1970, kdy při pobřeží došlo k zemětřesení ($M = 7.75$), které vyvolalo svahové pohyby, z nichž největší následky mělo řícení a na něj navazující kamenný proud (či bahnotok) ze severního vrcholu Huascaránu. Tato událost, a jí podobná o 8 let starší (1962), byla poměrně dobře popsána a zdokumentována. Nicméně vzhledem k charakteru údolí Santy v oblasti pod Huascaránem a podle názoru některých autorů (např. Plafker, Ericksen, 1978) bylo v prehistorické době úpatí Huascaránu svědkem patrně ještě většího (větších ?) řícení.

Vzhledem k tomu, že je údolí Santy hustě zalidněno a že se osídlení opětovně vrací do již jednou postižených oblastí (1962 a 1970), vyvstává nutnost podrobného mapování rizikových oblastí.