PRELIMINARY REPORT

ON THE EFFECTS OF THE JUNE 6, 1994 *SIS*

(PAEZ EARTHQUAKE), SOUTHERN COLOMBIA

by

U.S. GEOLOGICAL SURVEY RESPONSE TEAM

Thomas J. Casadevall
U.S. Geological Survey MS 903
Denver Federal Center, Denver, CO 80225

Robert L. Schuster
U.S. Geological Survey MS 966
Denver Federal Center, Denver, CO 80225

Kevin M. Scott
U.S. Geological Survey
Cascades Volcano Observatory
5400 MacArthur Blvd., Vancouver, WA 98661

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. It is prepared primarily to provide a timely record of the USGS team visit and to aid INGEOMINAS geologists in their field studies.

July 29, 1994

INTRODUCTION AND MISSION OBJECTIVES

On June 6, 1994, a magnitude 6.4 earthquake in southern Colombia triggered landslides from an area south of the Nevado del Huila volcano. Landslides into the drainage of the Rio Paez caused debris flows and associated flooding which eventually buried several villages, took more than 150 lives, and displaced more than 20,000 people with more than 500 persons listed as missing. Debris flows also destroyed six bridges and approximately 100 km of roads along the Rio Paez drainage. Damage was caused by at least three mechanisms: 1) earth shaking related to the earthquake; 2) landslides and earthflows; and 3) flooding by the debris flow.

Nevado del Huila Volcano (5,265m; 17,060 ft) contains active hydrothermal areas in the summit region and is covered with glaciers above approximately 4,400 m elevation. The seismic activity at Huila volcano is monitored by the INGEOMINAS observatory in Popayan located 83 km to the southwest of the volcano.

At this time, the immediate threat of additional landslides appears to have subsided and officials have initiated reconstruction efforts. It is essential that these efforts involve geological studies to determine the suitability of reconstruction sites and to ensure that future events of a similar nature not produce a similar disastrous effect.

The primary objective of the U. S. Geological Survey mission to Colombia was to assist scientists of INGEOMINAS to evaluate the nature and magnitude of the post-June 6 landslide and flood events and to determine the possibility of future events. The focus of work was on the Rio Paez drainage and its principal tributary drainages, including the Rios San Vincente, Moras, Simbola, and Negro. Once the landslide and flood events have been evaluated, scientists will be in a position to advise public officials about the feasibility of reconstruction efforts.

A second objective was to evaluate what effect the earthquake had on the seismic activity and hydrothermal system at the Nevado del Huila volcano. Could the strong ground motion from the June 6 earthquake possibly have disturbed this presently quiet volcano? In these efforts, the USGS team worked closely with scientists of INGEOMINAS to evaluate these geological problems.

Nevado del Huila bears a strong resemblance to Mount Rainier Volcano in Washington State. Lessons learned from studying the Huila situation will have direct bearing on assessing the possibility of similar hazards at Mount Rainier. Mount Rainier is the Decade Volcano for the United States, and is the object of concentrated study by USGS, National Park Service, university, and other geologists.

During this mission, the team produced a video tape showing the areas affected by the June 6 events. A limited number of copies of this video are available from Kevin Scott.

LANDSLIDES AND SLOPE FAILURES -- OCCURRENCES AND MITIGATION MEASURES

CLASSIFICATION OF MASS MOVEMENTS

Mass movements due to slope failures in the drainage area of the Rio Paez and its tributaries can be defined by type as follows (Varnes, 1978):

FALLS -- Failure of vertical or nearly vertical slopes. Falls are known as <u>rock falls</u> if they occur mainly in rock; this is the most common fall mode. If in soil, they are known as <u>soil falls</u> or <u>earth falls</u>. Only a few small rock falls were noted in the Rio Paez drainage area because most slopes are not steep enough to produce falls.

SLIDES -- (*derrumbe*) Slope failures that occur along single or multiple failure surfaces. The surface(s) may be approximately planar, in which case the failure is a translational slide, or they may be approximately rotational, in which case the slide is known as a rotational slide or slump. In the Rio Paez drainage area, many of the slope failures began on steep slopes as slides. If these slides occurred in rock they are known as rock slides; if they occurred in soil, they commonly are known as earth slides; if they include a considerable amount of both, they are known as debris slides. In this area, most slides were earth slides derived mainly from residual soils that have developed on the bedrock.

ROCK AVALANCHES -- (*avalancha de roca*) Broken up masses of rock that commonly move by rolling, bouncing, and falling. Rock avalanches usually occur on steep slopes at high velocities. The average particle size becomes smaller as the rocks break up during movement. Rock avalanches are not common in the Rio Paez area because most failures occur mainly in residual soil with relatively small amounts of bedrock involved.

DEBRIS AVALANCHES -- (*avalancha de escombro*) Similar to rock avalanches except that the mass includes significant amounts of fine material (i.e., soil) as well as rock fragments. In the Rio Paez area, debris avalanches often formed from slides that broke up on steep slopes. The avalanches traveled at high velocities.

EARTH FLOWS -- (*flujo de tierra*) Debris avalanches often deteriorate into earth flows, which run out onto flatter slopes (mostly terraces) from the steep slopes that the slides and avalanches originate on.

DESCRIPTION OF LANDSLIDES

1. Nearly all landslides triggered by the June 6, 1994 Rio Paez earthquake originated on steep slopes (commonly 30 degrees or greater). Most began as shallow slips in residual soils. The activating force was earthquake shaking; however, there would have been far fewer slides if the residual soils had not been saturated due to heavy rains over the preceding few weeks, and the slides that did occur would not have shown the high mobility caused by their saturated states. Saturation of the soils reduced their shear strengths considerably, a major factor in the slope failures and in the velocity of downslope movement.

2. Most of the slides on steep slopes were translational and thin (about 1-2 m thick); these thin slides almost immediately liquefied; i.e. they were transformed into either debris avalanches or earth flows, as they moved rapidly down the steep slopes. A very few of the slides were thicker (i.e., deep seated); these were considerably larger in volume than the thin slides, and appear to have moved more slowly and without long runout distances. However, some of the few deep-seated slides were transformed into debris avalanches or earth flows, which ran considerable distances downslope and onto terraces.

3. The slides themselves usually did no direct damage because they occurred on steep slopes that were not inhabited. However, these water-charged thin slides were almost instantaneously transformed either directly into earth flows or into debris avalanches that then changed into earth flows as they reached flatter slopes. Most of the landslide damage in upriver villages, such as Irlanda and Wila, was caused by earthflows that ran out onto the relatively flat terrace surfaces. These earth flows were relatively thin (e.g., about 2 m thick at Irlanda), but were totally destructive where they encountered houses or other structures. Interestingly, some of the damage done at

Irlanda appears to have been caused by an earth flow that began in the Quebrada de Quindaya on the east side of the Rio Paez and crossed the river at high velocity to enter Irlanda.

4. On the steep upper slopes of the valleys of Rio Paez in the general area of Dublin, Irlanda, and Toez and along the upper reaches of the Rio San Vincente and the Rio Moras, a high percentage of the valley walls have been stripped of their vegetative cover and residual soils. Locally, this percentage exceeds 50 percent (Figures 1 and 2).

5. It is possible that failure of landslide dams may have made minor contributions to the large amounts of water that formed surges of debris flows and floods in the rivers and creeks. However, the only reported case of a landslide dam (based on interviews with local inhabitants) was a 15-m-high dam on the upper Rio Moras. This blockage reportedly failed about one week after the earthquake, apparently causing a debris flow surge down the Rio Moras and into the Rio Paez. Some surges may have been caused by water and debris backing up at extremely narrow river courses, forming what we have called "hydraulic dams," in which ponding occurs because discharge is inhibited by the extremely narrow channel.

RECOMMENDATIONS

1. It generally is not possible to prevent slope failures under the conditions encountered on June 6 (i.e., earthquake shaking, very steep slopes, and weak, saturated soils). Engineering remedial measures will be of no help on these slopes. Drainage of saturated areas, which often is used to increase slope stability at specific usable sites, may help locally but will be of little help to the large slope areas encountered here.

2. Reforestation has been used successfully in other areas of the world to reduce the hazard from unstable slopes. New trees lower the moisture content of the soil and their roots directly increase the shear strength of the soil. However, the scale of the unstable area is so large here that it would require a reforestation program of a magnitude that probably would be economically infeasible. In addition, reforestation will only be successful in the long term; as much as 20 years may be required before new trees have a positive effect on slope stability.

3. Because engineering remedial measures will be of little immediate help, the only hazard management method available is avoidance, i.e., the re-establishment of villages and individual households in locations that will not be affected by major landslides. This is easy to say, but difficult to do, because the terraces that served as inhabited areas in the past are located at the foot of very steep slopes that continue to be susceptible to landslide activity.

4. Many of the slides and avalanches that occurred as a result of the earthquake remain in unstable condition, especially where tension cracks are present on the slide margins. Future heavy rains will cause new failures, either by reactivation of the June 6 slides, by new sliding in marginal areas with cracks, or by erosion of the existing slide areas. **Thus, it is recommended that there be no resettlement directly beneath existing landslide areas.** In the case of Irlanda, we feel that the entire village site and adjacent areas, even though located on a relatively flat terrace, will continue to be endangered by avalanches and earth flows from above; thus, we feel that the site should be abandoned except for agricultural purposes.

CHANNEL AND FLOW HYDRAULICS--RISK ASSESSMENT AND MITIGATION

GLOSSARY

To clarify our discussion, we first would like to define some terms we will use.

Mudflow = *flujo de lodo* (this is a variously defined term for a mud-rich debris flow). The term often used by the media and general public, but is best not used in scientific writing.

Debris flow = *flujo de escombro.* The best general term to describe the sediment-dominated flows in the Rio Paez.

Debris avalanche = *avalancha de escombro.* Many debris avalanches--blocky flows of high velocity--transform rapidly to debris flows.

Sediment-gravity flow = *flujo de detrito.* Excellent term for any flow in which the sediment moves the water, rather than the water moving the sediment as in normal streamflow.

Earthflow = *flujo de tierra.* A local debris flow with high yield strength; i.e. a high percentage of soil and rock as compared with water, generally occurring on steep slopes. Term is not commonly used for flows in channels.

Hyperconcentrated streamflow = *flujo hyperconcentrada.* Flow with 40 to 80 percent sediment by weight, equivalent to 20 to 60 percent by volume.

Sediment-laden streamflow = streamflow with normal concentrations of sediment. Normal streamflow contains less than 40 percent sediment by weight, equivalent to 20 percent by volume.

EFFECTS ON HYDRAULICS AND FLOW REGIME

Several dramatic, profound changes in regime and conditions of flow have very important implications, both for analysis of the event and for resettlement and mitigation of the flow effects. They are:

1. The hydraulic roughness of the channel is greatly reduced by the removal of stream- and valley-side vegetation. **This means that any future flow will travel farther and at a higher velocity.** The volume of the flow may be the same, but the deposits will be distributed over a greater area.

2. The channel capacity (and hydraulic conveyance) have been greatly reduced. This is evident from qualitative observations at bridge sites, from buried trees that have remained vertical, but especially from the calculations of fill in the vicinity of Balalcazar. Several channel cross-sections there record from 29 to 32 m of fill. **Thus, the reduced carrying capacity of the channel means that a future flow of the same size will extend to much higher levels.** Approximately 2 m of fill was estimated at our observation farthest downstream near Paicol.

3. A third and extremely important effect is the complete change in flow regime (including channel pattern). Over the next several years, the Rio Paez river drainage will be establishing a new pattern of both meanders (the sinuosity of the flow within the larger channel and flood plain) and pools and riffles. New riffles and rapids will occur at sites where very coarse material has been contributed from lateral tributaries. **The change in regime and pattern of flow will cause large and unpredictable amounts of local bank (lateral) erosion. This will continue for several years**

and will probably result in the destruction of some habitations and facilities that were untouched by the 1994 debris flow.

4. There will be a fundamental change in rainfall-runoff relations, especially in the zone in the upper Rio Paez drainage around the epicenter where a large proportion of the land surface is disturbed. **Flood peaks and total runoff volumes will be increased until the natural revegetation occurs, probably within several years.**

5. **Substantial loss of reservoir capacity at Betania Reservoir will occur over the next several years, possibly in the range of 10 to 20 percent, depending on the trap efficiency of the structure. We recommend that releases be maximized, consistent with basic power generation agreements, over the next two years. An annual reservoir sediment survey can form the basis for future operations.**

HYDRAULICS OF THE 1994 PEAK FLOW

1. Eyewitnesses generally observed that the initial flow wave was the largest and the one that formed the trimline. They suggest that the peak required only several minutes to pass, an observation that is probably not particularly accurate, judging from the rate of downstream attenuation of the wave form. Much material was entrained in the flow from the channel perimeter, and the cross section of the debris flow observed far downstream at the bridge site near Paicol was surprisingly large, in large part for this reason. Rates of attenuation for cohesive debris flows are generally smaller than those of their noncohesive counterparts.

2. Flow velocity (celerity of the main flow front) was probably in the range of 15 to more than 20 m/s, with gradual downstream decrease in the vicinity of Paicol to 8 to 12 m/s. These figures are based on two sets of eyewitness recollections. A measurement of runup, believed to be as accurate as such measurements can be, was made at the confluence of the Rio Paez and the Rio Negro. This measurement indicated a minimum flow velocity (probably close to flow-wave celerity in a channel that confined) of 14.1 m/s. This figure is a minimum because the angle of impact was slightly less than 90 degrees and the runup slope was densely vegetated (high roughness; the calculation assumes a frictionless surface).

3. Volume of flow can be estimated only very crudely. Estimates of the volume of slide materials will be extremely difficult, because only a small proportion of many failures reached the channel and contributed to the main waves. Similarly, determinations of volume of flow from volumes of deposits will be difficult, because, throughout the river system, most deposits are fill within the channel, and this volume is greatly enlarged by entrained alluvium. Subaerial flow deposits are remarkably thin, being rarely more than a meter, and commonly a "skin" of only 1 to 2 cm. The flow-wave volume can, of course, be determined from the inflow stage recorder at Betania reservoir, and possibly from a stream-gauging station, normally positioned upstream from reservoir backwater. These volumes will be of little application to the size of the flow in the Paez, however, because of the dilution effect of the Rio Magdalena. Time of arrival at the reservoir can also be determined, as well as the timing of any significant later surges that might reflect aftershocks (unless the effects are totally damped by the amount of dilution of the Rio Magdalena).

4. Calculations of peak discharge throughout the main Rio Paez channel will be relatively easy, based on channel cross sections and nearby runup calculations.

OBSERVATIONS AND INTERPRETATIONS

1. The 1994 debris flows in the Rio Paez were clearly in the category of *cohesive debris flows* (those containing more than approximately 3 percent of sediment in the range of clay-size sediment (< 0.004 mm). The significance of a debris flow in the cohesive range is that it attenuates relatively slowly and continues generally as a rheologic debris flow; that is, it retains the yield strength that characterizes debris flows to its distal end. Cohesive flows typically travel very long distances.

2. The 1994 flow in the Rio Paez and its larger tributaries was near the middle of the size range of the events recorded by the deposits of previous debris flows in lateral terraces along the river. **Most of these larger, prehistoric flows, however, were of the noncohesive type which indicates that they were related to volcanic activity, probably explosive, at Nevado del Huila. Just because there has been no recorded activity since 1550 does not mean there is no substantive risk of volcanically generated flows.** Several huge noncohesive flows were observed in terrace deposits throughout the watershed, as well as their downstream transformations to hyperconcentrated flow. An impressive deposit of hyperconcentrated flow was seen along the Rio Paez on the south side of the bridge near Yapona.

3. We strongly recommend that a paleoflow and paleoeruptive analysis be made of the Rio Paez and its tributaries. Two factors make this an unparalleled opportunity: (a) The bank erosion described above will create many new exposures of the sequence of older flow deposits, and, (b) the Rio Paez and its tributaries drain the entire volcano! This is truly an incredible opportunity. Such an analysis should be able to define the magnitude and frequency of both volcanic flows from Huila (these will generally be noncohesive) and the probable flows resulting from future earthquakes (a cohesive texture and clast composition can accurately distinguish these from the volcanic flows). We believe that the staff of the Popayan office of INGEOMINAS is entirely capable of this work. The staff of the USGS Cascades Volcano Observatory will be glad to serve in an advisory capacity. The result can be a world-class risk analysis of flow hazards related to earthquakes and volcanoes, and, for the first time anywhere, a comparison of the two at a single volcano.

4. **The initial approximation of flow risk can consider the 1994 peak flow as a design event, with all areas affected by 1994 flow to be confined to agriculture. Resettlement of sites as dangerous as Irlanda, Wila, Talaga, and possibly even Toez, should not be encouraged in any way.** However, the higher terrace levels should generally be safe. These include the main, very planar surface approximately 80 to 100 m above the river and underlain by ignimbrite such as at Ricaurte, and a lower terrace 20 to 30 m above the river and formed by an inset sequence of volcanic flows and fluvial deposits such as at Cohetando. We stress that it is important to include in site assessment the factors on flow regime and hydraulics mentioned above in addition to landslide factors.

SUMMARY OF HYDRAULIC AND HYDROLOGIC RECOMMENDATIONS

1. In appraising resettlement sites, leave a safety margin that will reflect the greatly reduced channel capacity. Encourage agricultural exclusively in the area below the inset terrace described above.

2. Definitely undertake a paleoeruptive and paleohydrologic analysis of the older flows in the system (use the various references by Scott cited below as introduction to the techniques. Use the following criteria as working hypotheses: (a) Cohesive flows with textures like that of the 1994 flows will probably reflect past seismic events, unless lithologic types clearly documenting an origin exclusively from the volcano (ignoring the entrained rounded lithologies) show otherwise. The large slope failures known as <u>sector collapses</u> from the volcano may yield similar flows but other factors

noted in the references can distinguish the differences. (b) Noncohesive flows with granular, angular matrix (also ignoring the entrained rounded lithologies) can distinguish the flows related to activity at Huila Volcano.

Thus, the magnitude and frequency of each of the two types of flows--seismically induced and volcanically initiated--can be determined! Based on our quick reconnaissance analysis, the flows related to volcanism appeared larger (in general) than those seismically induced.

There are some very impressive hyperconcentrated-streamflow deposits (the flow type into which noncohesive flows almost invariably transform) in downstream reaches beyond La Plata. These record very large flows extending probably in excess of 100 channel km from the volcano.

3. Exercise caution in planning new roads and bridges. The totally new flow regime will trigger huge amounts of lateral erosion at places that cannot now be estimated. Bedrock-supported abutments should remain stable, of course.

4. The events of 1994 will occur again, with the probability that can now only be related to earthquake recurrence. The result of the magnitude and frequency analysis may well document that flows from the volcano are actually the greatest risk in the Rio Paez system. Again, it is difficult to underestimate the fortuity of the combination of the new exposures that will occur after the 1994 events, as well as the draining of the entire edifice by a single river system.

5. The short-term response may be one of a relatively small amount of additional fill, in part related to the increased bank erosion. The true long-term response, however, will be one of degradation back to the original river level.

GEOLOGICAL OBSERVATIONS

1. **Effects of the earthquake on local seismic activity**: The June 6 *Sismo de Paez* (Paez Earthquake) was not preceded by any clear change in the normal, background seismicity in the region. The epicenter of the June 6 earthquake was located at approximately 2,400 m elevation on the southwest flank of the volcano Nevado del Huila, approximately 6 km from the summit of the volcano.

The earthquake appears to have had no significant affect on either the background seismicity at the volcano or on the glaciers at volcano Nevado del Huila. Following the June 6 earthquake, there was a series of aftershocks (*replicas*) which persisted during the time of our visit. These earthquakes were recorded on the 2 station seismic network at 4,200 m on the southwest flank of Nevado del Huila Volcano. While no earthquakes of volcanogenic origin have been recorded since the June 6 earthquake, a number of very small magnitude earthquakes related to glacier movement have been recorded.

2. **Stability of the upper volcanic cone**: Above approximately 4,400 m, the volcano is covered with glaciers. Early reports of the events on June 6 indicated that glacier ice was involved in the avalanche deposits. However, no ice has been found to date in deposits associated with the June 6 events in the Rio Paez drainage.

The first overflight of the volcano after the June 6 earthquake was on July 7, 1994. These aerial observations found no detectable changes in either the distribution of glaciers, the surface appearance of the glaciers, or of the vigor of emissions from fumaroles near the summit of the main cone. At the present time, there are no indications that the June 6 earthquake disturbed or caused changes to the hydrothermal system at Nevado del Huila volcano.

3. **Bedrock geology**: The flood events since June 6 continue to provide new exposures in the channel of the Rio Paez. These exposures provide a unique opportunity to evaluate the channel bedrock. INGEOMINAS geologists plan to map the bedrock geology of the channel. This mapping will provide valuable information about the stability of the Paez channel and should be carried out as part of the effort to evaluate potential relocation sites. Mapping the geology of the channel bedrock might be best carried out by mapping the geology exposed along the roads that parallel the channel of the Rio Paez.

4. **Distribution of landslides**: Mapping the distribution of landslides attributable to the June 6 earthquake is well underway by INGEOMINAS geologists. This mapping is especially valuable in order to determine the region affected by landslide activity. Mapping the distribution of landslides by INGEOMINAS geologists indicates that the main area of landslides lies south of the main volcanic edifice and on the lower flanks of the volcano with a maximum altitude of approximately 3,000 m in an area of *bosque de niebla* (fog forest).

5. **Source(s) of water for debris flows**: Both the water and soil for the debris flows was derived principally from the water-saturated materials involved in the landslides. As nearly as we can tell, landslide dams played essentially no role in causing the flows.

6. **Similarity to events in other countries**: The widespread stripping of saturated surficial materials and vegetative cover from steep slopes that was caused by the magnitude 6.4 Paez earthquake has been preceded by similar events in subtropical mountainous areas of other countries. The greatest similarity was shown by the March 5, 1987 events that followed magnitude 6.1 and 6.9 earthquakes that were centered approximately 100 km north of Reventador Volcano in northeastern Ecuador (Hakuno and others, 1988; Schuster, 1991). The quakes occurred after one month of heavy rain that had saturated the residual soils in the area. Thousands of thin (1-2 m thick) landslides occurred on slopes of 40° or more. The total volume of mass wasting was estimated at 75-110 million m^3. As in the Rio Paez case, these thin slides quickly changed into debris avalanches, debris flows, and floods that devastated downstream river valleys. An estimated 1,000 people were killed and US$1 billion in damages occurred (mainly from the aftermath of the partial destruction of the TransEcuadorian oil pipeline). As was the case in the Rio Paez drainage, there was no evidence of major landslide damming in which failed dams would have caused the flooding that occurred. Instead, the debris flows and floods in the outlet rivers were the result of massive amounts of water-saturated soil that flowed down slopes to enter the tributaries and main streams of the drainage system.

In September 1935, two shallow earthquakes (magnitudes 7.9 and 7.0) in the Torricelli Range on the north coast of Papua New Guinea caused "hillsides to slide away, carrying with them millions of tons of earth and timber, revealing bare rocky ridges completely devoid of vegetation". Approximately 130 km^2 (8 percent of the region affected) was denuded by the landslides (Simonett, 1967; Garwood and others, 1979). Materials from the slides flooded the valleys, and, in some cases, blocked major rivers. In November 1970, a magnitude 7.9 earthquake, which was centered along the north-central coast of Papua New Guinea, triggered landslides that removed shallow soils and tropical forest vegetation from steep slopes in the Adelbert Range (Pain and Bowler, 1973). About 25 percent of the slope areas in the 240-km^2 area that was affected by landsliding were denuded (Pain, 1972) with soil debris and vegetation cover flowing into streams.

In 1976, two shallow earthquakes (magnitudes 6.7 and 7.0) struck the sparsely populated southeast coast of Panama, causing huge areas of landsliding. Garwood et al. (1979) calculated that the slides denuded approximately 54 km^2 (12 percent of the affected region of 450 km^2). Although the magnitude 9.2 earthquake that struck southern Chile in May 1960 occurred in an area of temperate forest rather than in subtropical vegetation, it caused slope failures in the Valdivian Andes similar to those noted here. Veblen and Ashton (1978) estimated that more than 250 km^2 of forest slopes were denuded in the 1960 event.

FOLLOW-ON ACTIVITIES

1. On Friday, July 8, the final afternoon of the mission, the USGS team met with counterparts from INGEOMINAS in Bogota to discuss follow-on activities. INGEOMINAS staff expressed their gratitude that the USGS team had turned in a preliminary report of the mission, carried out training of INGEOMINAS staff in the field, and presented technical lectures in both Popayan and Bogota.

INGEOMINAS staff discussed their work plan for future studies in the Rio Paez drainage. Over the next 4 months they plan to complete geological and geotechnical studies in the Paez area. INGEOMINAS asked if a USGS scientist could be detailed to work with INGEOMINAS field crews during the end of this period (i.e. in September or October 1994).

2. Beyond the period of study of the Paez earthquake and its effects, INGEOMINAS staff indicated that they would like to develop a cooperative program of study between the USGS and INGEOMINAS in the area of landslides and hydrological hazards, with a focus on volcanic terrains. This program could include visits by INGEOMINAS staff to USGS facilities in the United States, work by USGS scientists in Colombia, and graduate-level study of selected INGEOMINAS staff at universities in the United States. INGEOMINAS asked that we provide them with information about USGS training programs and that we consider possible USGS-INGEOMINAS cooperation.

3. Upon completion of field work by INGEOMINAS geologists in the Paez area, we plan to work together to produce a jointly authored report for journal publication.

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SCHEDULE

The USGS team of Kevin M. Scott, Robert L. Schuster, and Thomas J. Casadevall spent a total of 24 man-days in Colombia. Our schedule was as follows:

June 30	USA to Bogota
July 1	briefings in Bogota
July 2	Bogota to Popayan, Departemento de Cauca; drive to Inza
July 3-4	Helicopter-supported field work in Rio Paez area
July 5	drive from Inza to La Plata
July 6	drive from La Plata to Popayan via Purace
July 7	Popayan for report preparation, consultations, and lectures
July 8	Popayan to Bogota for work and lectures at INGEOMINAS
July 9	Bogota to USA

PARTIAL LIST OF OFFICIALS CONTACTED

INSTITUTO DE INVESTIGACIONES EN GEOSCIENCIAS MINERIA Y QUIMICA (INGEOMINAS)

Dr. Adolfo Alarcon Guzman	Director General
Sr. Fernando Muñoz Carmona	Sub-Director de Geofisica
Sr. Juan Manuel Martinez	Sub-Director de Ingeneria Geoambiental
Sr. Julian Escallon Silva	Coord. Programa de Ocurrencia y Pronostico de
Sr. Hector Cepeda	Director Unidad Operativa Popayan
Sta. Diana Rubiano	Ingeniera (Bogota)
Sr. Jaime Romero	Geologo (Bogota)
Sr. Guillermo E. Avila Alvarez	Ingeniero (Bogota)
Sra. Adriana Agudelo	Geologa (Popayan)
Sr. Carlos Antonio Forero	Ingeniero

DIRECCION NACIONAL PARA LA PREVENCION Y ATENCION DE DESASTRES

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U.S. EMBASSY / USAID (Bogota)

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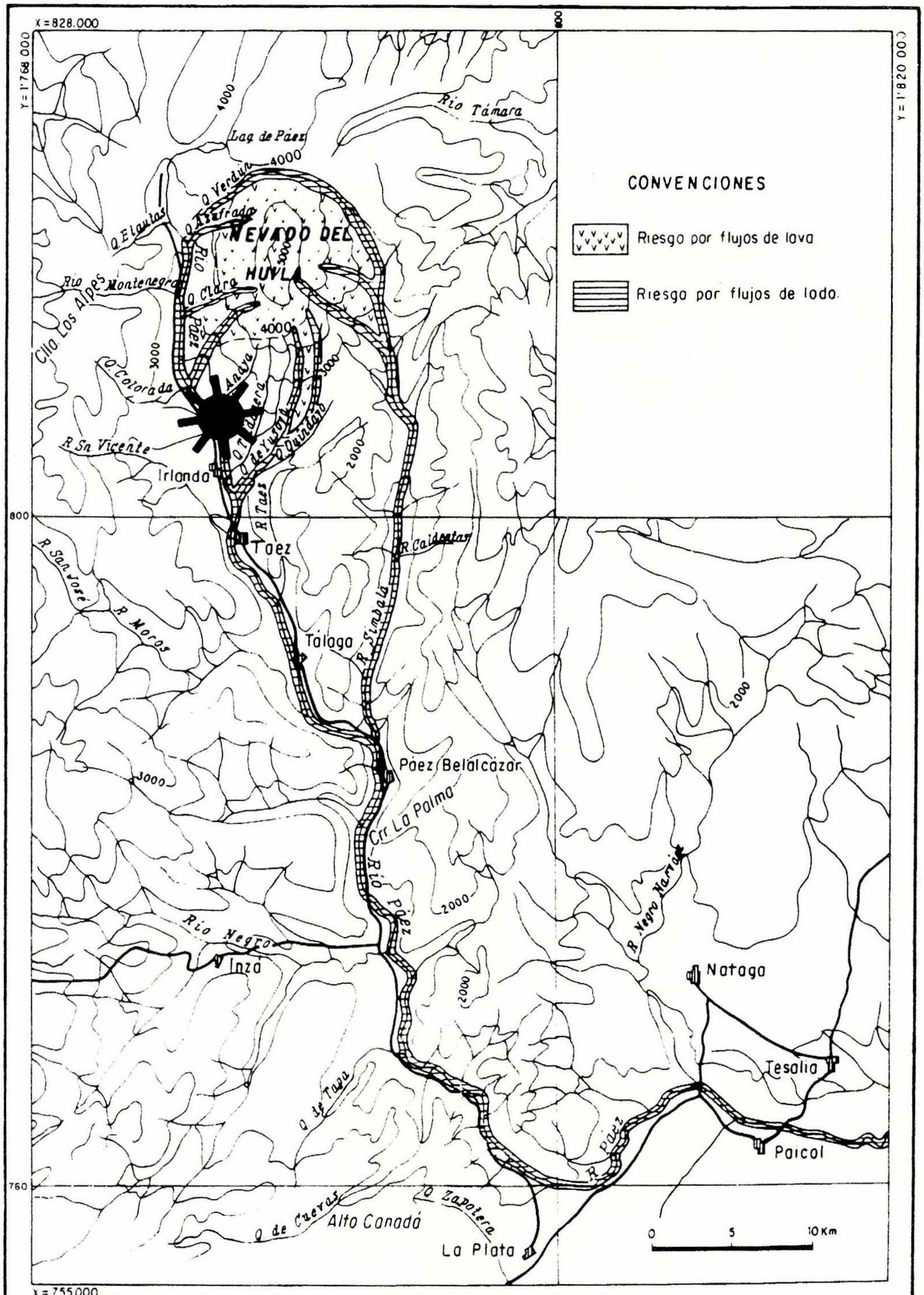
Volcan Nevado del Huila and the Rio Paez drainage. Map shows topography, Rio Paez drainage, and the larger towns mentioned in this report. Symbol shows approximate location of epicenter of June 6, 1994 Sismo de Paez. Map originally prepared by Cepeda and others (1986) to show areas at risk from volcanic debris flows. Deposits from June 6, 1994 event followed much the same course as projected volcanic debris flows below an altitude of approximately 3,000 m.



MAPA PRELIMINAR DE RIESGOS VOLCANICOS POTENCIALES DEL NEVADO DEL HUILA

BOL. GEOL., VOL. 30, No. 3, 1989

Figure 1: Aerial view to north showing area affected by June 6, 1994 earthquake. Rio Paez drainage on right (east), Rio San Vincente on left (west). In Background note landslide scars. Note debris flow deposits in both river drainages. USGS photograph taken July 3, 1994.

Figure 2: Aerial view looking to the south down the drainage of the Rio Paez. Remains of the village of Irlanda in foreground. Note earth flows (right side of photo) and debris avalanche and debris flow deposits in main channel of Rio Paez. USGS photograph taken July 3, 1994.