Landslide of April 25, 1974, on the Mantaro River, Peru: Report of Inspection (1975)

Pages
81

Size
8.5 x 11

ISBN
0309346908

Lee, Kenneth L.; Duncan, J. M.; Committee on Natural Disasters; Commission on Sociotechnical Systems; National Research Council

LANDSLIDE OF APRIL 25, 1974 ON THE MANTARO RIVER, PERU

report of inspection

by

Kenneth L. Lee
University of California, Los Angeles

and

J. M. Duncan
University of California, Berkeley

submitted to the

Committee on Natural Disasters
Commission on Sociotechnical Systems
NATIONAL RESEARCH COUNCIL

National Academy of Sciences
Washington, D.C.
1975

This report was prepared for the Committee on Natural Disasters of the Commission on Sociotechnical Systems of the National Research Council. The information contained herein is a part of the working papers of the Committee, but does not constitute a report of that Committee. All references and attributions should be solely to the authors.

Financial support for publication of this report was provided by the National Science Foundation.

The National Research Council was established in 1916 by the National Academy of Sciences to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy by authority of its Congressional charter of 1863, which establishes the Academy as a private, non-profit, self-governing membership corporation. Administered jointly by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine (all three of which operate under the charter of the National Academy of Sciences), the Council is their principal agency for the conduct of their services to the government, the public, and the scientific and engineering communities.

Copies of this report may be obtained from the office of the Committee on Natural Disasters, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418.

Printed in the United States of America

Order from
National Technical
Information Service,
Springfield, Va.
22161
Order No. PB291 287

FOREWORD

A part of the mission of the Committee on Natural Disasters of the Commission on Sociotechnical Systems of the National Research Council is the investigation of natural disasters and particularly the damage to engineered structures caused by the disaster. Reports of the findings of the investigating teams are published in order to provide engineering disciplines with information that will result in design improvements better to enable engineered structures to withstand the effects of natural disasters.

This document is the result of the investigation of a landslide on the Mantaro River in Peru on April 25, 1974. It describes the landslide and the events immediately following, which affected inhabitants and structures for a great distance downstream from the event. Although landslides of themselves are not particularly unique, the magnitude of this slide and the extent and nature of its effects make it especially interesting.

Direct expenses of field investigators and report writers were supported under a contract between the National Science Foundation and the National Academy of Sciences.

Nathan M. Newmark, Chairman
Committee on Natural Disasters

COMMITTEE ON NATURAL DISASTERS

Chairman: Nathan M. Newmark
Department of Civil Engineering
University of Illinois (Urbana)

Members:

Jack E. Cermak
Department of Civil Engineering
Colorado State University

Ray W. Clough
Department of Civil Engineering
University of California (Berkeley)

Alan G. Davenport
The Faculty of Engineering Science
The University of Western Ontario

George W. Housner
Division of Civil Engineering
and Applied Mechanics
California Institute of Technology

Chairman, Panel on Earthquakes:

Paul C. Jennings
Division of Engineering and
Applied Science
California Institute of Technology

Chairman, Panel on Fire:

Howard W. Emmons
Division of Engineering and
Applied Physics
Harvard University

Chairman, Panel on Landslides:

Kenneth L. Lee
School of Engineering & Applied Science
University of California at Los Angeles

Chairman, Panel on Wind:

Richard D. Marshall
Building Research Division
National Bureau of Standards

Members, Panel on Wind:

Gary C. Hart
School of Engineering & Applied
Science
University of California at
Los Angeles

Harold I. Laursen
Department of Civil Engineering
Oregon State University

Kishor C. Mehta
Department of Civil Engineering
Texas Tech University

Dale C. Perry
Department of Civil Engineering
Georgia Institute of Technology

James T. P. Yao
School of Civil Engineering
Purdue University

Chairman, Panel on Wind Engineering Research:

Jack E. Cermak
Department of Civil Engineering
Colorado State University

Steering Group, Panel on Wind Engineering Research:

Alan G. Davenport
The Faculty of Engineering Science
The University of Western Ontario

Frank A. Gifford
Atmospheric Turbulence &
Diffusion Laboratory
National Oceanic &
Atmospheric Administration

L. E. Robertson
Skilling, Helle, Christiansen, Robertson

Liason Member, Panel on Wind Engineering Research:

Michael P. Gaus
Engineering Division
National Science Foundation

Staff: Executive Secretary, Committee on Natural Disasters:

Nelson T. Grisamore
Commission on Sociotechnical Systems
National Academy of Sciences

Administrative Secretary, Committee on Natural Disasters:

Joan M. Sieber
Commission on Sociotechnical Systems
National Academy of Sciences

ACKNOWLEDGMENTS

The writers express appreciation to the Committee on Natural Disasters of the Commission on Sociotechnical Systems of the National Research Council for encouraging and supporting this fact-finding mission and report. The success with which we were able to accomplish all objectives of the mission in Peru in the very short time available was due to the outstanding cooperation and assistance given by a large number of Peruvian people. The authors express special appreciation to the following: Ing. Prof. Bernardo Fernandez, Universidad Nacional de Peru, who provided introductions and valuable planning assistance in Lima; Ing. Luis Sebastian C. Caja Maguina of the Ministerio de Transportes y Comunicaciones who provided ground transportation over the 425 km highway to the town of Pampas, the nearest accessible location to the site; Colonel Arturo la Torre di Tolla and Sra. Sara Parodi of the Civil Defense in Lima who generously provided valuable information from their studies; General Rodolfo Acevedo del Campo, Commander of the 22nd military division in Huancayo who not only arranged for a helicopter inspection of the site, but provided much information and copies of color slides from his personal collection; Colonel Herman Cevasco, Commander, and Captain Carlos Valderrama of the 43rd Battallion, Pampas, for providing the helicopter inspection trip to the site; Dr. Ernesto Deza of the Instituto Geofisico for sharing his time and information in discussions concerning the recorded earth waves resulting from the slide; Ing. Hugo Jaen La Torre, Servicio de Geologia y Mineria for discussions and information concerning the geologic aspects of this landslide; Ing. Alfonso Alcedan, Director of the Laboratorio-Nacional de Hidraulica for providing a demonstration of a complete hydraulic model test to coincide with the writers' visit to the laboratory. Finally, the writers wish to express sincere appreciation to Ing. Prof. Luis Zapata Baglietto of the Universidad Nacional de Ingenieria, Lima for outstanding personal assistance in transportation and other arrangements during all aspects of the writers' stay in Lima.

After returning from Lima, the writers benefited from informal discussions with E. Kojan and J. N. Hutchinson who had inspected the slide in behalf of UNESCO.

CONTENTS

MANTARO RIVER, PERU LANDSLIDE OF APRIL 25, 1974

by

Kenneth L. Lee* and J. M. Duncan**

INTRODUCTION

On April 25, 1974, at about 9:00 p.m. local time, a massive landslide occurred in the valley of the Mantaro River in Peru, killing about 450 people. The vibrations caused by the moving earth were equivalent to a magnitude 4.5 earthquake. This slide, with a volume of 1.6×10^9 m^3, dammed the Mantaro River and formed a lake which reached a depth of about 170 m and length of about 31 km before overtopping on June 6th-8th, 1974. In overtopping the landslide dam, the Mantaro River eroded a gorge about 107 m deep, and the resulting flood caused extensive damage downstream: approximately 20 km of road, and three bridges were destroyed. About 1000 persons had to be evacuated from their homes during the flood, and many whose farms were destroyed, will have to leave their homes permanently.

Nature of Inspection Trip and Sources of Information

Immediately prior to the visit the writers were given a copy of a memorandum report by J. Barry Cook (1974) who had just returned from inspecting the site. The writers visited Peru from the 3rd to the 13th of July, 1974, on behalf of the Committee on Natural Disasters of the United States National Research Council, to study the disaster making a helicopter flight over the landslide site on July 7. While in Peru they visited the following organizations to obtain data concerning the landslide and the disaster relief operations; Instituto Geofisico, Instituto Geologico, the Ministerio de Transportes y Comunicaciones, the Defensa Civil, and the Laboratorio Nacional de Hidraulica in Lima.

---

*Assoc. Professor, Mechanics and Structures Dept., University of California, Los Angeles.

**Professor, Dept. of Civil Engineering, University of California, Berkeley, California.

Landslide Predicted in Advance

In November 1973, Sr. Jorge Galdos Bustamente completed a geological study of the precise area of this landslide and presented his report (Galdos Bustamente, 1973) to the Servicio de Geologia y Mineria, Division de Geotecnica, which is a branch of the federal government of Peru. The report is not large or detailed, but the conclusions are clearly stated to the effect that there is considerable evidence of past and current ground movements and slope instability; these are likely to continue in the future, probably causing a large landslide and numerous smaller landslides. The report recommends that the inhabitants of the area be moved, and that some protective measures be taken in the form of ground water and drainage control. Unfortunately these recommendations were not acted upon, and some 5 months later, at the end of the next wet season, the landslide occurred, perhaps even larger than imagined by Galdos Bustamente.

GEOGRAPHICAL AND GEOLOGICAL BACKGROUND

As indicated in Figure 1, the Mantaro River originates at Lake Junin in the highlands of the Peruvian Andes at an elevation of about 4100 m and flows south, then north to reach the Amazon River. In the region between the cities of Huancayo and Ayacucho the river flows through a narrow vee-shaped valley about 1.9 km deep with side slopes of the order of three or four horizontal to one vertical. The area is composed of deeply weathered sedimentary rocks (shales, sandstones and limestones) underlain by basement granitic rock. There is evidence of extensive faulting which plays a significant role in defining the topographic features, especially in governing the courses of the streams and rivers.

The climate in this zone is concentrated wet and dry. The average annual rainfall is about 702 mm of which about 95% falls during the period October through April. The combination of heavy concentrated rainfall, deeply weathered soil and rock cover plus steep valley slopes has resulted in numerous large and small landslides throughout the area. Indeed, in traveling through or flying over the area one is struck by the extensive amount of landslides which have occurred in the valley of the Mantaro River and along its tributary streams. Many of the scarps appear to be fairly fresh, and are very large in size, yet few of them have been described in popular or in technical periodicals.

One of the exceptional few to be described is a major slide on the Mantaro River, about 50 km downstream of the slide reported herein. This older landslide occurred August 16, 1945 and is described by Snow (1964). It involved about 7.3×10^6 yd^3 of material over an area 300 ft long, 180 ft wide and an elevation difference of 1,700 ft. The slide created a thundering noise and earth tremors. Like the present slide, this 1945 slide also dammed the Mantaro river. The river remained dammed for 73 days at which time the debris dam was overtopped and quickly eroded away creating a flood fifty times the maximum annual flood of the river.

A smaller but also relatively large slide occurred in 1930 about 30 km upstream from the present slide, and almost opposite the support village and electrical switchyard for the Tablachaca concrete arch dam built in the period 1967-1971. An aerial photograph of this 1930 slide

(Figure 2) shows the electrical facilities and the concrete arch dam. Note that the lake caused by the present landslide dam reached to within about 2 km of this old slide to a point just inside the right side of the photograph. This slide also dammed the river for a period of 60 days, but little other data is available.

Thus, although this present landslide is of extraordinary size, it is not a particularly unusual event for this area of the world.

Detailed Geological Conditions at the Landslide Site

The writers are indebted to the report by Galdos Bustamente (1973) for detailed geological data in the slide area prior to the landslide. Figures 3 through 9 and the accompanying description has been taken from this report.

A topographic and location map of the landslide area is shown in Figure 3. The Mantaro river, located in the upper right hand corner which flows from north to south is a major topographic feature in the area. Two creeks running down narrow side valleys or ravines (Quebradas) flow into the Mantaro river at approximately the same location, suggesting the existence of a fault along these creek beds, although no fault is shown on published geological maps. Similar geological features exist at other locations along the river, suggesting that there are many faults which run approximately perpendicular to the Mantaro river valley, which is also probably fault related.

The place names indicated only by letter symbols on Figure 3 are defined fully on Table 1. Note that at the mouth of these two ravines there were two large farms H3 and H4, which involved homes for many people. Approximately midway between the Mantaro river and the crest of the mountain was located the town or village of Mayunmarcha, also involving many homes.

A cross section along the Quebrada Ccochacay (Q4) running southwest from the Mantaro river up and over the mountain peak is shown in Figure 4. Except near the crest of the mountain the slope is covered with a thick (100-200 m estimated) layer of weathered alluvium or detritus. This material is of variable texture and includes cobbles, gravel, sands and clays without significant cementation. Below this upper detritus cover and exposed near the top of the slope are extensive layers of interbedded

TABLE 1

Place Names Corresponding to Symbols Shown on Figure 3

(Cerros) Hills		
C1	Comuisayhua	Elev. 4400 m
C2	Cussuro	4300 m
C3	Potrero	4300 m
C4	Vicunayoc	4300 m
C5	Yanaorca	4400 m

(Haciendas) Large Farms		
H1	Huanupata	
H2	Yanac	
H3	Huaccoto	(Destroyed by slide)
H4	Ccochaca	(Destroyed by slide)
H5	Ropac	
H6	Palmero	
H7	Sillero	
H8	Pieda Labrada	
H9	Lirio Huaycko	
H10	Jatan Ckasa	

Towns		
	Mayunmarcha	(Destroyed by slide)

(Lagunas) Small Lakes		(Quebrada) Creek, ravine	
L1	Aljaccocha	Q1	Zapprailla
L2	Minasccocha	Q2	Sojosbamba
L3	Unnamed?	Q3	Huachac
L4	Unnamed?	Q4	Ccochacay
L5	Yanacocha?	Q5	Tinte
		Q6	Hospitalhuacycko

Rivers

Pumaranra (small)

Mantaro (large)

sandstones and clay shales. The mountain is an anticlinal feature so that the bedding in this sedimentary rock zone dips approximately parallel to the ground surface. The materials exposed near the crest of the slope are intensely fractured, providing a source of local instability, and an aggravation to the overall stability by providing ready seepage paths for ground water percolation.

With regard to seepage, Galdos Bustamante (1973) emphasizes the significance of the river Pumaranra and several small alpine lakes at high elevations on the other side of the ridge from the landslide area. He suggests that these may be a source of ground water seeping into the slope on the Mantaro river side. A number of springs (M) are located on Figure 3 in the upper zones of the slope, which feed the various tributaries to the main stream, Quebrada Ccochacay.

Whether due to seepage from the other side of the ridge, or due to other causes including general groundwater movement in the area, the entire valley of the Quebrada Ccochacay appears to have been rather unstable for a considerable length of time prior to the geological study by Galdos Bustamante. As shown in Figure 3, a major scarp in excess of 10 m high runs around the upper part of the valley at about the location of the contact between the detritus cover and the underlying sandstone and clay shale layers. Other scarps and cracks of lesser dimension, but still major topographic features, occurred throughout the area.

Some of these major topographic features are illustrated in the following photographs. Figure 5 shows a panoramic view looking down onto the town of Mayunmarca. The ravine Q2 is a major feature in the foreground. A recent small landslide on the bank of this ravine is visible and indicates the general instability of the area.

Figure 6 is another panoramic view looking down past the town of Mayunmarca in the center of the photograph, to the Mantaro river not seen, but located in the upper third of the picture. The white slide scarps in the upper part of the photograph are on the banks of Quebrada Tinte (Q5), which flows into the Mantaro river directly across from Quebrada Ccochacay (Q4). Note that the Quebrada Tinte area was also unstable before the landslide. In the foreground of Figure 6, there are some major recent ground cracks or fractures, indicating the general marginal stability of the detritus cover at that location.

Figure 7 is a photograph of one side of the Huachac ravine Q3. The top layer of soil is detritus material; clays, sands, gravels and large cobbles. The dark streaks are locations of ground water seepage.

Figure 8 is another panoramic view of the area showing the fluvial-alluvial terraces on which the town of Mayunmarca and the surrounding farms are located. A fairly large old landslide scarp in the upper right corner of the photograph gives another indication of the local marginal stability of these soils.

Figure 9 is a view taken along the major old scarp near the top of the slope looking southwest. The peak of the Vicunayoc hill (C4) at elevation 4300 m is seen in the background. The area shown in the photograph is just above the zone of detritus cover shown in Figure 4. The undisturbed material in the foreground is composed of sandstone with some layers of highly compacted clay shale. This is the northeast side of the Pumaranra anticline indicated in the section on Figure 4. The bedding slopes NE at 40° to 45° with respect to the horizontal in the same direction as the ground surface. The natural instability of this formation is clearly indicated by the extensive fractures and amounts of broken rock and by the old landslide scarp in the background.

In a quantitative sense, Galdos Bustamante lists the following damage that has occurred in recent times in and around Mayunmarca due to the ground instability problems that existed at the time of his field inspection in August 1973.

(i) Loss of 850 hectares of cultivated land due to severe ground cracks which makes further farming impossible.

(ii) Partial destruction of a number of farm houses located between the Huachac (Q3) and Sojosbamba (Q2) ravines.

(iii) Evacuation of the community center building of Mayunmarca because of an imminent landslide into the ravine in front of the building.

(iv) Destruction of part of the road between the hill Vicunayoc (C4) and the town of Mayunmarca.

These damages were evaluated at about 3,300,000 Peruvian soles ($600,000 U.S.) which is a significant amount for this underdeveloped farming community.

Based on the geological engineering data summarized in the foregoing paragraphs, Galdos Bustamante predicted that not only would the present trends of localized ground movement continue, but that the entire area may be affected by a landslide or a system of landslides coming from the surrounding hills. He recommended that the people living in the village of Mayunmarca be relocated on stable ground outside the area, and that certain seepage and drainage control measures be installed to stabilize the ground.

Unfortunately, these measures had not been accomplished before the predicted major landslide did occur. Although in retrospect one may feel that something should have been done, there are also many extenuating circumstances that work to maintain the status quo. The area is in a remote and relatively underdeveloped part of Peru. The people in the area have lived there for many generations and became accustomed to the topography, the slides, the water seepage and other geological features that alarms a newcomer with good geological training and experience. There is no easily accessible place where land exists onto which the affected people could be readily relocated. Transportation is limited to foot and donkey so that close proximity between home and farm is essential. Furthermore, as mentioned earlier in this report, this type of potentially unstable ground is the rule rather than the exception in most of the side valleys all along the Mantaro river. In fact, at the time of our visit to the Geotechnical Division in Lima, the writers were shown a draft of another geological study in a nearby valley with remarkably similar conditions.

An example of the general instability of the Mantaro river valley in this area is indicated in the photograph in Figure 10. This photograph, taken during a helicopter trip to see the main slide, was a typical scene in an adjacent side valley to the Mantaro river. The general topography and vertical elevation difference is quite similar to the Quebrada Ccochacay area, with small plots of cultivated ground all up and down the general slope. Sometime in the not-too-distant past a rather large landslide has occurred in the upper reaches of this side valley obviously destroying many of these farms. Nevertheless the event was apparently not considered to be very important because there appeared to be no information available concerning this slide.

Given a similar situation elsewhere, it is doubtful that people would react much differently. In fact many examples can be cited of situations throughout the world where people have lived complacently in areas of known or predicted serious geological or environmental hazard. Examples include the Aberfan Wales flowslide of a coal mine tailing pile, October 21, 1966 which killed 164 people (Bishop 1973), and the Frank, Alberta, Canada rockslide of April 29, 1903 (Cruden and Krahn 1973). An example of the reluctance of people to leave their homes in the face of clear warnings includes the example of the Baldwin Hills, California dam failure, December 14, 1963, in which five people were killed by the resulting flood. Some of the people living below the dam were very reluctant to leave their homes despite several hours of intensive police warnings to evacuate (Cooke 1964).

Cleveland (1975) describes a flash flood in the Nevada desert, September 14, 1974, which caused extensive destruction and killed nine people at the village of Nelsons Landing located in a narrow canyon at the head of a wash. He notes that, "Ironically, a year ago the National Park Service recognized the hazard and warned the residents of the danger of having the town in a narrow canyon." A public meeting was held at which the local residents objected to moving, noting that within the past 74 year history of the settlement no serious flood damage had occurred. Unfortunately before the Park Service could force positive action the feared flood occurred.

Another example is described by Morimoto *et al.* (1967). Geological mapping of ground cracks caused by recent earthquakes, concluded that a landslide was imminent, and posed an immediate serious threat to a village below the slope. After describing the situation to the town council an evacuation order was issued and the people left their homes at midnight. By morning, when the threatened slide had not materialized the people were desirous of returning to their homes and began seriously debating the legality and validity of "last night's evacuation". Fortunately they remained a safe distance away from the area and at 2:00 p.m. that afternoon witnessed the forecast slide.

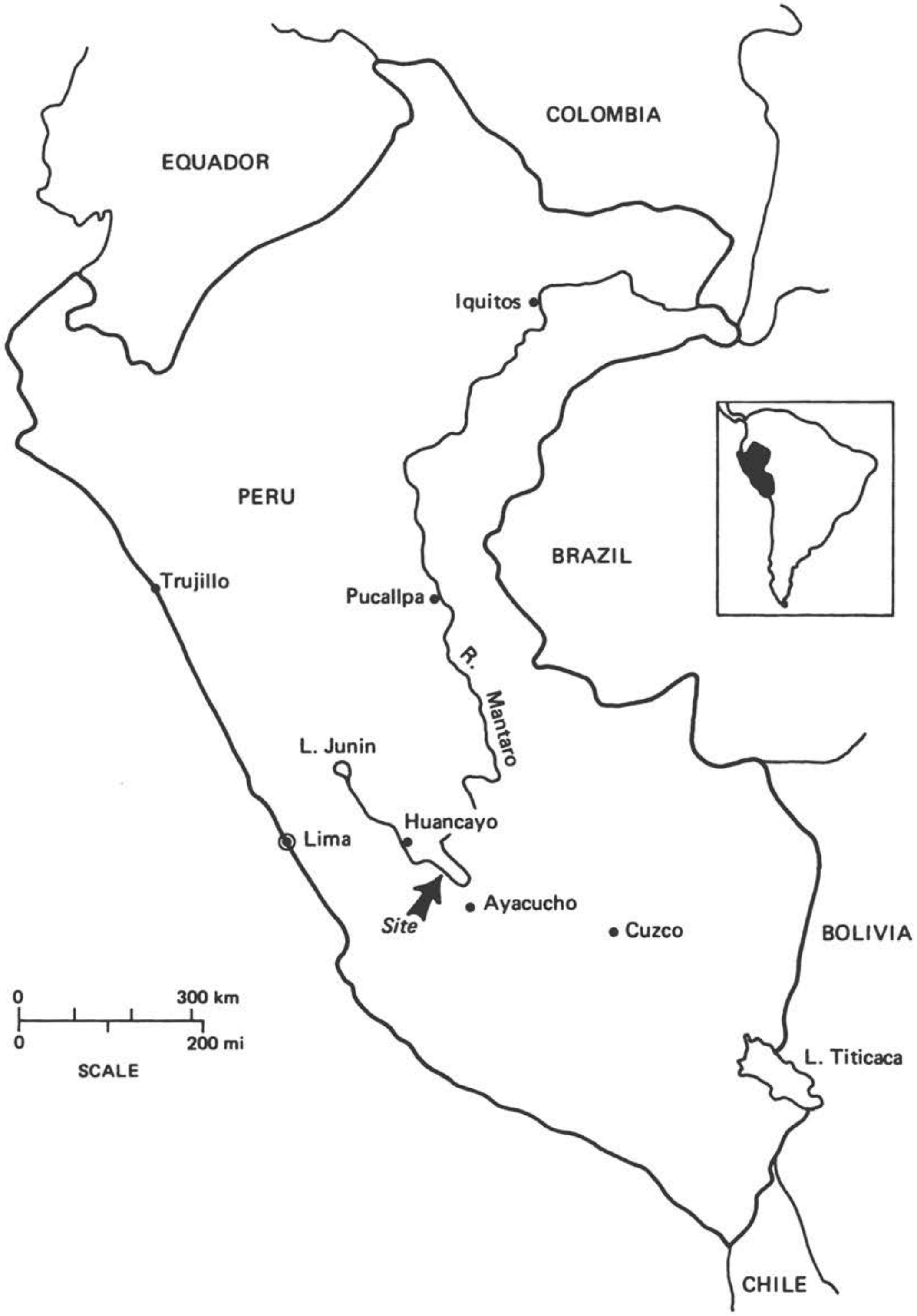


FIGURE 1. Location Map.

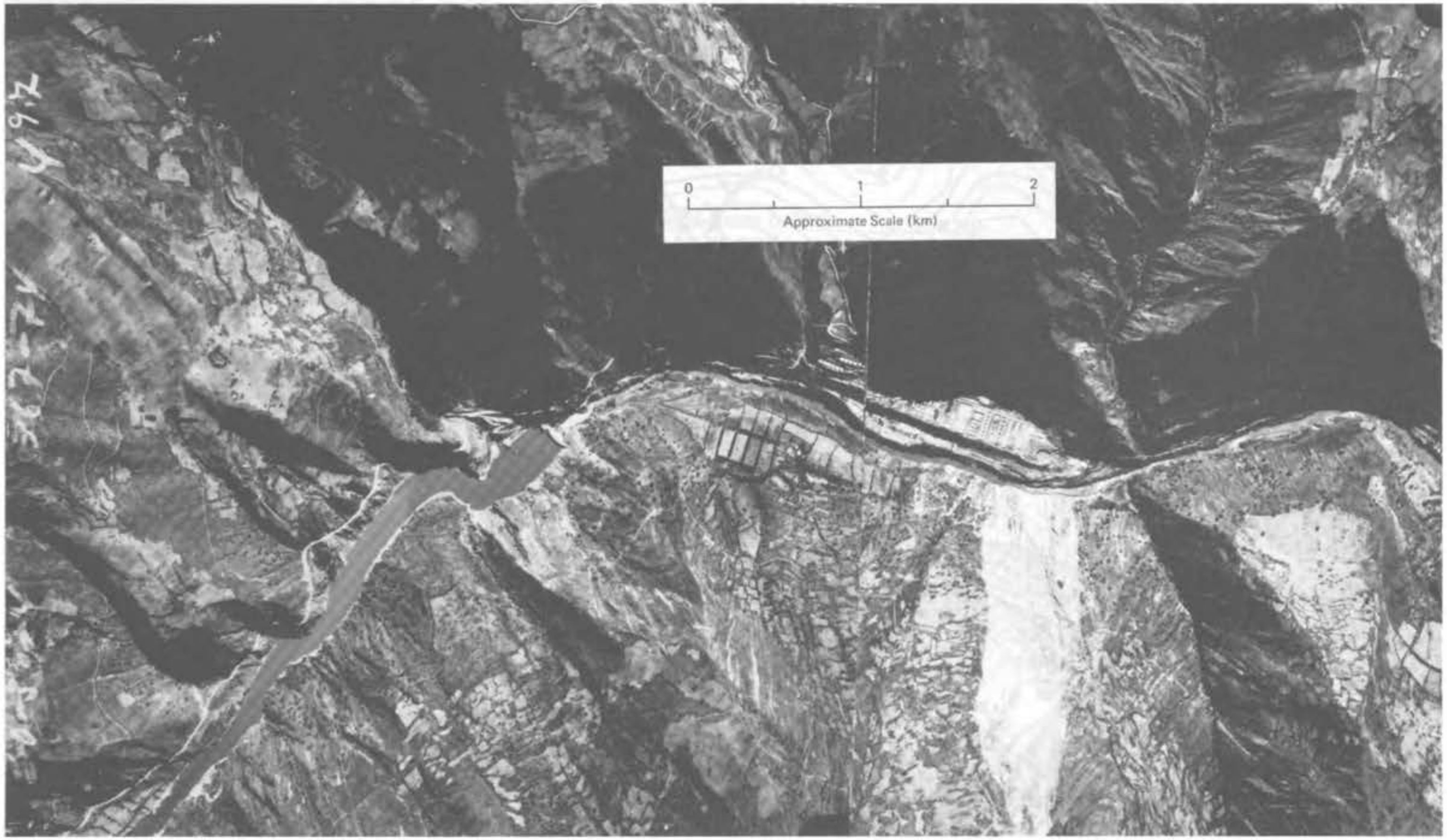


FIGURE 2. Aerial view of Tablachaca dam and electrical station, with the scarp of a 1930 landslide in the foreground. (Defensa Civil Photograph)

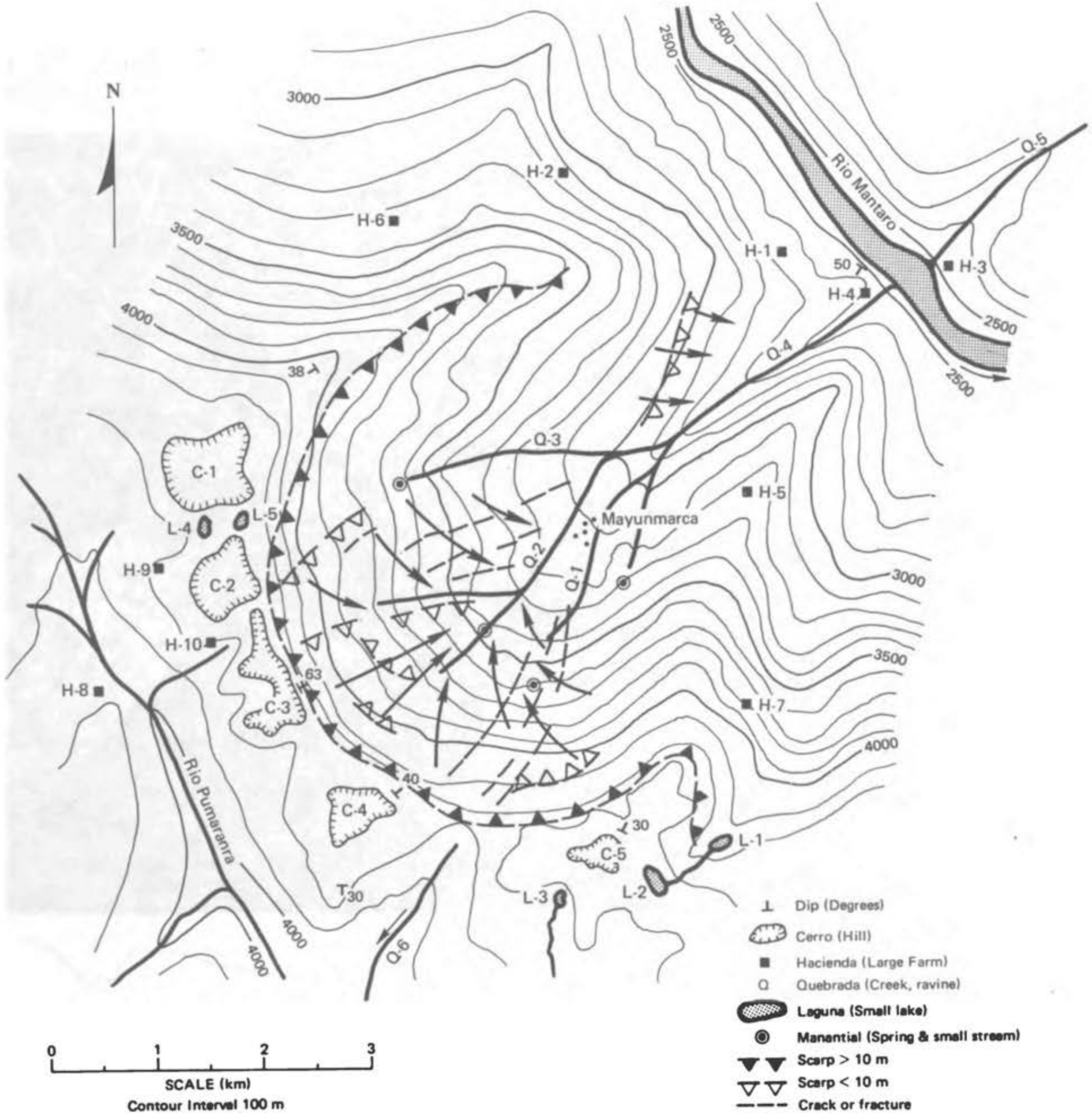


FIGURE 3. Plan of the area showing the major topographic features prior to the landslide of 4/25/74. (After Galdos Bustamante, 1973, Ref. 8)

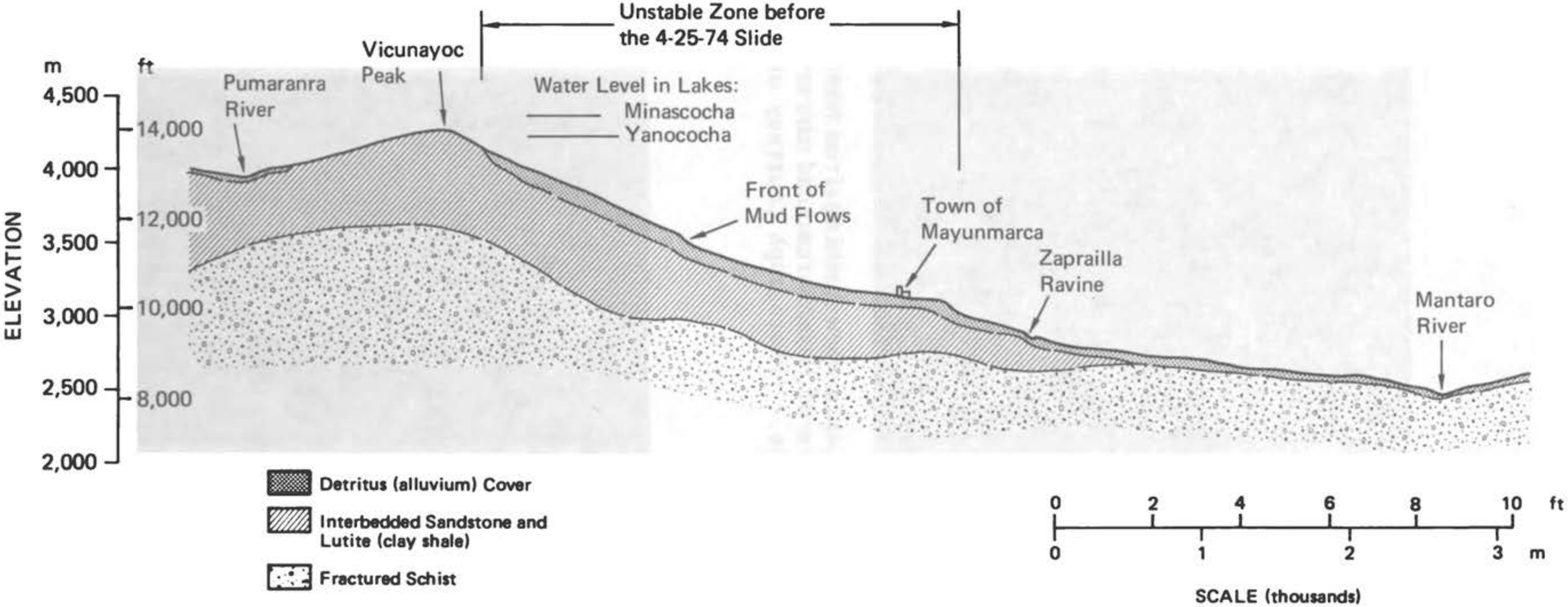


FIGURE 4. Geological cross section of Mantaro River slide area prior to the 4/25/74 slide. (After Galdos Bustamante, 1973, Ref. 8)

FIGURE 5. Panoramic view looking from North to South showing the community center of Mayunmarca, and the unstable slopes of the Sojosbamba ravine. (Photograph courtesy of Galdos Bustamante)

FIGURE 6. Panoramic view looking from South to North showing a system of recent fractures located 300 meters from the community center of Mayunmarca. (Photograph courtesy of Galdos Bustamante)

FIGURE 7. Left side of the Huachac ravine, 400 meters from Mayunmarca showing water seeping from the detritus slope. (Photograph courtesy of Galdos Bustamante)

FIGURE 8. Panoramic view from SE looking NW showing the fluvial alluvial terraces on which the town of Mayunmarca was located. (Photograph courtesy of Galdos Bustamante)

FIGURE 9. View from the SE looking towards the Vicunayoc hill near the crest of the Pumaranra anticline. Part of the old scarp is visible in the distance, and blocks of the sandstone and shale layers which dip NE at 40 to 45 degrees are seen in the foreground. (Photograph courtesy of Galdos Bustamante)

FIGURE 10. View of a typical side valley dipping into the main Mantaro river valley, and located near the Ccochacay ravine. No information is available concerning the slide shown here.

THE LANDSLIDE

The Mantaro river landslide, which was the subject of this investigation, occurred shortly after dark, at about 9:00 p.m. local time on the evening of April 25, 1974. No eyewitnesses were found by any of the several groups of scientific investigators that visited the site shortly after the slide, although it was rumored that one survivor who rode down on the slide debris was in the hospital suffering from shock and unable to talk.

One of the most impressive features of this slide is its size, which must be one of the largest in recorded history. A second impressive feature was the lake which formed behind the slide debris which dammed the river, and the subsequent overtopping and downstream flooding. Some of the size statistics are as follows, the size and volumes were estimated from aerial photoreconnaissance surveys.

Slide Data

Total volume of slide material	1.6×10^9 m^3
Volume of slide material forming the dam in the river	1.3×10^9 m^3
Remainder on the slide slope or in the valley on the opposite side of the river	0.3×10^9 m^3
Length of slide scarps	7.5 km
Height of slide scarp	1.9 km
Duration of sliding	about 3 minutes
Estimated velocity of sliding	140 km/hr

Debris Dam Data

Height of slide debris dam at the river	170 m
Length of slide debris dam in the river canyon	3.8 km
Crest width of debris dam in the river canyon	1 km

Casualties and Damage

People killed	estimates range from 200 to 600 persons

People evacuated following the slide	2500 in ten population centers
Road destroyed by the slide	3.8 km
Road destroyed by flooding	30 km

A plan view of the slide area is shown in Figure 11. Reference to Figure 3 indicates that the area which actually slid was approximately the same as the endangered area indicated by Galdos Bustamante. The entire town of Mayunmarca on the slope was carried away and the haciendas, Huaccoto (H3) and Ccochaca (H4), were buried by the slide debris. The vibrations caused by the slide movement were transmitted as seismic ground waves and recorded on several seismological stations, indicating the duration of major movements to be about three minutes, from which the 140 km/hr velocity was determined.

There is also other evidence to indicate that high velocities must have been developed. In at least one location, above the hacienda Huanupata (H1) on Figure 11, the sliding debris appeared to have become airborne as it encountered a major rock spur. A large amount of mud splatter was found on the slopes high above the river on the Quebrada Tinte side (opposite the river from the slide). Furthermore, the slide material appeared to have first flowed up the slopes of the Quebrada Tinte, across the river from the major slide, and then flowed back down 150 to 200 m to a lower final position, indicating that the debris must have been in a fairly fluid state during the sliding. Some sand boils were found in the debris near the Quebrada Tinte bank, again indicating that some of the material at least must have been in a liquefied state during the sliding with the sand boils becoming created as the debris consolidated after coming to rest between the two banks of the Mantaro river.

A photograph of the bank of the Mantaro river on the Quebrada Tinte side is shown in Figure 12. The slope on the right hand side shows striations indicating where the debris had run up, and then slid back down to a more stable position. There is a small ridge, visible on the extreme left side of the photograph, which was formed when the slide debris fell back down the slope. This debris must have been in a fairly fluid state, at least in the lower levels, to have slid down and come to rest in that fashion.

A further evidence of the liquefied state of at least part of the slide debris is the sand boil shown in Figure 13, which was typical of several such sand boils found along the trench between the rock slope and the small ridge on the debris shown in Figure 12.

The slide debris completely dammed the Mantaro river, which remained absolutely dry downstream with no seepage, until overtopping began on June 6th some 42 days after the slide occurred.

A vertical air photograph of the slide debris at the toe is shown in Figure 14. This photograph was taken May 30, 1974, just six days before the lake level reached the crest of the dam. An oblique air photo showing the entire slide area is shown in Figure 15. This photograph was taken June 9th, 1974, the day following the dam breach. This photograph conveys something of the size and extent of the slide which as mentioned, extended over a total horizontal distance of over 7 km and a vertical elevation difference of almost 2 km. Another slightly lower angle oblique air photo of the slide area taken July 7, 1974 is shown in Figure 16. A view of the lower lake area, taken July 7th, one month after the breach, is shown in Figure 17. An indication of the extent of upstream flooding and secondary sliding on the reservoir slopes can be seen in the photograph. The foreground portion of the photograph shows the Quebrada Tinte side of the Mantaro river valley where the fluidized slide material ran up and then fell back down the slopes. Also visible is the zone of mud splatter which is the dark area above the lighter shaded run up zone.

Plan views of the slide area taken from air photos made before and after the event are shown in Figures 18 and 19 respectively. A cross section along the length of the slide scarp area is shown in Figure 20. Note that this drawing is made with the horizontal scale shortened by half in comparison to the vertical scale, giving a distorted concept of the slope. From this drawing and from the other information gathered while on the inspection trip it appeared that the depth of sliding may have reached up to 150 meters below the original ground surface, and that the depth of slide debris deposited at the toe and in the Mantaro river valley may have been about the same.

An enlarged plan view of the area at the toe after the slide is shown in Figure 21. The first exit path for the overflowing lake is indicated. An enlarged true scale sectional view of this enlarged area is shown in

Figure 22 indicating the depth of the slide debris above the ground level before the debris dam was breached. While the old river canyon is a small feature in comparison with the surrounding topography, nevertheless it was sufficiently significant to leave a valley feature at the surface of the slide. This depression provided the exit for the subsequent overtopping.

A true scale transverse section across the slide debris at the river level, which is really a cross section of the debris dam is shown in Figure 23a. Note that the elevation of the debris is considerably lower in the old river valley than over the old banks or abutments to this debris dam.

For reference, the extent of down cutting in the erosion channel through the debris dam during the overtopping on June 6-8, 1974 is shown in Figures 22 and 23. Note that after the initial flood had subsided, a substantial dam some 63 m high still remained, creating a sizeable lake upstream. No doubt this will continue to erode slowly until the old regime slope of the river has again been established. At the time of our visit, about one month after the initial overtopping, there was still a sizeable lake behind this debris dam. However the water in the river downstream was very muddy indicating that erosion was continuing.

In order to illustrate the enormity of this landslide and resulting debris dam, a comparison has been made with two other subjects which may be familiar to many readers. On Figure 23c an outline of the maximum section of the Oroville dam in California has been superimposed on the cross section of the debris dam from the Mantaro river landslide. At the time of its construction about ten years ago the Oroville dam was the tallest earth dam in the world, being some 230 m high at the maximum section. Note that although it is higher than the slide debris in the river channel, it is not as high as the level of the debris on the abutments. Furthermore, the steep side slopes of the Oroville dam lead to a considerably smaller structure than this landslide debris dam. The Oroville dam is only about 1/20th the volume of this debris dam.

On Figure 24 a comparison is made of the slide area along the Quebrada Ccochacay from the mountain peak to the Mantaro river, with the south side of the Grand Canyon along the Bright Angel - Garden Creek Trail from the south rim to the Colorado river. The vertical and horizontal dimensions are roughly the same, with the Mantaro river slide zone being slightly larger.

Nature of the Slide Material and Mechanism of Sliding

Very little serious study has been made of the nature of the slide debris or the engineering evaluation of the mechanism of sliding. The enormity of the affected zone, the remoteness from Lima where engineering facilities are available, and the relatively depressed economical situation in the area of the slide have not been conducive to performing a serious geotechnical engineering investigation of the slide. Immediately following the slide the major efforts were expended in saving lives from the effects of the flood when the debris dam would be overtopped, and other geotechnical studies not related to this goal were extremely limited. Now that the flood has passed, the need for immediate action has also been reduced so that such future geotechnical studies as may eventually be undertaken will probably be a long time developing.

No deep soil borings were made, but those who made superfical examinations of the slide debris reported it to be a well graded heterogeneous mixture of clay, silt, sand, gravel and boulder sizes. A photograph of some men standing on the debris is shown in Figure 25a. Note that many large boulders are visible. There are many boulders even larger than shown in this photograph. These boulders which appear to have originated in the shale and sandstone beds are the upper levels of the slide scarp.

A close up photo of the interior of the debris dam along the stream channel after breaching is shown in Figure 25b. Although boulders are clearly visible, the predominate impression is of a well graded fine to coarse material.

The material was quite impervious. There was no seepage emerging from the downstream toe during the entire 42 days in which the lake was building up. A small test hole dug in the debris near the lake, extending below the lake level, did not fill with water or become wet inside.

Although some remanents of sand boils were visible near the Quebrada Tinte side of the slide, the soil near the surface of the debris was reported to be dry and did not give the appearance of being saturated throughout. However, perhaps some zones were saturated, which could lead to the formation of the observed sand boils. A possible alternate explanation is that heat generated by the rapid sliding movement may have vaporized some of the pore water into steam, which would have a lubricating effect on the slide, and could lead to the formation of the small sand volcanoes as the steam escaped to the ground surface. The physical conditions for such a situation to develop have been discussed by Habib (1967) who showed that steam generation at the sliding surface was possible where large masses and high velocities were involved.

During the inspection trip the writers heard several theories and hypotheses concerning the cause, nature and mechanism of the slide. As will be described in more detail in a later section, the possibility of it being caused by a local earthquake has been fairly well ruled out (Berrocal 1974). This then seems to require the existence of a substantial effect from water in the soil. The source of excess pore water and pore water pressure is not immediately obvious.

One school of thought suggests that a significant source of excess pore water could have come from the small river and alpine lakes in the mountains above the slide. This was the opinion expressed by Galdos Bustamante (1973) in his geological report of the area prior to the slide. Another school of thought suggest that rainfall and local drainage could have provided sufficient pore water to cause the slide.

The average annual rainfall in the area is reported to be about 700 mm. The rainy season extends from October through April during which time about 95% of the annual rainfall occurs. The year 1974 was apparently an average year with respect to rainfall. The slide occurred on April 25th, almost at the end of the rainy season, when the soil would have had the greatest amount of water, and local runoff from the surrounding hills into the Ccochacay area would have been at the greatest of any time during the year. This rain water, coupled with the known marginal stability of the slopes as reported by Galdos Bustamante (1973), was probably sufficient to cause the slide.

In his study of the seismograms recorded during the slide Berrocal (1974) indicates that three different types of movement seem to be present, suggesting three different stages in the landslide development. Others with whom the writers discussed the possible mechanism also suggested that the entire slide did not flow as a single mass, but came down in about three different major blocks, which broke up as they slid.

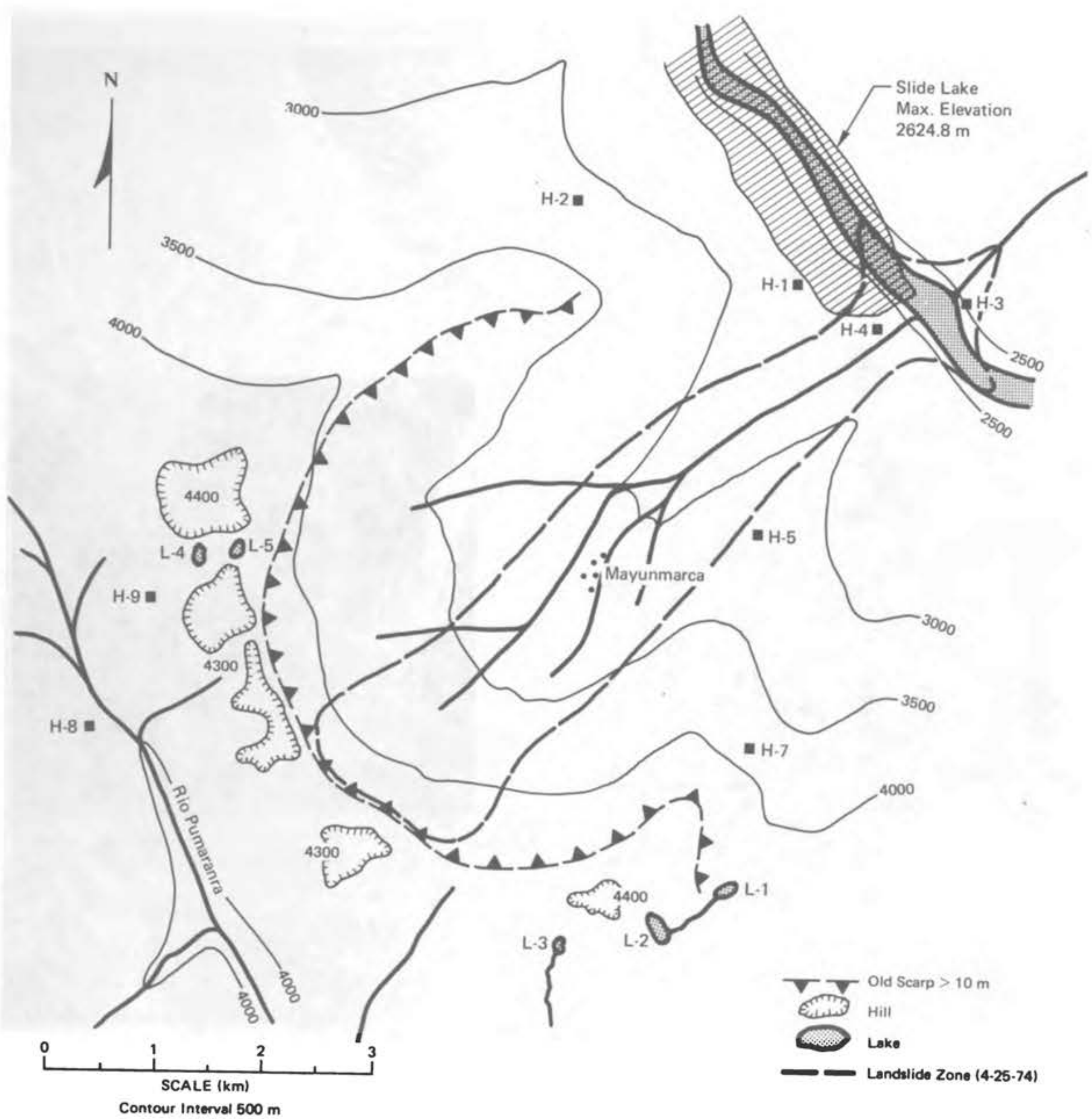


FIGURE 11. Plan of the Ccochacay ravine area showing the limits of the landslide zone of 4/25/74.

FIGURE 12. Steep slope of the Mantaro river valley opposite the main slide showing where the slide debris had run up and then fallen back down the slope. (Kojan-Hutchinson, Ref. 11)

FIGURE 13. Sand boils located in the fall back debris from the slope shown in Figure 12. (Kojan-Hutchinson, Ref. 11)

FIGURE 14. Vertical air photograph of the debris dam taken May 30, 1974 some nine days prior to the dam being overtopped. (Defensa Civil Photograph)

FIGURE 15. Oblique air photo taken June 9, 1974, the day following the major flooding from overtopping. (Servicio Aerofotografico Nacional, Peru)

FIGURE 16. Oblique air photo taken July 7, 1974, about one month after overtopping.

FIGURE 17. Air photo taken July 7, 1974 looking upstream from the debris dam showing the debris fall back zone and some areas of mud splatter in the foreground.

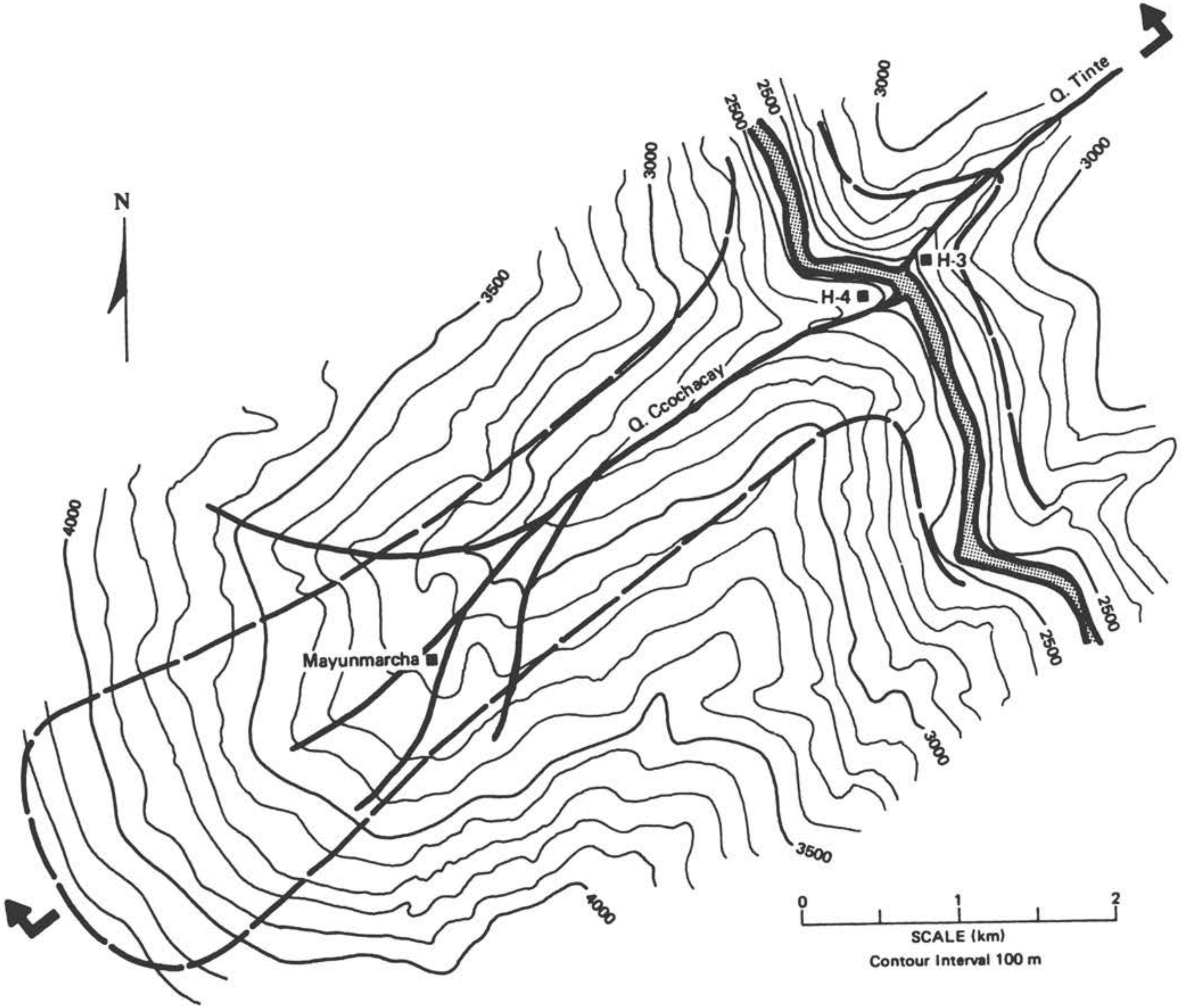


FIGURE 18. Plan of area before landslide of 4/25/74.

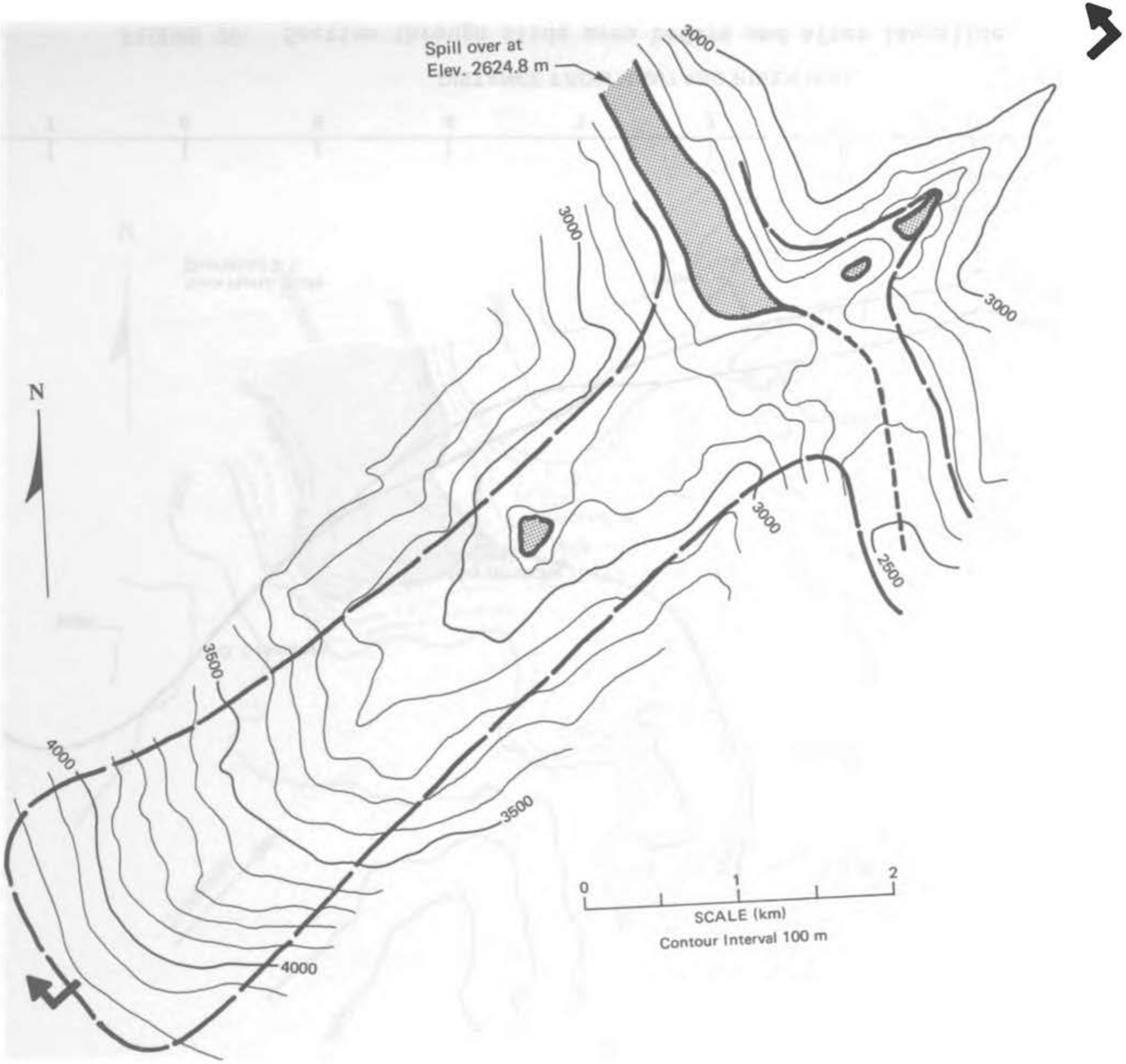


FIGURE 19. Plan of area after landslide of 4/25/74.

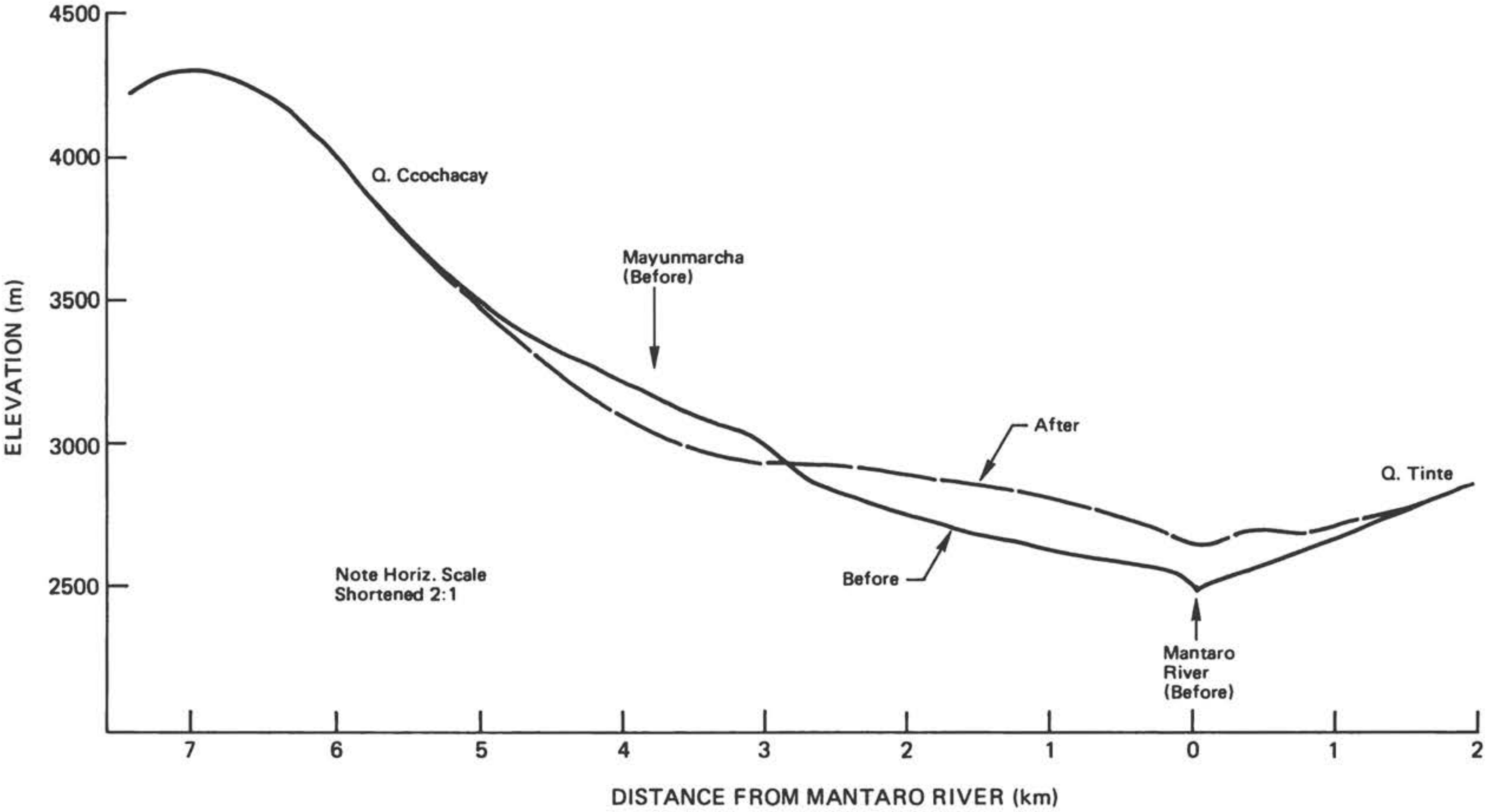


FIGURE 20. Section through slide area before and after landslide.

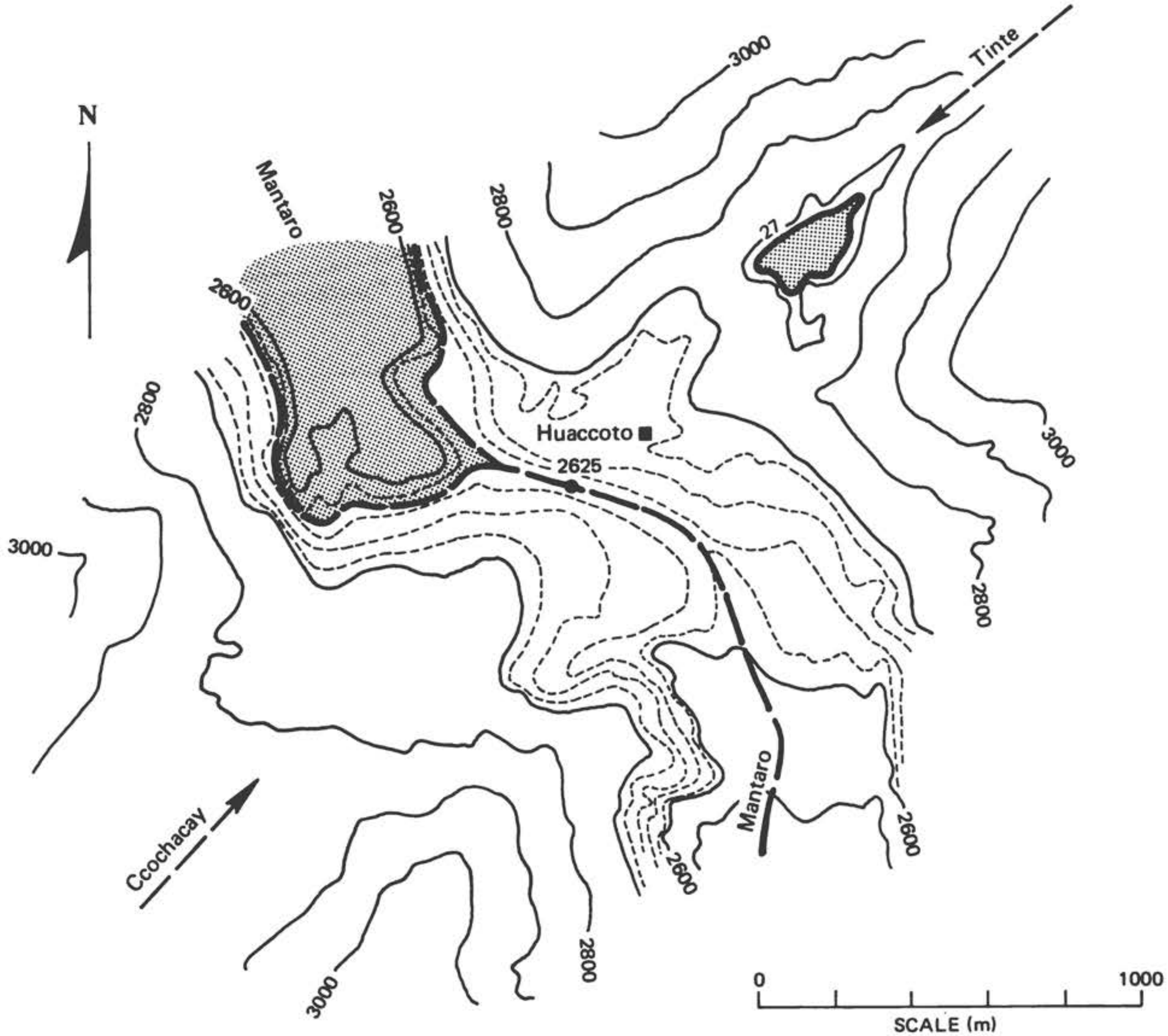


FIGURE 21. Enlarged contour plan of area at Mantaro River after landslide.

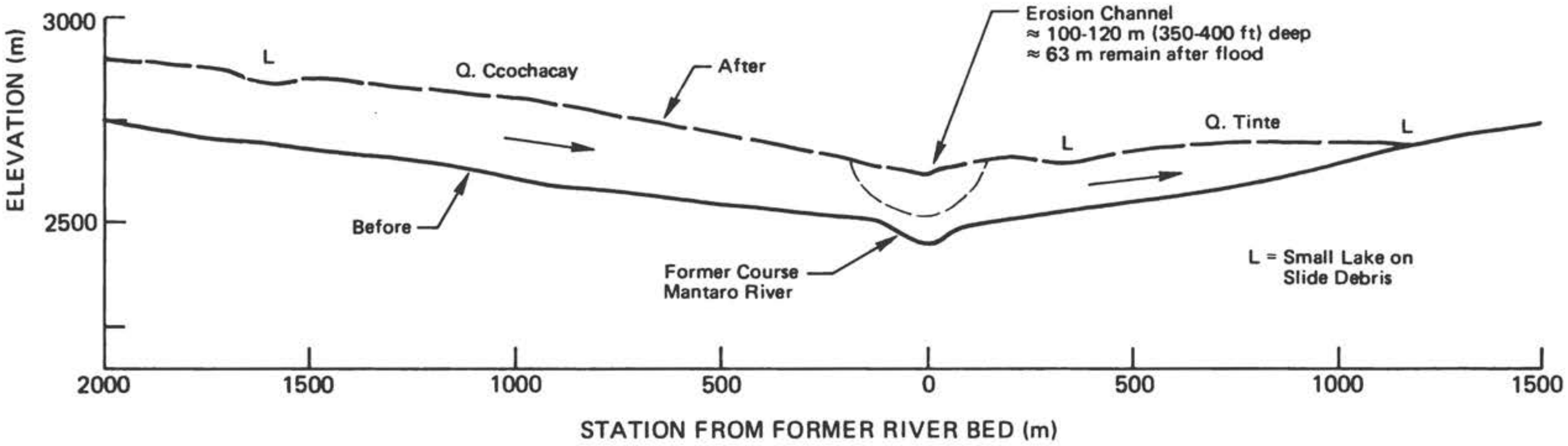
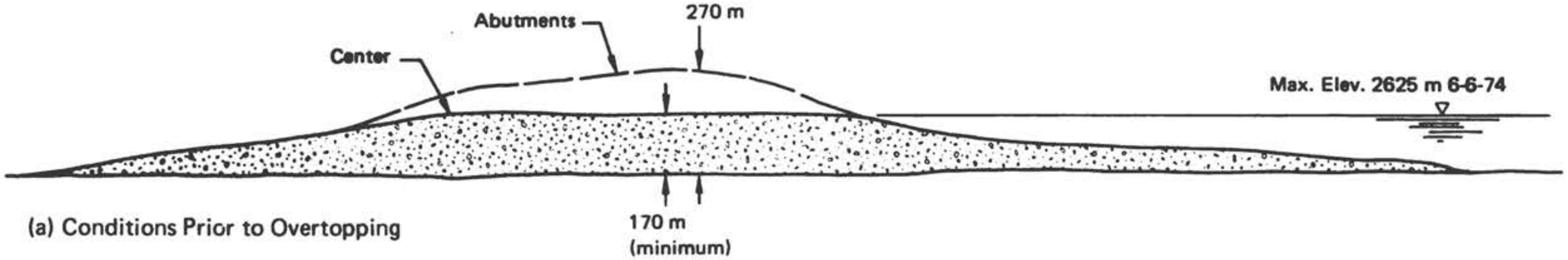
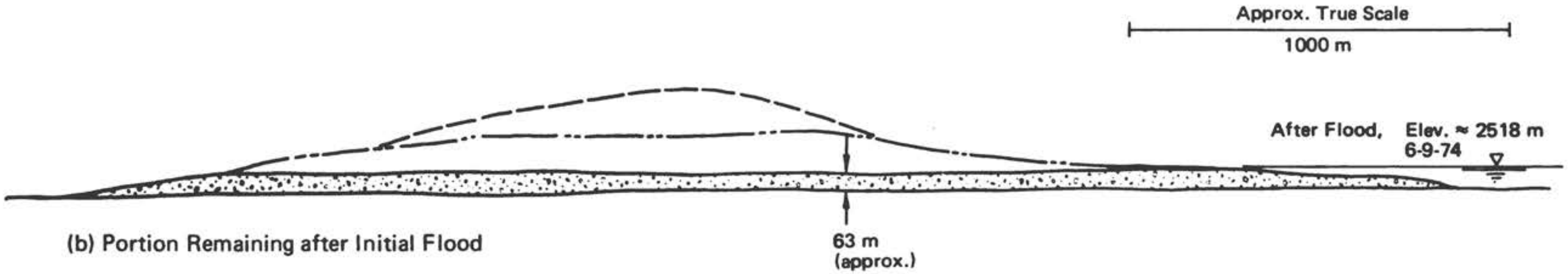


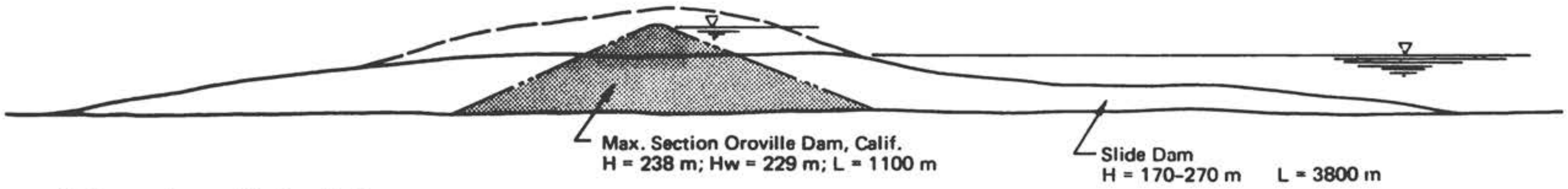
FIGURE 22. Enlarged longitudinal section along slide debris.



(a) Conditions Prior to Overtopping



(b) Portion Remaining after Initial Flood



(c) Comparison with Oroville Dam

FIGURE 23. Transverse section of slide dam for various comparisons.

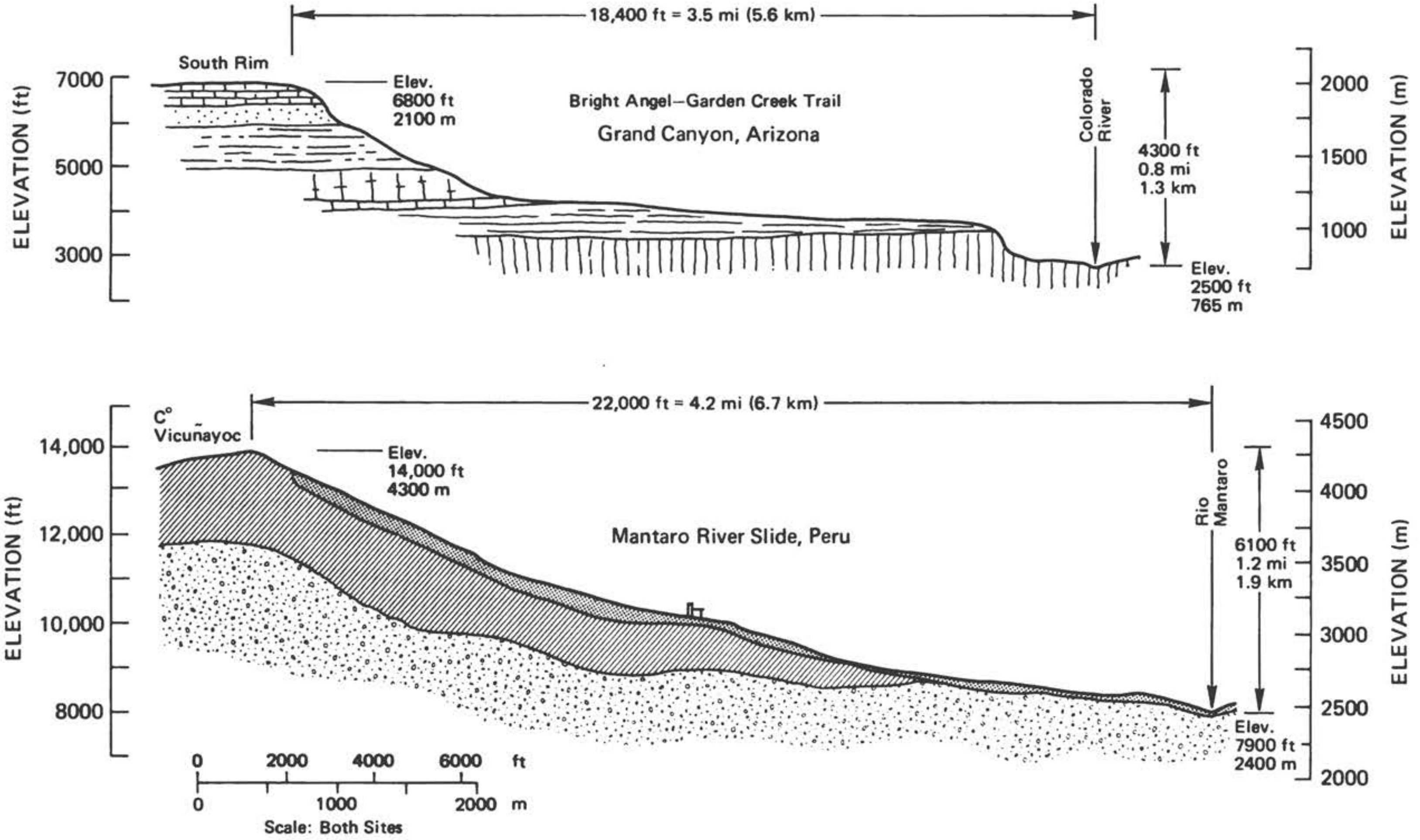
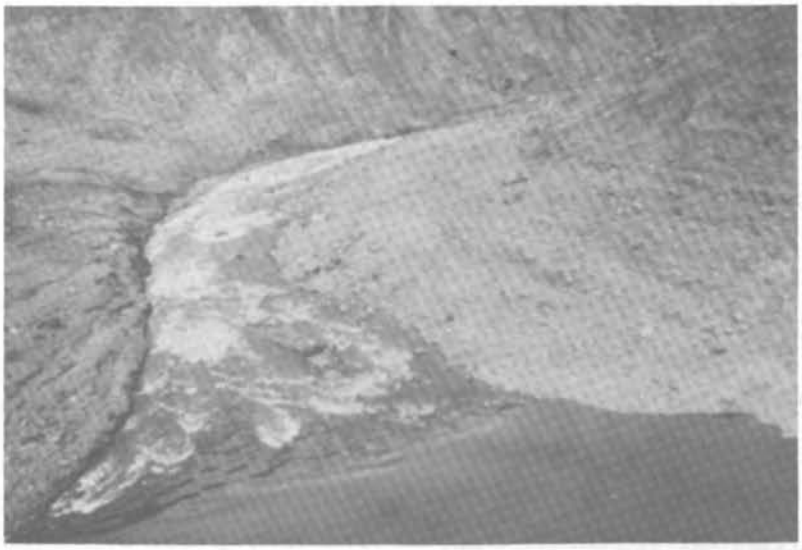


FIGURE 24. Comparison of cross sections: Grand Canyon, Arizona and Mantaro River slide.

(a) Men working on slide debris before overtopping.



(b) After overtopping, showing nature of material exposed in the erosion slopes.

FIGURE 25. Close up views of slide debris. (Photographs courtesy of General Rodolfo Acevedo del Campo)

SECONDARY EFFECTS

Reservoir Filling Following the Slide

The Mantaro River normally flows at a rate of about 100 to 300 m^3/s, and at this time of the year being the end of the rainy season was probably flowing at the higher rate. Thus, when the slide dammed the river, a lake immediately began to form. This posed several hazards.

1. The rising waters would flood low property along the lakeshore above the dam.
2. Landslides, triggered by the rising water, occurred on the steep banks along the shoreline of this lake posing a threat to life and property in their path.
3. More slides in the reservoir area of the rapid drawdown type could be anticipated as the lake emptied.
4. Erosion and flooding downstream would occur when the dam overtopped and eroded away.

As a result of these fears the Peruvian government, acting through the military and the Civil Defense, undertook immediate action to minimize these losses as much as possible.

As a first step all people living in low areas in the lake area above the slide dam and in the potential flood areas along the river below the dam were immediately evacuated to impromptu refugee camps on safe higher ground. These camps were then continually supplied by helicopter, and where possible by road.

As a second step air photos were taken to provide a better basis of assessing the engineering aspects of the problems than was possible from existing maps. Studies made from these airphotos and the maps derived therefrom enabled the engineers to predict the extent and the rate of lake buildup, and the day of overtopping.

Supplemental to these studies, the hydraulics laboratory at the National Engineering University (UNI) constructed some scale models of the slide debris dam and studied the nature and rate of drawdown erosion and flooding which could be expected from the effect of overtopping.

A plan view of the slide dam and the lake formed thereby is shown in Figure 26. This lake was only a few hundred meters wide, but stretched for a length of over 31 km along the tortuous path of the Mantaro River Valley. At its highest elevation before overtopping the slide dam, the upper end of the lake reached to within about 4 km horizontal distance and 5.4 m vertical elevation of the Tablachaca concrete dam which had been built in 1967-71. The location of the old 1930 slide shown in Figure 2 is also indicated in Figure 26 as being only about 2 km above the upper reach of the lake at its greatest elevation. Had the lake level reached the toe of this old slide it is possible that it may have been reactivated as were many other slides along the lakeshore. As shown in Figure 2 this old slide was directly opposite the river from some important structures in connection with this hydroelectric facility and the debris from a major new slide in the area could have crossed the river to damage these structures. The extent of the lake behind the Tablachaca concrete dam is also shown in Figure 26; it is considerably smaller than the lake behind the slide dam. At its maximum elevation, the slide dam lake held an estimated volume of 670×10^6 m^3 of water.

Photographs showing typical landslides on the sloping sides of the reservoir are presented in Figures 27-30. There were many such slides. The largest of these involved about 7×10^6 m^3 of material. This is a major slide by most standards, but small in comparison with the main slide which involved about 1.6×10^9 m^3 or about 230 times as much material as this secondary reservoir slide. Note that these reservoir slides destroyed the road which ran along the river, probably to such an extent that it will not be possible to safely and economically rebuild it.

Description of Overtopping

As the lake level rose men and equipment were brought to the site and set to work doing what they could to prepare the surface of the debris dam in such a way as to minimize the effect of overtopping. Some steps were cut in the potential flood path and rolls of wire mesh filled with rock were placed in the path to retard rapid erosion. Later, acting on engineering advice, these obstacles were removed in order to hasten the overtopping and thus minimize the amount of water collected in the reservoir. These effects were probably only of trivial benefit.

By June 6, 1974, some 41 days after the landslide, the lake level had reached the crest of the dam and began to trickle over the top. For the first two days the flow rate was very slow, increasing from about 1 to 50 m^3/s, and much less than the normal river flow of about 100 to 300 m^3/s. A vertical and an oblique aerial photograph of the flow at this time, taken June 7th, are shown in Figures 31 and 32 respectively.

Then at about noon on June 8th the overflowing water began to seriously erode into the debris dam, and the flow increased at a greatly accelerated rate. By 4:00 p.m. that afternoon the flood had reached its peak flow of some 10,000 m^3/s, some 30 to 100 times greater than the normal river flow and some eight times greater than the peak recorded natural flood. A helicopter photograph of the flow out of the lake taken at about this peak flood time is shown in Figure 33a and a view from a vantage point on a hill overlooking the debris dam is shown in Figure 33b.

This peak flood rate lasted for only a short period of time, and by nightfall the rate of flow had significantly reduced. By daylight the next morning the river flow was back to normal and a 107 m (350 ft) high gorge had been eroded through the debris dam. Some 63 m of material was not eroded leaving a substantial lake remaining.

The storage capacity of the remaining lake was estimated at about 170×10^6 m^3 or some 25% of the total maximum reservoir capacity before the flood. An aerial photograph of the debris dam and the remaining lake taken June 9, 1974, the day following the flood, is shown in Figure 34.

Closeup air photos of the erosion gorge taken by the writers during their visit one month later are shown in Figures 35 and 36. Note that the steep banks of the erosion channel are some 110 m or more high. The volume of this erosion gorge is about 400×10^6 m^3 of soil which was washed into the stream and which settled out on the flood planes below the debris dam.

A graph showing the rate of discharge from the reservoir at various times throughout the flooding is presented in Figure 37. Unfortunately, since the flooding ended after dark, the drawdown curve is not well defined for a long period after the peak, and it is not known exactly how long it actually took to drain the reservoir, but it must have been only about 12 hours or slightly more.

Because the inhabitants of the region had all been evacuated from the lower ground by the river prior to overtopping, the flood passed without causing any loss of life or human accident. However, there was considerable property damage. Upstream in the lake areas new slides developed as the lake level was rapidly lowered. Downstream, farmlands, houses, towns, and bridges were destroyed. A photograph of a concrete arch bridge at the town of Mayoc taken before the flood is shown in Figure 38. Another photograph of the same bridge taken just after it was destroyed during the flood is shown in Figure 39.

A map of the Mantaro River with notes describing types of damage caused at various locations is presented in Figure 40.

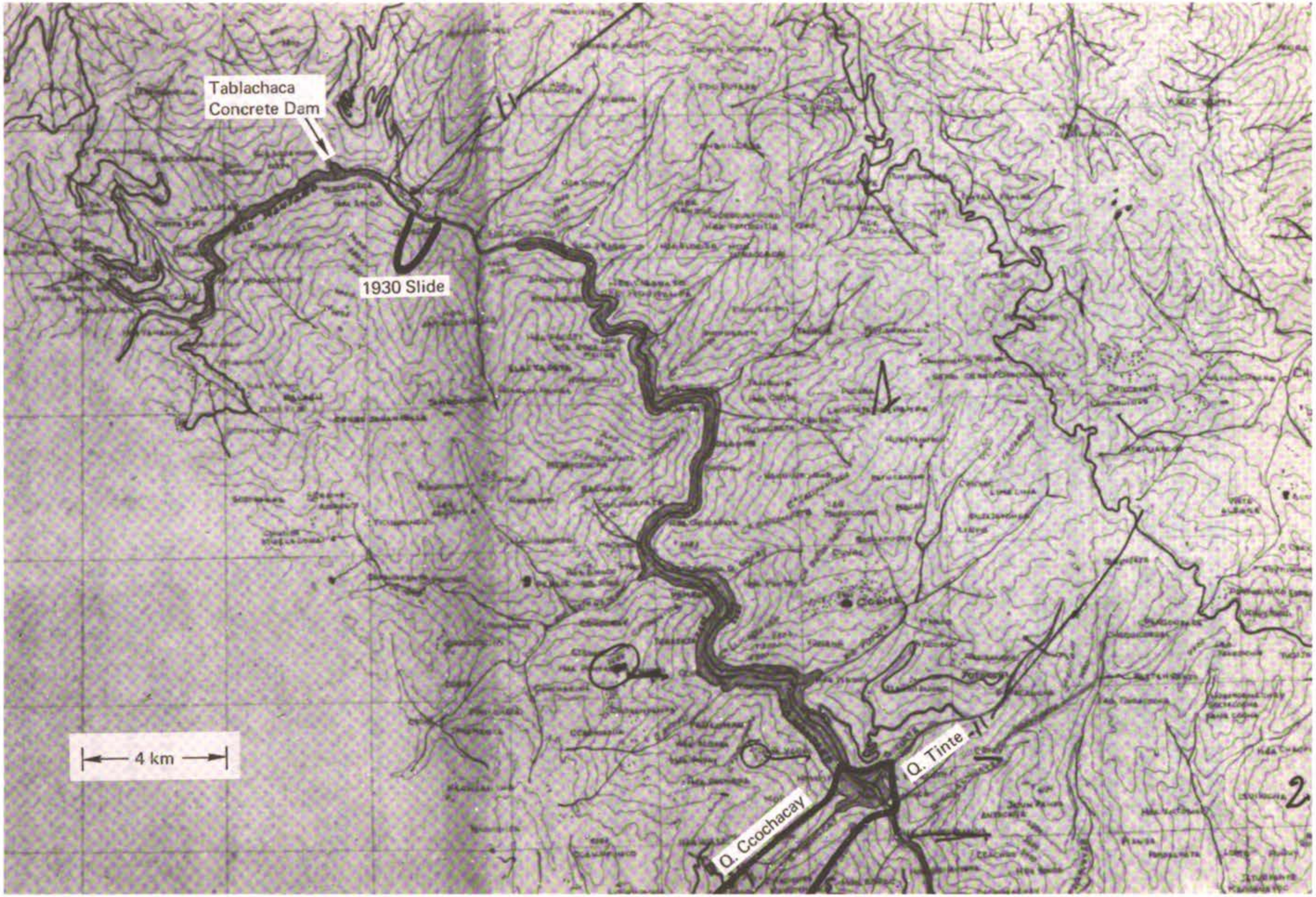


FIGURE 26. Map showing extent of lake which formed behind the slide dam.

FIGURE 27. Small landslide on the lake shore caused by rising water.

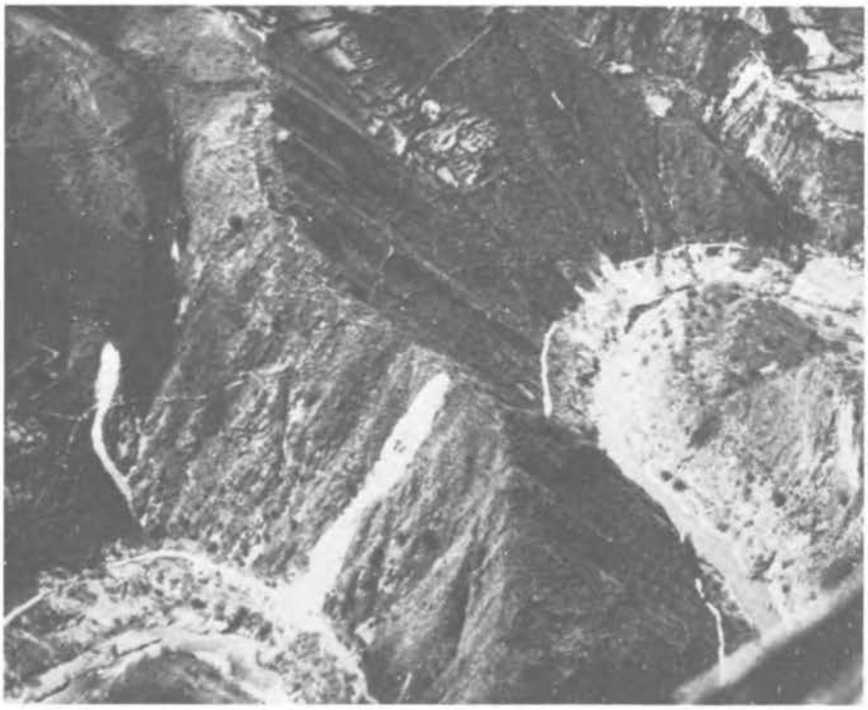


FIGURE 28. Landslide along lake shore caused by rising water.

FIGURE 29. Landslide along the lake shore caused by rising water.

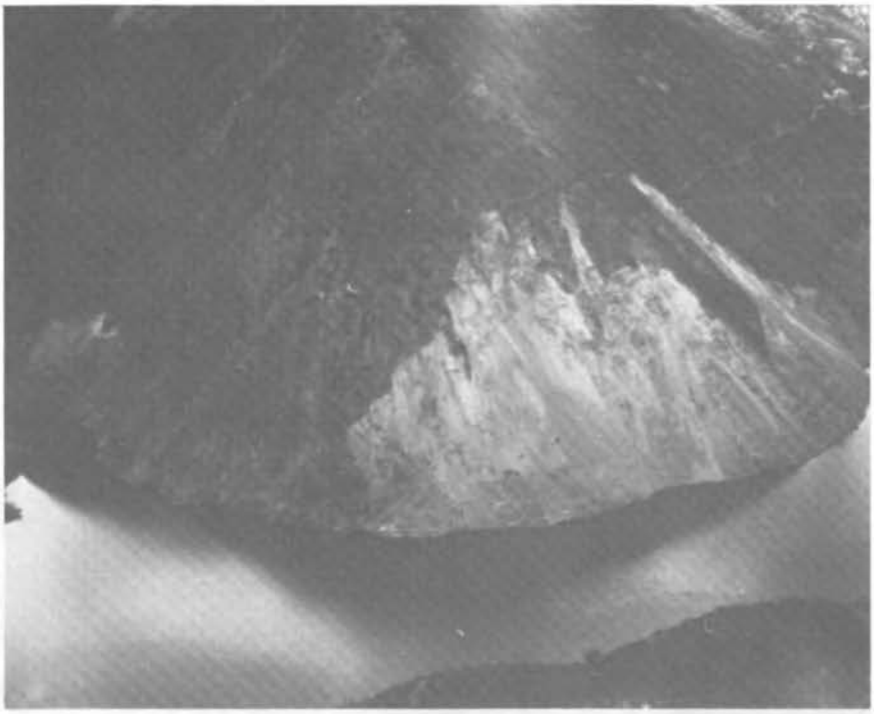


FIGURE 30. Extensive landsliding along the lake shore caused by rising water.

FIGURE 31. Air photo taken June 7, 1974, just as the water began to trickle over the debris dam. (Defensa Civil Photograph)

FIGURE 32. Oblique air photo taken June 6, 1974, showing water as it begins slowly to flow over the debris dam. (Defensa Civil Photograph)

(a) (General Rodolfo Acevedo del Campo Photograph)

(b) (Hutchinson-Kojan Photograph)

FIGURE 33. Two views of the Mantaro River flood over the debris dam during periods of high flow rate.

FIGURE 34. Oblique air photo looking downstream across the debris dam, taken June 9, 1974, the day after the flood. (Defensa Civil Photograph)

FIGURE 35. Air photo looking upstream across the debris dam, taken one month after the flood.

FIGURE 36. Air photo looking downstream along the erosion channel, taken one one month after the flood.

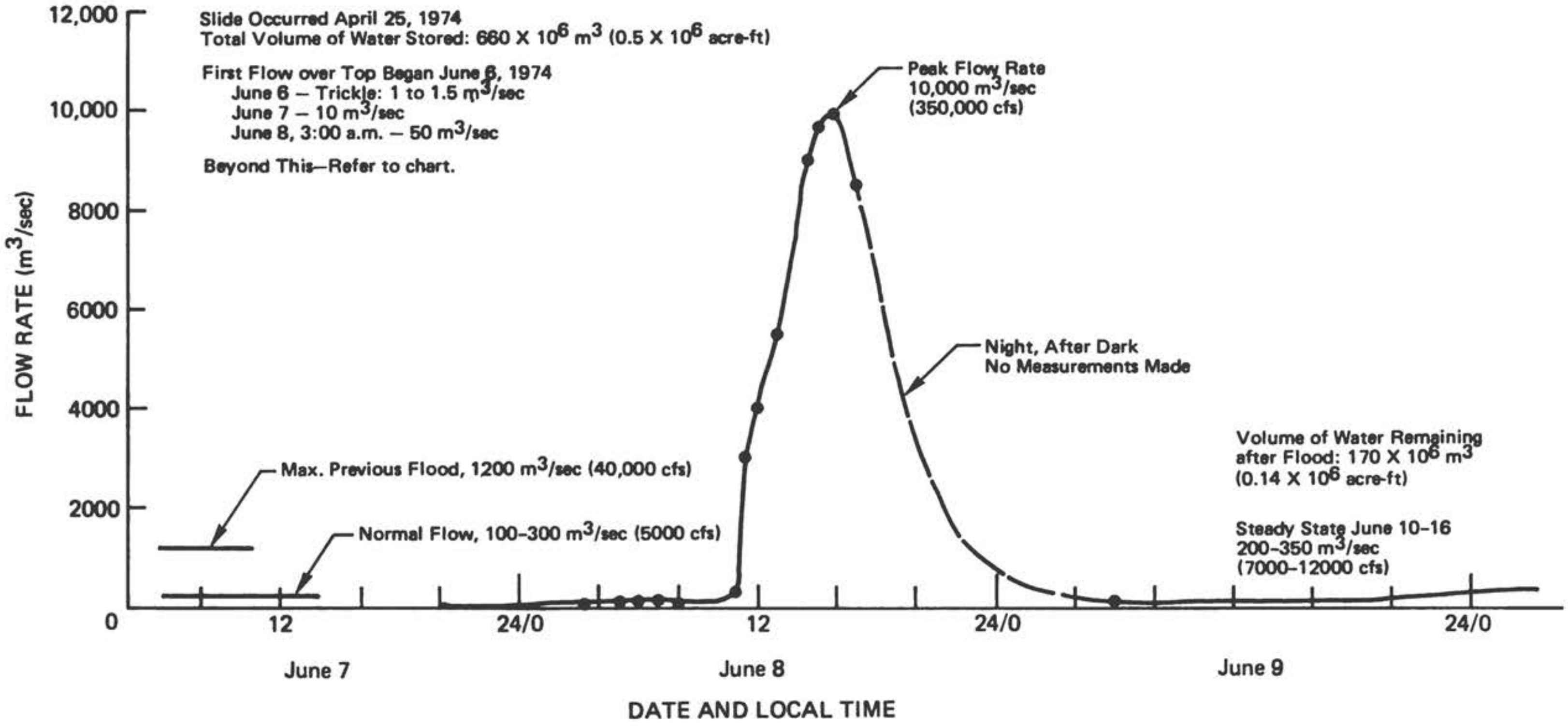


FIGURE 37. Measured flow rate as the reservoir emptied.

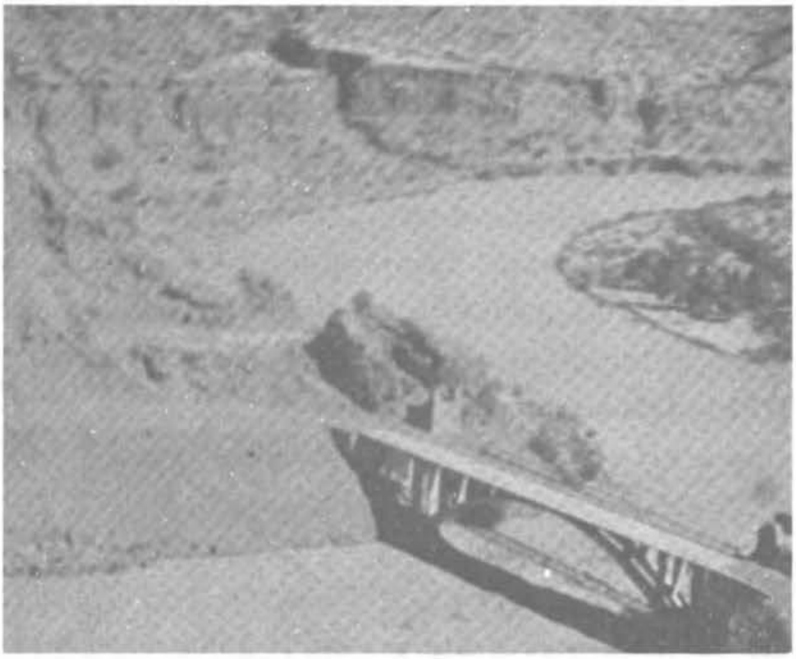


FIGURE 38. Mayoc bridge across the Mantaro River taken as the flood waters were rising. (Photograph courtesy of General Rodolfo Acevedo del Campo)

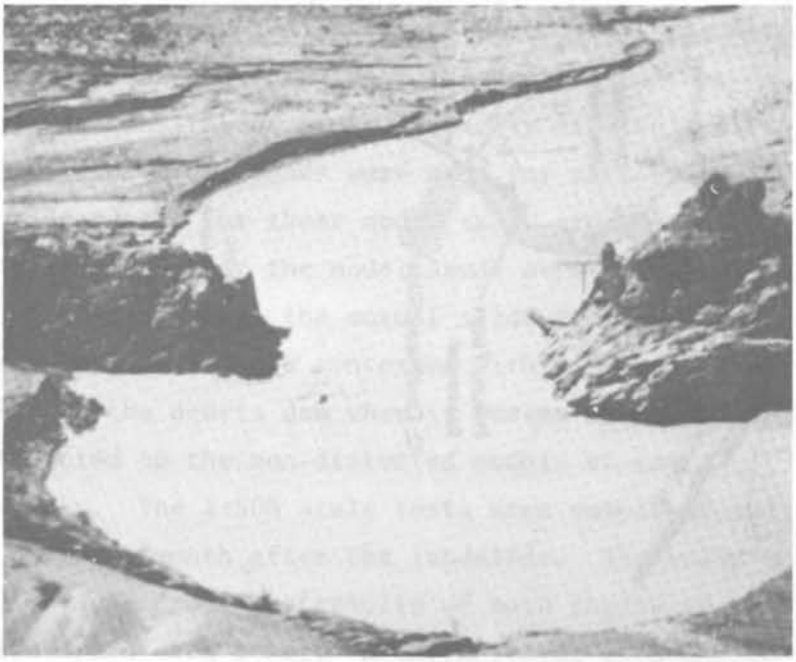


FIGURE 39. Mayoc bridge across the Mantaro River after destruction by the high flood water. (Photograph courtesy of Gen. Rodolfo Acevedo del Campo)

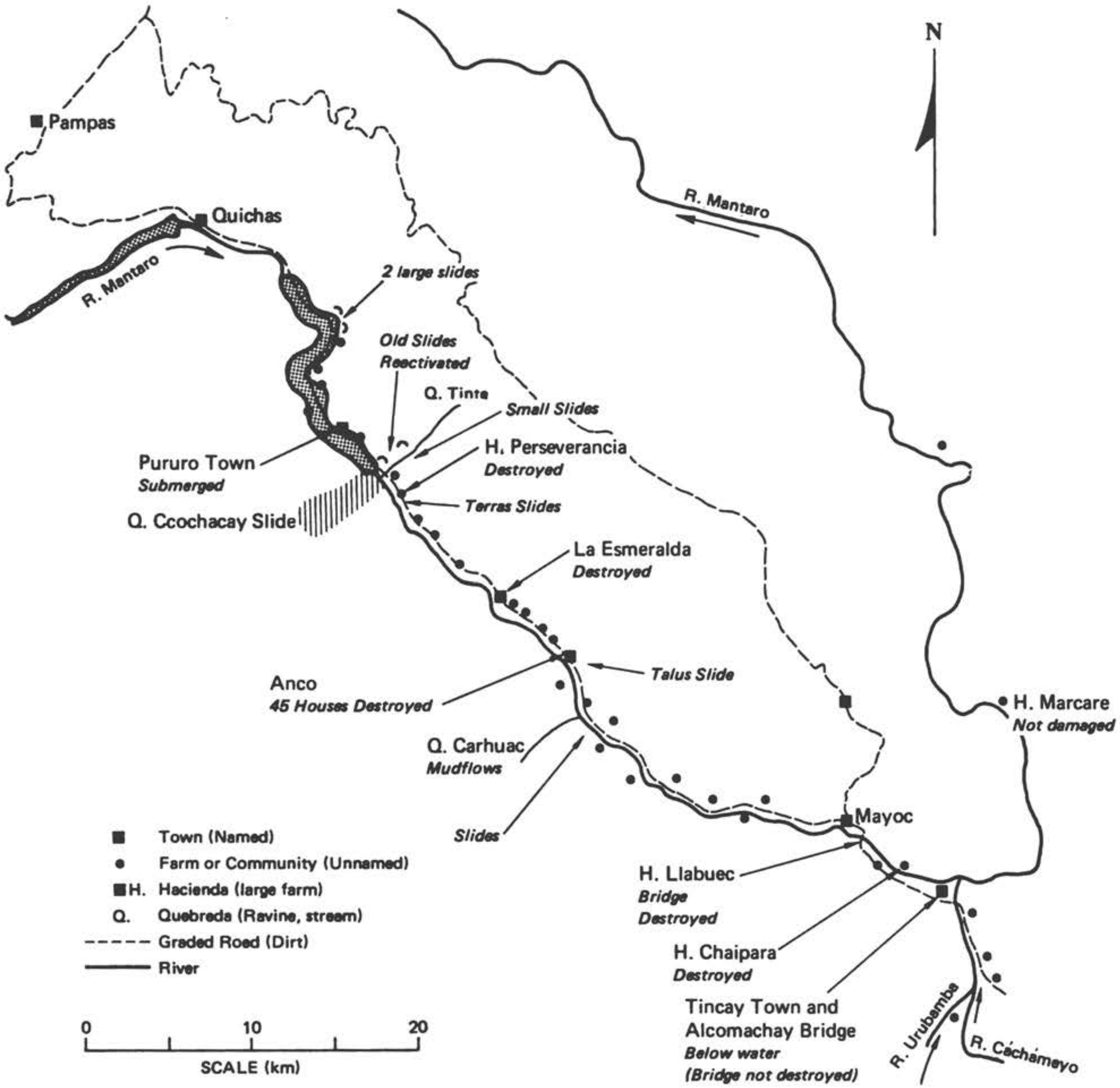


FIGURE 40. Location of major damage.

HYDRAULIC MODEL STUDIES

Very soon after the landslide, some hydraulic scale models were built to study the nature of erosion and flooding to be expected when the lake overtopped the debris dam. These studies were carried out at the hydraulics laboratory of the National Engineering University in Lima under the sponsorship of the Ministry of Agriculture. The results are presented in two reports (Humata *et al*, May 1974, and Ministerio de Agricultura, June 3, 1974). Both of these were published before the dam was overtopped on June 8th, and the data were of course available before publication.

An inspection team sent to the site drilled four holes along the lowest part of the overflow channel to a maximum depth of 4 m and some soil samples were recovered. From the grain size analysis of these samples and measurements of larger rocks on the surface, a representative grain size distribution curve for the soil along the flood path over the debris dam was obtained and is reproduced in Figure 41. The maximum size shown on this grain size curve is approximately one meter, but the above cited reports mention that rocks in excess of three meters in diameter were to be seen on the surface of the debris.

The model was constructed of sand readily available at the laboratory. Four different model sands were used for various tests. The grain size distribution curves for these model sands are also shown in Figure 41. It is noted that the model sands were more uniformly graded and contained less fines than the actual slide debris.

The first model tests were concerned with studying the nature and rate of erosion of the debris dam when it became overtopped. These tests were conducted on the non-distorted models at scales of 1:500 and 1:250 respectively. The 1:500 scale tests were completed and reported on May 23, 1974 only one month after the landslide. The 1:250 scale tests were reported on June 3rd. The results of both series of tests were similar and confirmed each other. A third series of model tests were then conducted using a distorted scale 1:5000 horizontal and 1:250 vertical to study the nature of the flooding downstream from the dam. In retrospect, considering what was actually observed, and also considering the haste at which these tests were conducted, there was a remarkable agreement between the model test predictions and the observations.

A summary of the results from the 1:250 non-distorted model to study the flood erosion through the debris dam is presented in Table 2, along with observed data during the actual flood. Note that the erosion depth and volume of eroded debris was accurately predicted. Also the rate of maximum discharge and the time required was also predicted in the correct order of magnitude. In addition the model studies showed that the rate of discharge would begin very slowly and the protective works placed on the dam would cease to function when the flow rate reached about 100 m^3/s, which is very small compared to the estimated peak flood rate of 100 times this amount. The rate of water flow was predicted to cause turbulent waves which would rapidly erode the debris dam, causing large landslides from the sides of the gorge into the flood waters.

TABLE 2

Hydraulic Model Predictions and Actual Observations for Reservoir Discharge

Hydraulic Model Test Number	1	2	3	4	Actual Observation
Erosion depth into debris dam (m)	110	103	96	105	107
Volume of material eroded (10^6 m^3)	640	630	610	630	400
Time for lake to empty (hr)	12	20	28	29	12
Maximum flood discharge during peak 15 min. (m^3/sec.)	23,000	18,000	18,000	12,000	10,000
Average flood discharge (m^3/sec.)	14,000	9,000	6,000	6,000	

Data for non-distorted hydraulic model scale 1:250 similar data obtained for model scale 1:500. See elsewhere in text for grain size distributions in field and in model dam.

(Model data from Ministerio de Agricultura).

These predictions were of value in the subsequent relations between authorities and the local residents who were evacuated from the area. When the first overtopping actually began very slowly and continued for two days without seriously eroding away the debris dam or causing any significant flooding downstream the natural tendency of the residents downstream was to return to their homes. However, armed with this knowledge from the model tests that the initial slow start would soon lead into a major flood, the authorities kept the people out of the area and thus avoided the possible further disaster had they been permitted to return.

During the writers' visit to the hydraulics laboratory in Lima, one of these model tests was rerun for the visual benefit of the visitors. Figures 42-45 are photographs taken during that particular test. The slow initial start of overtopping, the turbulent waves, the deep erosion and the landsliding into the flood waters are clearly visible in these photographs. Reference to the photographs in Figure 33 taken of the actual overtopping clearly shows the same phenomena of turbulent water, erosion and landsliding in remarkable similarity to the hydraulic model results.

In order to form a basis for estimating the probable nature of the flooding to be expected downstream of the dam, a distorted model was constructed to scales 1:5000 horizontal and 1:250 vertical, covering a 100 km reach of river below the dam. At these scales only the most important features could be modeled. Taking a conservative approach the flood water released in the model at the dam was at a maximum instantaneous rate of 50,000 m^3/s. This was twice the value measured in any of the model dam erosion tests, and five times the rate actually observed. Thus the measured flood wave height downstream in the model would be expected to be considerably greater than was subsequently observed.

The flood wave heights observed at various distances downstream are listed in Table 3. Unfortunately, the writers do not have data on the observed wave heights but such information as is known concerning the flood damage is also listed. Note that the predicted large flood waves were relatively realistic in that there was serious flood damage at locations a considerable distance downstream of the dam.

TABLE 3

Hydraulic Model Predictions and Actual Observations for Downstream Flooding.

Distance below debris dam km	Location Name	Predicted Height of Flood Water above River Bed meters	Actual Observation
10	La Esmeralda	45	Destroyed. 45 houses destroyed & landsliding.
15	Anco		
20	Larcay Bridge Carhuac Creek	26	Mud flow from slide debris reached here.
30		36	Road destroyed
35	Llabuec farm	31	Road destroyed
45	Mayoc Bridge	9	Destroyed
50	Chiapara Farm	16	Destroyed
60	Tincoy Alcomachay Bridge	14	Covered by lake
70	Marcane	17	Not damaged?

Data for distorted hydraulic model of 100 km reach of Mantaro River below the debris dam.
Model Scale 1:5000 horizontal; 1:250 vertical
(Model data from Ministerio de Agricultura)

Note: used maximum instantaneous reservoir discharge = 50,000 m^3/sec. as a conservative approach. This was two to four times the maximum discharge observed in any of the prior model tests (Table 2).

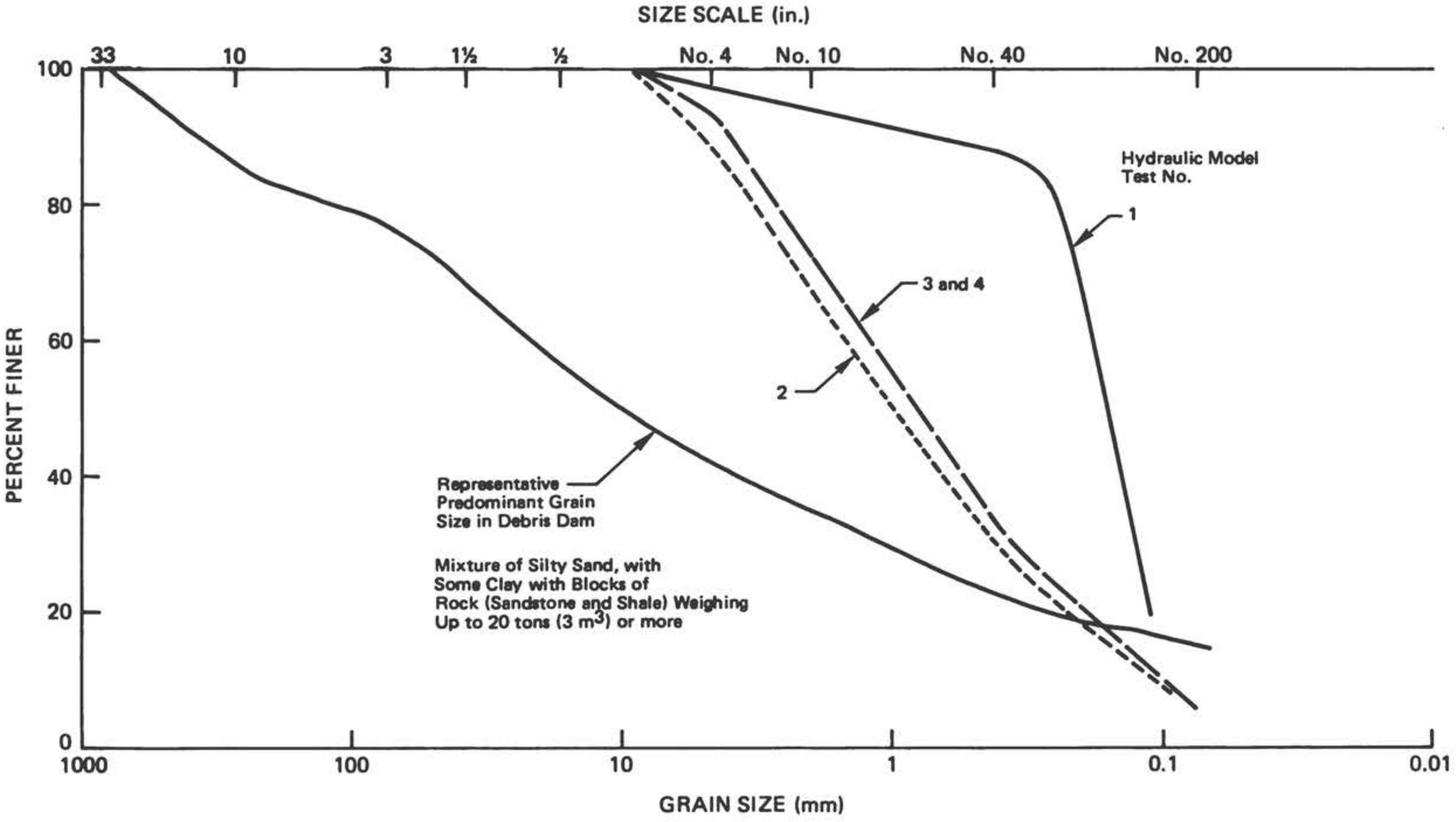


FIGURE 41. Grain size distribution curves, field and hydraulic model. (Ministerio de Agricultura)

FIGURE 42. Hydraulic model, looking downstream at the stage where water just begins to trickle slowly over the debris dam.

FIGURE 43. Hydraulic model looking upstream as water just begins to flow over the dam.

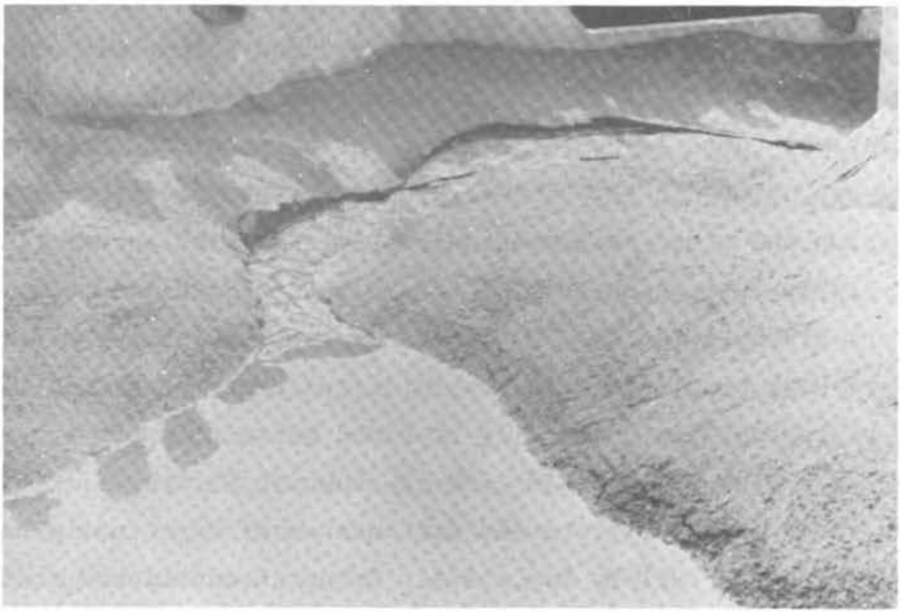


FIGURE 44. Hydraulic model looking downstream during peak flood.

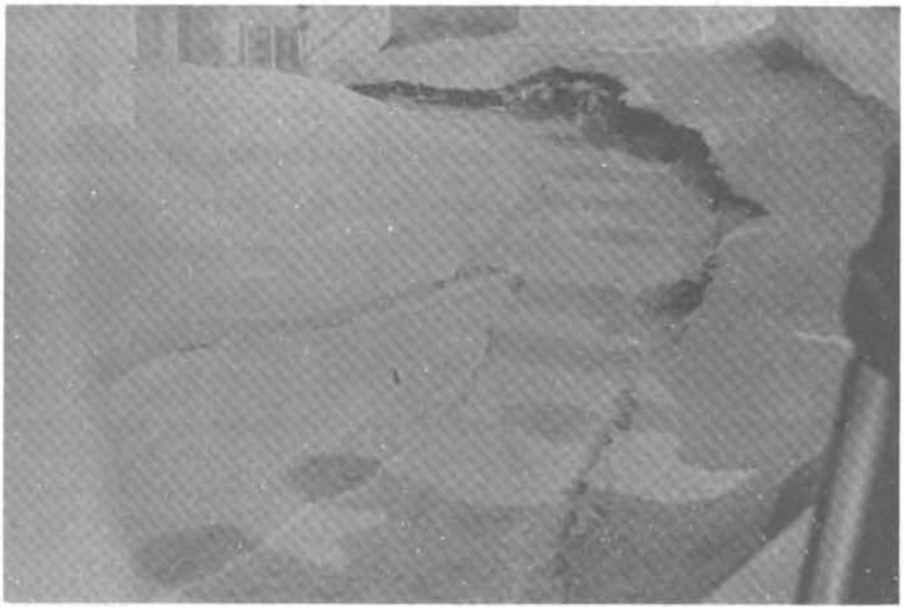


FIGURE 45. Hydraulic model looking upstream during peak flood.

SEISMOLOGICAL ASPECTS

Because seismographs in the region recorded strong vibrations at the time of the landslide, and because the area is known to be seismically active, there is an immediate question as to whether the landslide was set off by an earthquake. The Instituto **Geofisico has** addressed this question and other seismological aspects in a technical report by Berrocal (1974) from which much of the following data has been taken. The writers also visited the Institute, and spoke with the Director, Dr. Ernesto Desa concerning the seismological aspects of this landslide.

The historical instrumentally recorded seismicity of the area within a 100-150 km radius of the landslide is shown in Figure 46. This map shows the location of all recorded earthquakes of magnitude greater than 4 within the period 1911 to May, 1974. Berrocal considered that the seismic activity of the area was relatively low. Only one earthquake in this zone during this 63-year period had a magnitude of approximately 6.0. One of the two earthquakes located nearest to the landslide occurred March 14, 1974, some six weeks prior to the slide and had a magnitude of only 4.3. While it is possible that this earthquake could have loosened the soil somewhat, thus contributing to the slide, Berrocal suggests that this is highly unlikely. The focal depth of that earthquake was of the order of 100 km and thus the surface shaking would have been rather small.

The landslide was of such tremendous size that it produced seismic waves which were recorded by at least four Andean seismological stations. The stations and distances from the landslide are listed in Table 4, and range from 82 to 890 km from the landslide.

TABLE 4

Seismograph Stations Recording Earth Waves Produced by the Mantaro River Landslide of April 25, 1974

Station	Abbreviation	Distance From Slide (km)
Huancayo	HUA	82
Nana	NNA	240
Arequipa	ARE	580
Las Penas	PNS	889

A copy of a vertical ground motion record made at Huancayo, 82 km distant, is shown in Figure 47. This record was made on a one-second period instrument which passes considerable high frequency motion. Note that the total duration of strong shaking was of the order of three minutes. Records of three components of motion made on a ten-second period instrument, at the same station, are shown in Figure 48. This long period instrument filters out much of the high frequency motion, leaving only the predominant waves. Note again that the duration of strong shaking is indicated to be about three minutes. Records of three components of motion made on a similar instrument at 240 km distance are also shown in Figure 48. The magnification factor of both instruments was about the same. Note that both sets of records are remarkably similar, and of about the same amplitude, notwithstanding that one set was recorded at a location of about three times the distance of the other.

According to Berrocal (1974) these waves are typical of a near surface disturbance rather than a deep energy source such as a tectonic earthquake. The P-waves at the beginning were very ill defined in the two close records (HUA and NNA) and are not present at all in the two, more distant, records. In contrast there was strong long period motion typical of a very shallow origin. In personal discussions Desa suggested that these records were of similar appearance to the seismic records from the shallow ground subsidence earthquakes at Long Beach with focal depths of only about 2000 ft (Richter 1958).

In addition to the seismic records made during the slide, seismic instruments were brought to the site soon after the slide occurred, and recorded a number of small seismic events for many days as the lake level rose. These subsequent events were of two, readily distinguishable, types. All records of both types were of very small amplitude, in the microtremor range. One type appeared to be ordinary small deep focus microtremors with records resembling regular earthquakes, but smaller. There was a clearly defined P-wave followed shortly by the S- and surface waves. It was believed that these represented the general microtremor seismicity of the area. The second type was similar to the main records obtained at the time of the slide. There was no P-wave, but the other waves were relatively strong. These were interpreted as resulting from the secondary landslides which were frequently occurring along the lakeshore as the water level rose, and were shallow phenomena just as the shaking from the main slide. One of the purposes of installing the instruments in the area was to observe any induced earthquakes caused by the impounded reservoir water. However, none of the recorded small microtremors could be so identified.

Because the ground shaking from the main slide was different from that of a tectonic earthquake, the usual formulas for calculating magnitude from seismic records did not necessarily apply. However, using the formulas with correction factors based on various assumptions led to an estimate of equivalent earthquake magnitude for this event of between 3.7 and 4.7.

From conversations with the Peruvian engineers and seismologists and from the report by Berrocal (1974), it was learned that the seismographic records had played a significant role in helping to formulate the opinions concerning the mechanism of the landslide. Thus, combining the total travel distance from near the upper reach of the slide scarp to the lower toe (about 7 km) with the duration of strong ground shaking (about three minutes) leads to a calculated average velocity of 140 km/h. This estimated high velocity is compatible with other physical observations of the apparent fludity at depth indicated by sand boils, the run up and subsequent runback down the very steep Quebrada Tinte slope, and the observation that considerable material became airborne as it flowed over a rock bluff near the toe.

A mechanistic description of the slide was also advanced by Berrocal on the basis of seismographic records as follows. The records seemed to show three distinct stages, which were attributed to different aspects of the landslide.

Stage 1 - One Complete and Clean 20 to 24 second Period Wave.

It was suggested that this corresponded to the main break when a large portion of the material became freed from the ground and began to slide, thus releasing considerable elastic energy as the mass broke free of the underlying ground.

Stage 2 - A Train of Irregular Amplitude Shorter Period Waves.

It was suggested that these waves corresponded to the mass of material sliding down the slope and hitting the river bottom and the opposite bank of the Mantaro River Valley.

<u>Stage 3</u> - Small Amplitude Short Period Waves (Two Seconds) Superimposed on Longer Period Waves.

It was suggested that this final stage correspond to secondary slides of material from the sides of the main scarp as well as large blocks of rock sliding or rolling down from the upper reaches of the scarp.

At the time of the visit to Peru several hypotheses were being discussed among Peruvian engineers and geologists concerning the mechanism of the slide, all of which seemed to involve three distinct stages. Some hypotheses suggested the upper part slid first, some the low and some the middle. Unfortunately, the slide occurred after dark so there were no eyewitnesses, and there had been no detailed geotechnical investigation. It appears that these various explanations are all generally based on the above interpretation of the seismographical records as given by Berrocal (1974).

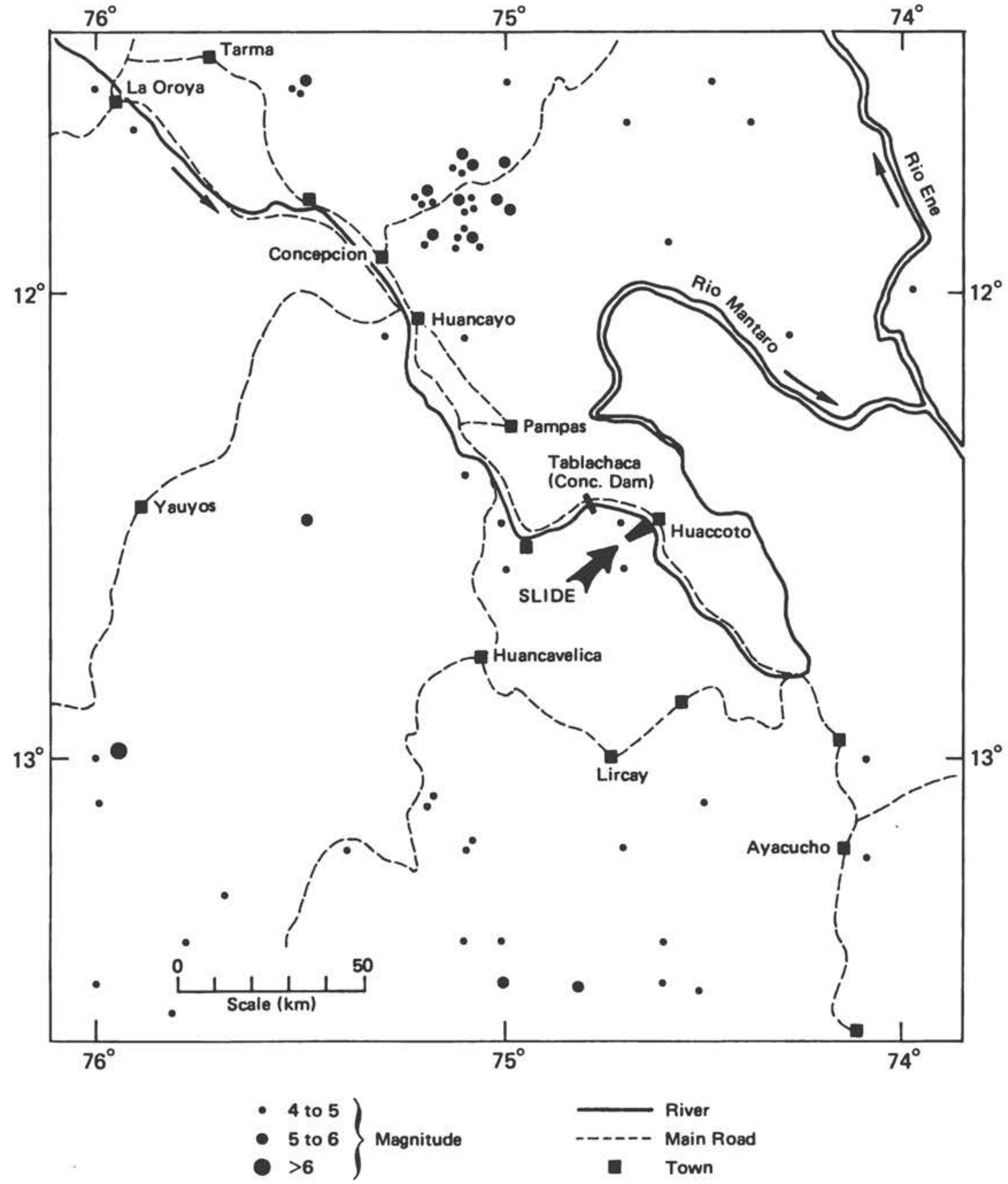


FIGURE 46. Historical Seismicity 1911-1974. (After Berrocal, 1974, Ref. 1)

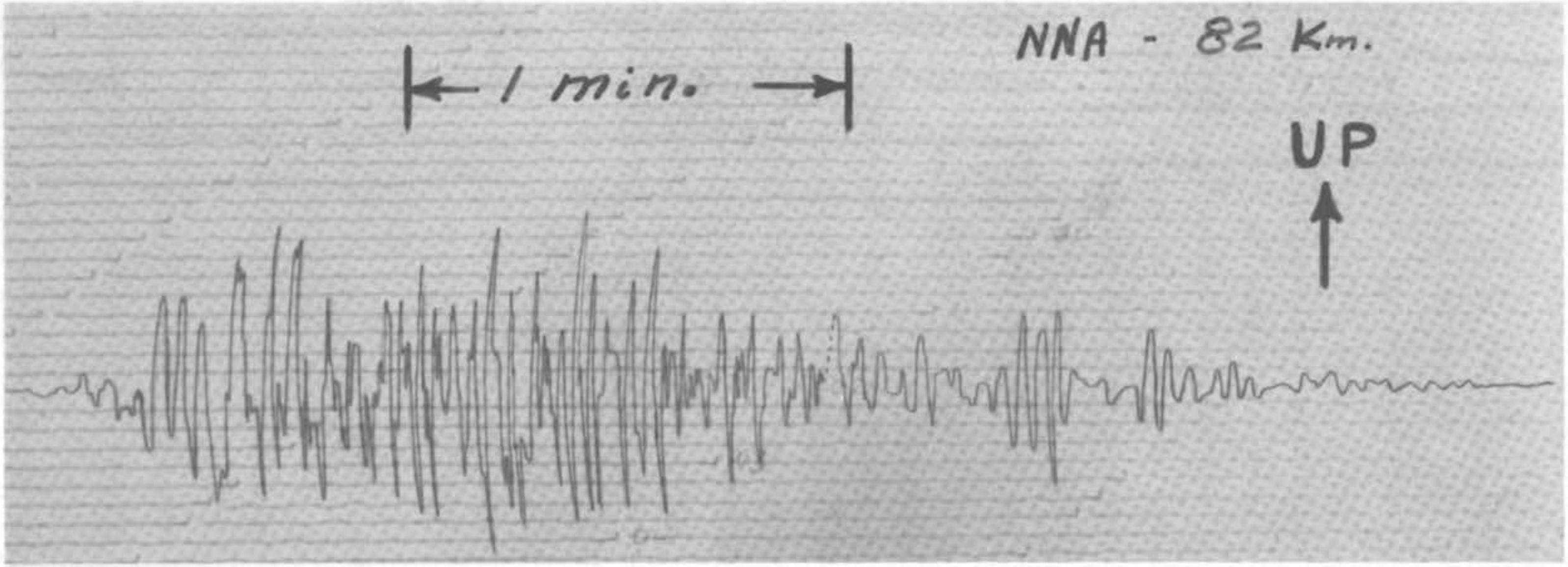


FIGURE 47. Seismograph record of vertical ground shaking caused by the Rio Mantaro landslide as recorded on a one-second period instrument at 82 km distance.

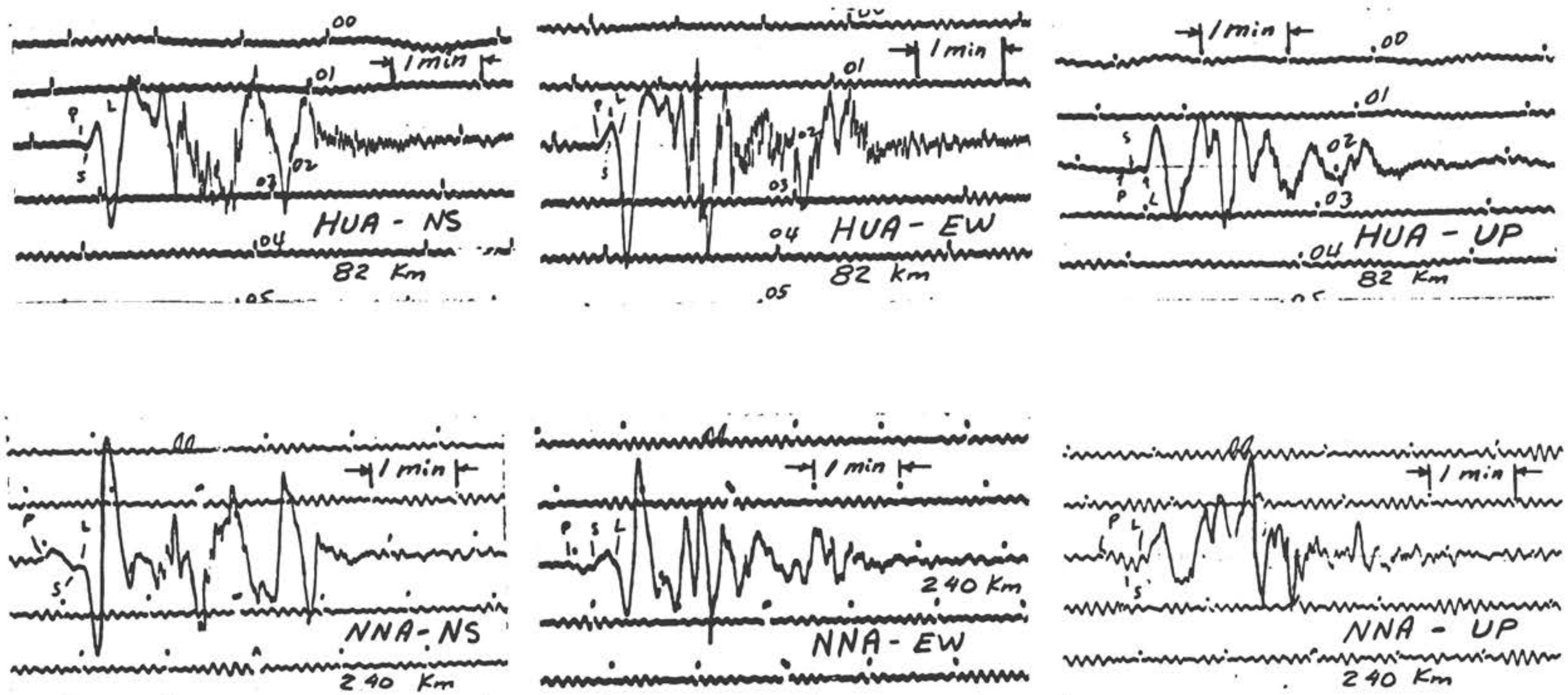


FIGURE 48. Seismograph records of the ground motion caused by the Rio Mantaro landslide, 10-second period instruments. HUA = Huancayo at 82 km from the slide. NNA = Nana at 240 km from the slide. Amplification: HUA = 40,000 NNA = 50,000.

DISASTER RELIEF

The disaster relief operations were carried out by the Civil Defense and the Peruvian Army. The Civil Defense was organized May 10, 1972, only two years prior to this event, to handle such disasters as may be caused by floods, storms, fire, earthquakes, landslides, etc. Its formation was inspired by the earthquake and landslide-avalanche disaster of May, 1970 where, among other things, the city of Yungay was totally destroyed (Cluff, 1971). It operates from a permanent headquarters in Lima with a small base staff. In addition it has on call a large number of volunteers in many technical areas. The Peruvian Army has permanent encampments at many locations throughout the country, and Civil Defense in the field is under direct command of the Army commander of the particular zone. The army supplies men and equipment for needed field operations.

The writers were impressed with the thorough and effective way in which problems related to the disaster were handled. Coordinated by the central Civil Defense office in Lima, the army battalion stationed nearest the site provided men and equipment for evacuation, food, clothing, and shelter of the farmers located in the danger areas. Some 1,000 people were evacuated from their farms and homes. They were housed in tents until it was safe to return. Those who lost their homes and property during the flood will continue to be cared for until they can be relocated in safer places. The relocation operations appeared to be thoughtfully administered with technical assistance from professional people such as engineers, geologists, social workers, etc.

In addition, surveyors, construction equipment, and explosives were brought in to construct a trench across the slide in an attempt to accelerate and control the water flow during the early stages of overtopping.

An 80 km portion of the main Huancayo-Ayacucho Highway along the Mantaro River between the Tablachaca dam and the town of Mayoc was so badly damaged, both upstream and downstream of the landslide, that it will not be rebuilt. Instead, plans are actively going forward to relocate much of this highway by constructing a new road on higher ground through the mountainous hills to the North.

ADDITIONAL STUDIES

The objective of this reported study was to make a quick fact finding trip to investigate the disaster and report the results that could be collected in this short period of time. The motives for this quick study were twofold: (1) to advise the United States National Academy of Sciences and National Academy of Engineering on the disaster, and (2) to provide a background to base a judgment on whether further in-depth studies would be appropriate.

At the completion of the visit it was decided that it would not be appropriate to recommend to the Academies that they sponsor additional immediate in-depth studies. The unique size and nature of this major disaster will probably initiate many additional in-depth studies. As mentioned elsewhere in this report, various groups of Peruvian professional people are already so engaged. However, because the area was largely rural, with no major engineering structures affected, from the Academies' point of view it was felt that immediate additional studies of this particular disaster would not materially improve the knowledge and technical abilities of engineers to handle similar problems affecting engineering structures. This recommendation was made to the Academies in a preliminary letter report immediately following the trip, and partly for this reason, this final report has therefore been somewhat delayed.

Recommending that the Academies not immediately sponsor additional in-depth studies does not mean that further detailed studies would not be appropriate or beneficial. Indeed, there are many geotechnical seismological and sociological aspects of this event which are perhaps unique in the recorded history of the world, and which could well justify detailed studies in many areas. However, the enormous size and scope of these problems, and the difficulties which would be involved to carry out meaningful on-site studies did not fall within the objectives and the means of the Committee on Natural Disasters.

The writers hesitate to make strong recommendations concerning additional studies that might be undertaken in the future pertaining to this event, especially in areas beyond their own professional field. The following general comments are offered, representing only their own impressions.

It is recognized that the point of view of Peruvian experts, with this landslide in the heart of their own country, and with many other locations offering similar hazard potential, may be somewhat different from experts in the United States. Nevertheless, the writers were impressed by two aspects of this event whereby the United States could benefit by studying the Peruvian methods. It should be recalled that, during the Montana earthquake of 1959 (Steinbrugge and Cloud, 1962), a similar type of problem occurred in which the Madison River was dammed by a landslide.

The first impressive aspect was the hydraulic model studies made to predict the nature and extent of the erosion and flood damage due to overtopping. In a period of only five weeks, and almost one week before the dam was overtopped, a carefully executed hydraulic model study was made and a report published. It seems to the writers that if this technique of hydraulic model studies could be perfected, it would be useful anywhere in case of similar disasters.

The second impressive aspect was the role of the Civil Defense in effectively handling both the scientific aspects and the physical emergencies related to this disaster. Of course the economics, technology, governmental system and lines of authority are different in our two countries. However, because of the apparent Peruvian success with an organization only two years old, the writers felt that the United States could learn from their experience.

Other areas of scientific interest which may provide fruitful areas of further research are briefly mentioned below.

Cause and Nature of the Landslide

This is one of the largest natural landslides to occur in recorded history, and therefore it would be of interest to define clearly the cause and the nature of movements which resulted in the creation of such a massive slide and in the creation of an enormous debris dam across the Mantaro River.

Recorded Ground Waves

As mentioned elsewhere the recorded ground waves caused by the main event, as well as the recorded local disturbances during the period of lake buildup and overtopping provide a unique set of seismological data from a surface event. While the Instituto Geofisico del Peru is studying these records in depth, other seismologists may also benefit from additional studies made from various different points of view.

Disaster Predictions and Warnings

At present there is considerable activity in the United States and elsewhere concerning earthquake prediction. With the possibility of reliable predictions becoming a feasible reality in the foreseeable future, many sociological, political and economic problems arise concerning the use and dissemination of prediction warnings.

As described elsewhere in this report, a major landslide disaster was predicted for this very area some five months before the slide actually occurred. The prediction was made in a geological report by a governmental agency. However, as also pointed out herein, much of the Mantaro River Valley was known to be unstable so that the local residents had become complacent about living in a landslide prone area. A study of the sociological, political and technical aspects of this prediction may be useful to those who face the need to make and publicize disaster predictions in the future.

REFERENCES AND SOURCES OF FURTHER INFORMATION

The size, scope and peculiar nature of this major disaster has initiated a number of studies which have or will result in various reports. A listing of studies known to the writers at this time is given in the bibliography. Reports by non-Peruvian investigators include a preliminary informal report by Cook (1974) written a few days prior to the flooding and an in-depth report by Kojan and Hutchinson (1974) who investigated the event in behalf of UNESCO. This latter report was still in press and therefore not available to the writers at the time of this writing. In addition, a listing of names and addresses of persons and organizations in Peru who were most helpful to the writers and who are most likely to have knowledge of additional information as it develops is given in the Appendix.

REFERENCES

1. Berrocal, J., "Aspects Sismologicos Relacionados Con El Deslizamiento de Mayunmarca," Informal Technical Note, No. 2, Instituto Geofisico, 1974.

2. Bishop, A. W., "Stability of Tips and Spoil Heeps," *Quarterly Journal of Geology*, Vol. 6, Nos. 3 and 4, pp. 335-376, 1973.

3. Cleveland, George B., "The Flash Flood at Nelsons Landing, Clark County, Nevada," California, *Geology*, pp. 51-56, March, 1975.

4. Cluff, L. S., "Peru Earthquake of May 31, 1970," *Bulletin of the Seismological Society of America*, Vol. 61, No. 3, June, pp. 511-534, 1971.

5. Cooke, J. B., "Investigation of Failure, Baldwin Hills Reservoir," Department of Water Resources, California, 1964.

6. Cooke, J. Barry, "Mantaro-Huaccoto Slide of 25 April 1974," Private Memorandum Report, J. Barry Cook Inc., 253 Laurel Grove Ave., Kentfield, California 94904, June 7, 1974.

7. Cruden, D. M. and Krahn, J., "A Re-examination of the Geology of the Frank Slide," *Canadian Geotechnical Journal*, Vol. 10, No. 4, pp. 581-591, 1973.

8. Galdos Bustamante, Jorge, "Estudio Geodiamico Del Area de Mayunmarca," Report of the Servicio de Geologia y Mineria, Division Geotecnia, Ministerio de Engergia y Minas, Lima, Peru, Nov., 1973.

9. Habib, Pierre, "Sur Un Mode de Glissement des Massifs Rocheux," C. R. Academy of Sciences, Paris, t.264, pp. 151-153, January 16, 1967.

10. Humala, *et al.*, "Desliziamiento y Represamiento Occuridos En Valle del Mantaro," Informe Technio, Universidad Nacional de Ingerieria, Lima, May, 1974.

11. Kojan, E. and Hutchinson, J. N., "The Mayunmarca Landslide of 25 April, 1974," Report 3124/RMO. RD/SCE, Division of Earth Sciences, UNESCO, Place de Fontenoy, 75700, Paris, France, 1974.

12. Ministerio de Agricultura, "Ensayos en Modelo Hydraulico Del Preso de Erosion de La Presa de Mayunmarca Huaccoto y la Anda da Ruptura el El Rio Mantaro," Laboratorio Nacional de Hydraulica Nacional de Ingerieria, Lima, June 3, 1974.

13. Morimoto, R., *et al.*, "Landslides in the Epicentral Area of the Matsushiro Earthquake," *Bulletin of the Earthquake Research Institute*, Tokyo, Japan, Vol. 45, pp. 241-263, 1967.

14. Richter, C. F., "Elementary Seismology," W. H. Freeman & Co., San Francisco, pp. 155-157, 1958.

15. Snow, D. T., "Landslide of Cerro Condor-Seneca, Department of Ayacucho, Peru," Engineering Geology Case Histories, No. 5, Geological Society of America, 1964.

16. Steinbrugge, K. V. and Cloud, W. K., "Epicentral Intensities and Damage in the Hebgen Lake, Montana Earthquake of August 17, 1959," *Bulletin of the Seismological Society of America*, Vol. 52, No. 2, pp. 181-234, 1962.

17. CODECIMA (Comité de Coordinación de Defenza Civil de la Zona de Emergencia del Mantaro), "Plan Preliminar de Rehabilitación y Desarrollo de la Zona Afectada por el Embalse del Rio Mantaro," Huancayo, Julio 1974.

APPENDIX

Names and Addresses of Persons and Organizations in Peru Particularly Knowledgeable about the Mantaro River Disaster.

Ing. Alfonso Alcedan
Director, Laboratorio Nacional de Hidraulica
Universidad Nacional de Ingenieria
Lima, Peru
and
Presidente de la Comision-Mesa Redonda
Sobre el Represamiento del Rio Mantaro
Colegio de Ingenieros del Peru
Ave. Areguipa 4947, Mira Flores
Lima, Peru
Tel: 45-6540

Ing. Ernesto Deza
Instituto Geofisico del Peru
Sector Educacion
Fisica Tierra Solida
Apartado 3747
Lima, Peru

Ing. Hugo Jaen La Torre
Servicio de Geologia y Mineria
Paz Soldan 225, San Isidro
Lima, Peru

Colonel E. P. Arturo la Torre di Tolla
Secretario Ejecutivo del Comite Nacional de Defensa Civil
Ministerio del Interior
Ave. Corpac S/N, San Isidro
Lima, Peru