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THE LANDSLIDE AT TUVE, NEAR GÖTEBORG, SWEDEN, ON NOVEMBER 30, 1977

by

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Committee on Natural Disasters
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This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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FOREWORD

The Committee on Natural Disasters of the National Research Council was formed to study the impact of natural disasters such as earthquakes, floods, tornadoes, and hurricanes on engineered structures and systems. The objectives of the Committee's work are to improve the protection against disasters by providing factual reports of the consequences of these extreme events of nature and to stimulate research needed to understand the hazards posed by natural disasters.

The landslide at Tuve in November 1977 began with a relatively minor embankment failure and retrogressively worked up a small valley underlain by sensitive clays. This report, by an investigating team appointed by the Committee chairman, describes the geotechnical conditions that contributed both to the initiation of the slide and to the successive retrogression up the valley for several hundred meters.

P. C. Jennings, Chairman
Committee on Natural Disasters

ACKNOWLEDGMENTS

The writers wish to thank their colleagues in the Swedish Geotechnical engineering community who provided the support necessary to make their study successful. These colleagues include Göram Sällfors of Chalmers Technical University, Ulf Lindbloom of Hagconsult, Oleg Wager of the Swedish Geotechnical Institute, and Leif Viberg of the Swedish Geotechnical Institute, without whose gracious and effective assistance this task could not have been accomplished.

INTRODUCTION

On November 30, 1977, at about 4:00 p.m., a massive landslide occurred in the community of Tuve, a suburb of Göteborg, Sweden. The landslide resulted in the destruction of 65 houses and the deaths of 8 people.

On December 2, 1977, the Committee on Natural Disasters of the U.S. National Research Council appointed an investigating team consisting of J. M. Duncan, G. Lefebvre, and P. Lade to go to Sweden to study the landslide, its causes, and its effects. The team spent from December 6 through December 8 in Göteborg, surveying the slide area on foot and from the air, collecting data, and discussing the causes and effects of the slide with various members of the Swedish geotechnical engineering community who were involved in investigating the slide. On December 9, 1977, the team visited the headquarters of the Swedish Geotechnical Institute in Linköping to discuss the geology and previous landslide activity in the area with various members of the Institute staff.

This report is based on the information obtained during the field investigation and from articles in Swedish newspapers. The writers are aware that this type of information, hastily gathered, may contain some inaccuracies. A more detailed investigation of the slide by the Swedish engineering community is under way, and a comprehensive report should be available in the near future.

GEOGRAPHY AND GEOLOGY OF THE AREA

The slide occurred in Tuve, a suburb about 6 km north of the center of Göteborg, as shown in Figure 1. The area involved in the slide lies on the west side of a valley located about 4 km west of the Göta River valley, which is notorious for the occurrence of many similar landslides in both ancient and modern times. The bottom of the valley is quite flat and contains only a minor stream at present; it is underlain by soft clay that is susceptible to drastic loss of shear strength when disturbed.

Small hills, often with rock outcrops at the top, can be seen from place to place along the sides of this main valley. Between these

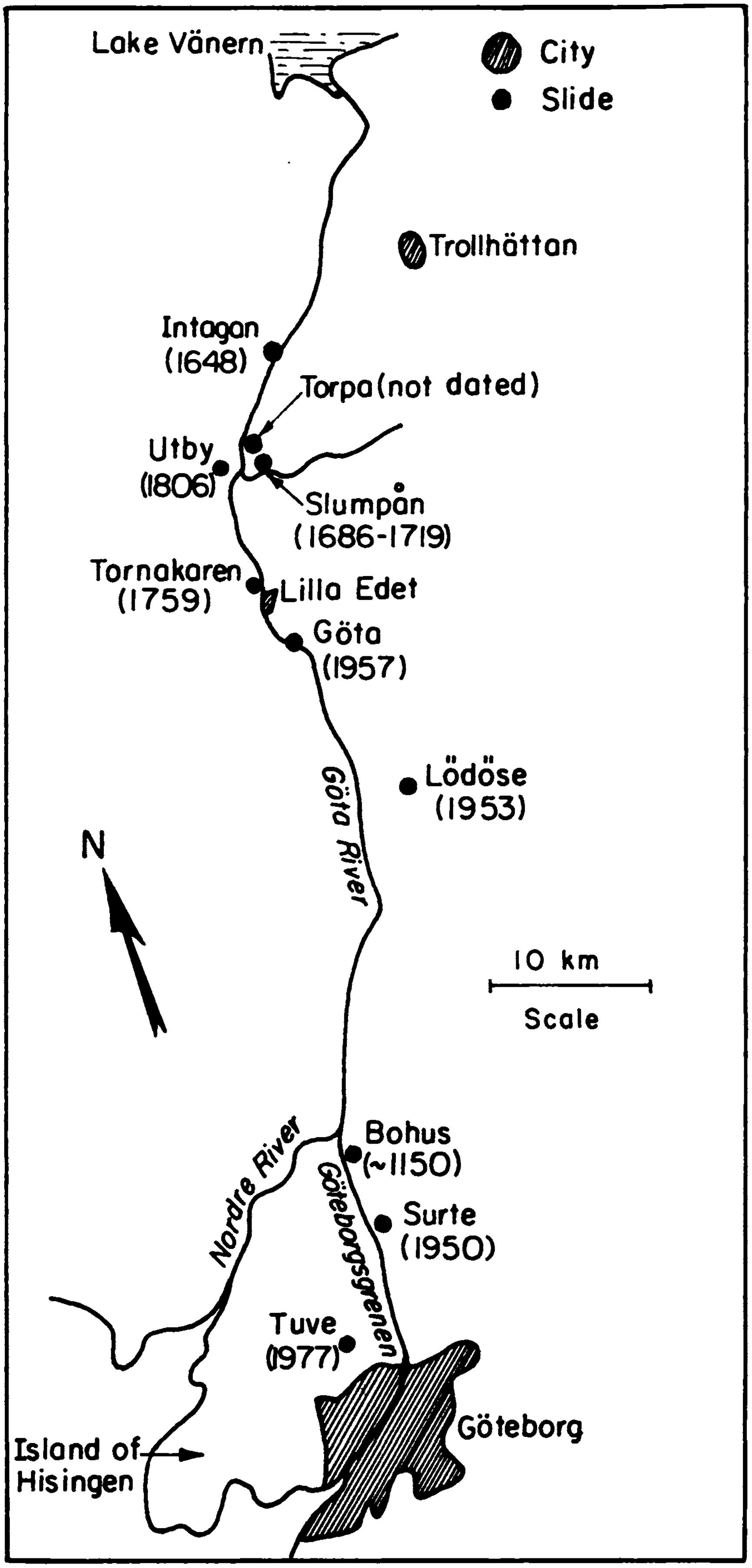

Fig. 1 Landslides in the Göta River Valley.

hills lie secondary small valleys that slope toward the main valley. The Tuve landslide occurred in one of these secondary valleys, which is shown on the topographic map in Figure 2 and in the air photo in Figure 3.

The elevation of the main valley floor is about 5 m above sea level. The floor of the secondary valley slopes upward to the west at an average gradient of about 1:25. The hills to the north and south of the secondary valley rise to heights of 40-50 m above the main valley floor.

Through the lower half of the secondary valley ran a small stream with steep banks a few meters high. These stream banks showed fresh clay, indicating fairly active erosion. The stream was fed at its upper end by an underground conduit, which drained the upper portion of the valley and emerged on the downhill side of a small roadway embankment running from southeast to northwest across the valley. The secondary valley was occupied by single-family houses and row houses that had been constructed 7 or 8 years before the slide occurred.

During the last glacial period (about 13,000 years ago) the advancing ice sheet had scraped all the loose materials off the underlying bedrock, leaving deep, steep-sided valleys in the rock. Because of the great weight of the ice sheet, which was 2000-3000 m thick, the land surface was depressed, and the area was inundated by a sound connecting it to the Baltic Sea. As the glacial ice sheet melted and receded, it left behind a thin sheet of granular glacial till material on top of bedrock. Subsequently, silt and clay materials filled the drowned valleys by sedimentation in the quiet marine waters. With the great weight of the glacial ice sheet removed, the land surface began to rebound, lifting the clay-filled valleys from beneath the sea. This rebound has amounted to about 95 m in the Göteborg area and is continuing at the present time at a rate of about 10 cm per century.

After the emergence of the clay above the level of the sea, fresh waters seeping slowly through the clay have gradually reduced the amount of salt in the pore water. This reduction of salt concentration and the organic content of these clays are thought to cause the drastic loss of strength in these clays when they are disturbed or remolded. This characteristic, called "sensitivity," reaches such extremes that some clays will flow like a liquid when their structure is disturbed. Scandinavians call these "quick clays."

Another interesting feature is that the glacial tills beneath the clay often contain water that is under artesian pressures because the till, which is more permeable than the clay, is charged with groundwater high on the edges of the valley, and the hydraulic head in these layers may thus be higher than the valley floor.

The clay involved in the November 30 landslide is a very soft and sensitive silty clay. Its natural water content was about 60 percent, which is about 10 percent above the liquid limit. The top 1-2 m had dried and weathered, forming a relatively stiffer, stronger crust over the underlying soft clay.

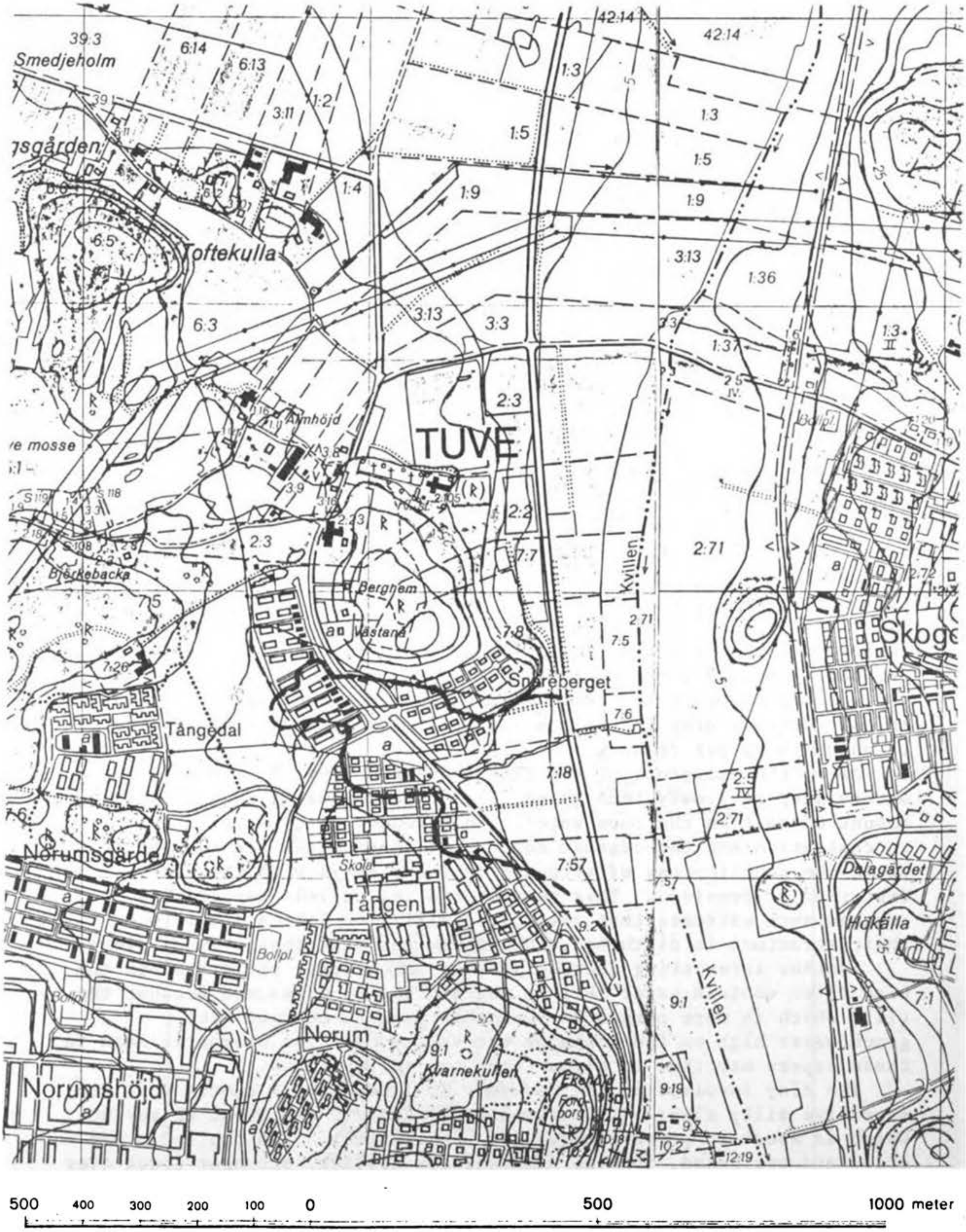

Fig. 2 Topographic map of the Tuve area, and outline of the slide area.

Fig. 3 Air photo of the Tuve region before the landslide of November 30, 1977.

PREVIOUS LANDSLIDES IN SWEDISH SENSITIVE CLAYS

The landslide at Tuve was not a unique event. In the past, many similar slides have occurred along the Göta River valley as shown on the map in Figure 1 and by the data in Table 1.

Typically these slides are retrogressive, beginning with a small slide in the river bank or at another point where the slope is steep, and spreading outward and upslope through a succession of increasingly larger slides. The retrogressive mechanism is related to the sensitivity of the clay, which results in a sudden loss of shearing resistance once the clay has been disturbed mechanically by loss of support from downslope. Retrogression stops when the slide reaches an area where the clay is stronger, less sensitive, or very thin.

Most notable among the slides listed in Table 1 are those that occurred in Intagan in 1648, at Surte in 1950, and Göta in 1957. The Tuve landslide is shown to be among the largest and most damaging of those on record in the Göta River valley.

Slides of similar type have also taken place in other parts of Sweden. At Swäta, about 80 km southwest of Stockholm, a large landslide occurred in September 1938 on a slope with an inclination of only 3 or 4 percent, destroying sections of a highway and a railroad. In February 1946, a landslide occurred in the bank of the Lidam River about 20 km upstream from Lake Vänern, damming the river completely.

Because of this history of frequent landslides, the Swedish government enforces a number of regulations and restrictions to prevent development practices that would increase the likelihood of landslides. In the Göta River valley, the Swedish Geotechnical Institute must approve all construction projects near the river and continually monitors erosion of the river banks. Stability studies have been performed for a number of sites along the river and measures have been taken to improve slope stability at those believed to be in most imminent danger of sliding. Over 60 km of the banks along the Göta River have been protected by dumping rocks along the banks at water level to prevent erosion and landslides.

THE SLIDE OF NOVEMBER 30, 1977

The area affected by the landslide is indicated on the topographic map (Figure 2) and may be seen in the photographs in Figures 4 and 5. The motion of the slide was from west to east, toward the main valley. The failure started with a small slide in the roadway embankment that traversed the area from southeast to northwest (Tuve Kyrkväg). From its point of beginning, it retrogressed across and up the hill; successive episodes of sliding continuing for a period of about 2 minutes. On December 3 and 4, a few minor slides occurred in the steep scarps that had been formed at the upper limits of the slide.

A plan of the slide area is shown in Figure 6. The numbers on the drawing indicate values of sensitivity (ratio of undrained strength before remolding/undrained strength after remolding), undrained shear strength (before remolding), liquid limit, and water content that were

Table 1 Major Landslides Along the Göta River

Place	Date	Area of Slide (km^2)	Fatal-ities	Damage	Remarks
Torpa	not dated	0.27			
Bohus	about 1150	0.21			Oldest known slide, dated by carbon 14 method
Intagan	Oct. 7, 1648	0.19	85		People drowned in flood wave caused by damming of river
Slumpån	1686 and 1719	0.06			
Tornakaren	1759	0.08			
Utby	1806	0.02			
Surte	8:20 a.m. Sept. 29, 1950	0.19 (volume 4 million m^3)	1	34 houses involved, most saved; 304 persons without shelter	Traffic on highway, railroad, and river affected
Lödöse	Apr. 13, 1953	0.005		Damage to railroad	
Göta	11:15 a.m. June 7, 1957	0.27	3	Buildings of a Göta factory	River dammed, traffic on river affected; damage estimated at 70 million Swedish crowns
Tuve	4:05 p.m. Nov. 30, 1977	0.28	8	65 houses; about 700 persons evacuated	Damage estimated at 50 million Swedish crowns

Notes: All locations are shown on map of Göta River.

Areas of slides determined from 3 maps of "Götaälvdalen" (Göta River valley) from Swiges Geologista Undersökning (Sweden's Geological Survey), and from photo of Tuve Slide.

Most other information from newspapers.

Fig. 4 Air photo of the Tuve region after the landslide of November 30, 1977.

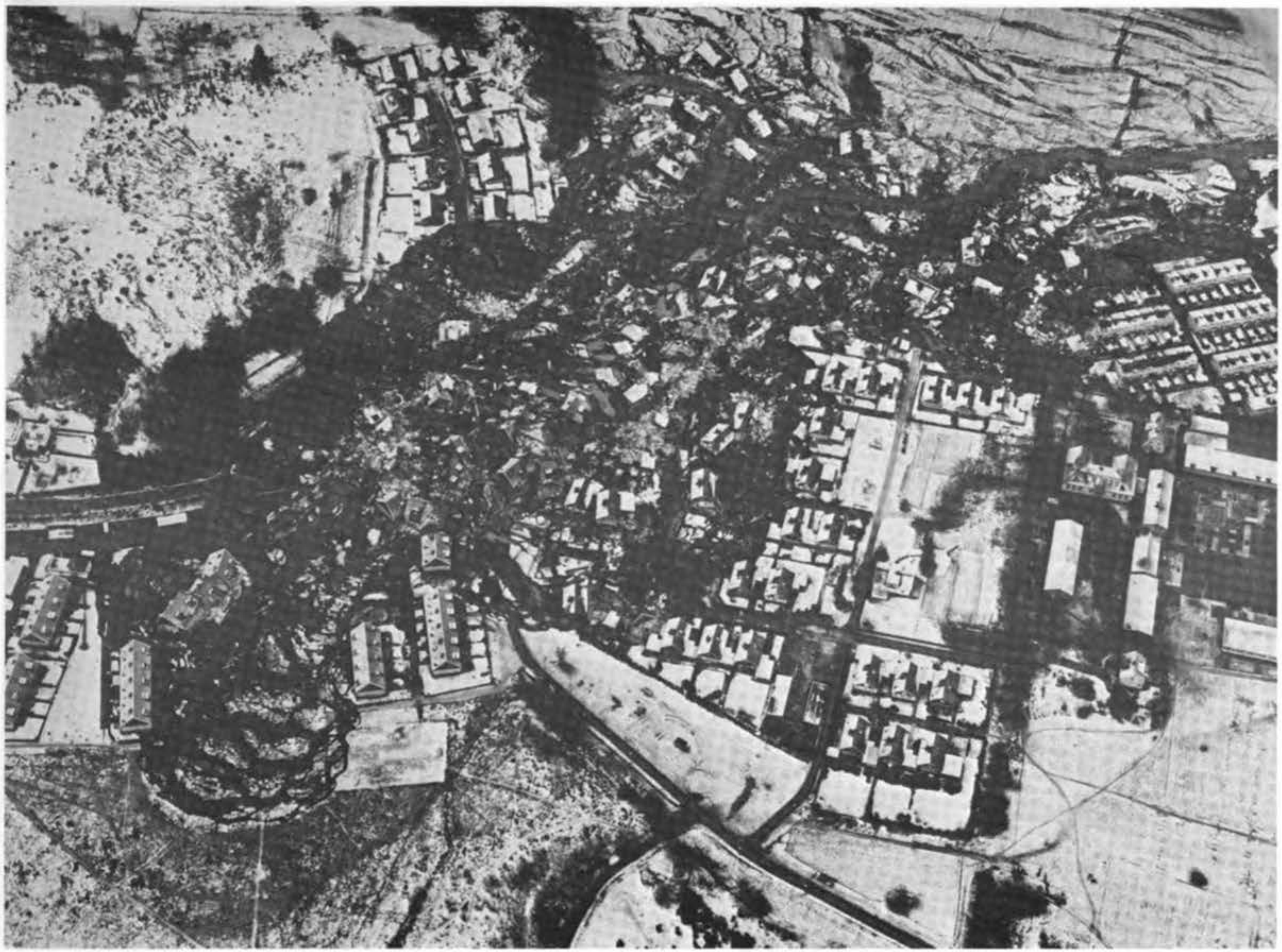

Fig. 5 Air photo of the Tuve slide area, looking northeast.

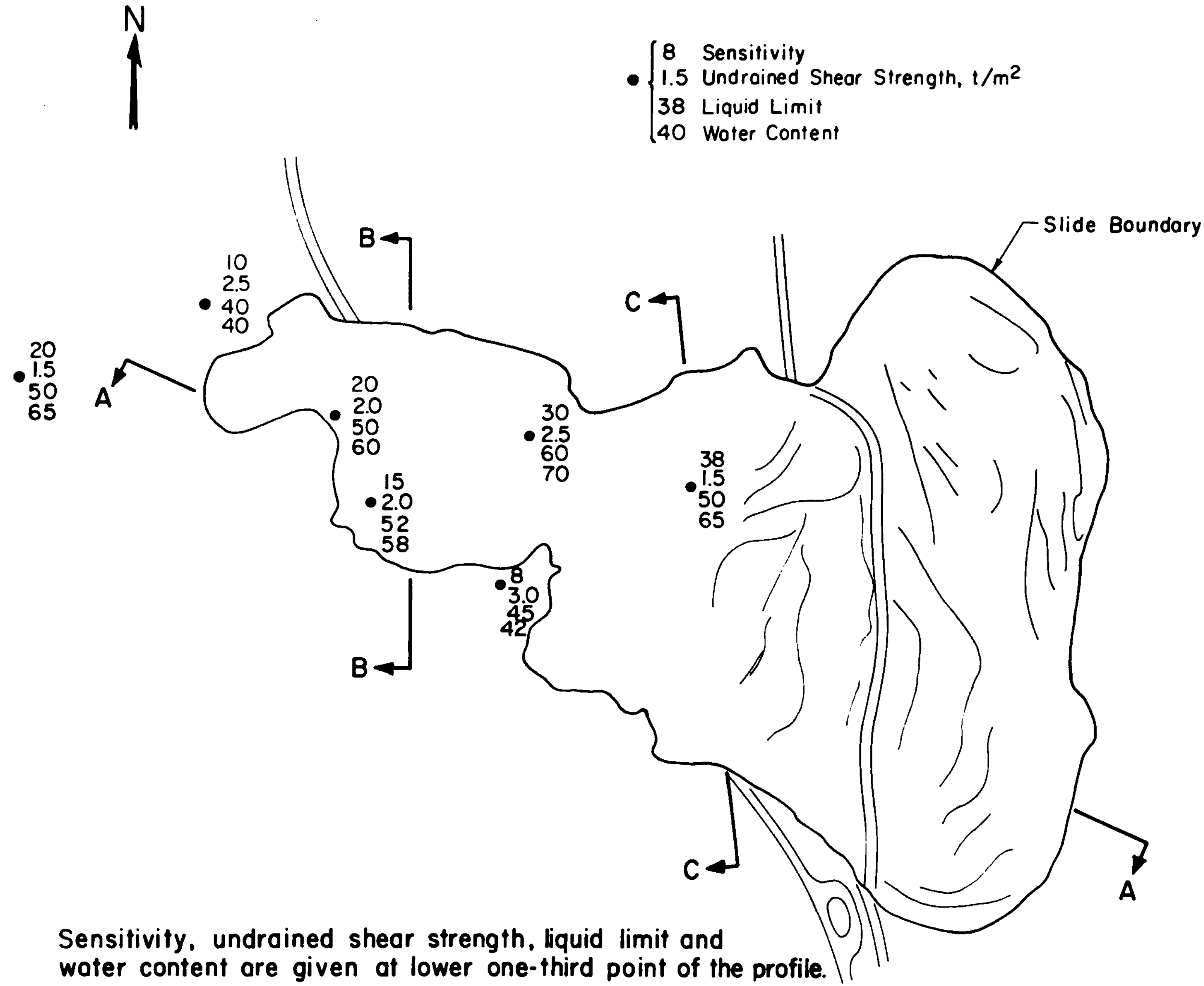

Fig. 6 Plan of the landslide area with soil properties determined before the slide (see cross-sections on Figure 7).

obtained from geotechnical investigations in the area before the slide. It may be noted that the undrained strength of the clay is low throughout the slide area, varying from 1.5 to 2.5 t/m^2 (from 300 to 500 lb/ft^2). The sensitivity increases toward the east, in the downhill direction. Throughout the area the natural water content is above the liquid limit, which is consistent with the fact that the clay has very low strength after remolding.

Three cross-sections illustrating conditions before the landslide are shown in Figure 7. The portion of the slide above section C-C was characterized by large displacements of the ground toward the main valley, with a consequent drop in the ground-surface elevation as the clay, flowing and sliding downhill, left a partly empty rock bowl with scattered pieces of the former landscape and houses resting at its bottom, as shown in Figure 8.

The portion of the area below section C-C also suffered large lateral movements that resulted in displacement of the road in this area about 40 m to the east, toward the main valley, as shown in Figure 9. The ground in this lower area was heaved upward and the surface was compressed, as soft clay from uphill forced itself against and beneath the stiff crust that blanketed the lower part of the slope. The bulging and compression of the ground surface in this area are shown in Figure 9.

The length of the slide, including the compression zone, was about 850 m, and its width at the toe was about 400 m. The slide involved most of the clay in the secondary valley. As shown in Figure 7, the thickness of the clay increased from about 15 m in the upper part of the area to more than 30 m in the lower part. The values of sensitivity of the clay varied from about 20 in the upper part to 40 in the lower part. Values of sensitivity of the clay in the main valley are reportedly more than 100.

All of the houses involved in the slide were severely damaged and rendered unusable. Larger houses and row houses were frequently broken apart by the movement, and in some cases their walls crumbled and collapsed completely, leaving only the more securely braced roof structure in a recognizable condition, as shown in Figures 10 and 11.

In a number of cases the slide scarp coincided nearly exactly with the wall of a house, leaving the house perched precariously at the brink of a newly formed vertical drop-off several meters high. Two such houses are shown in Figures 11a and 11b. This situation occurred with sufficient frequency to make it appear highly unlikely that it was due entirely to chance. Possible explanations are that the clay beneath the houses had been strengthened by consolidation under the added load of the houses and that the frames of the houses themselves offered additional strength or resistance to development of tension cracks around the margins of the slide.

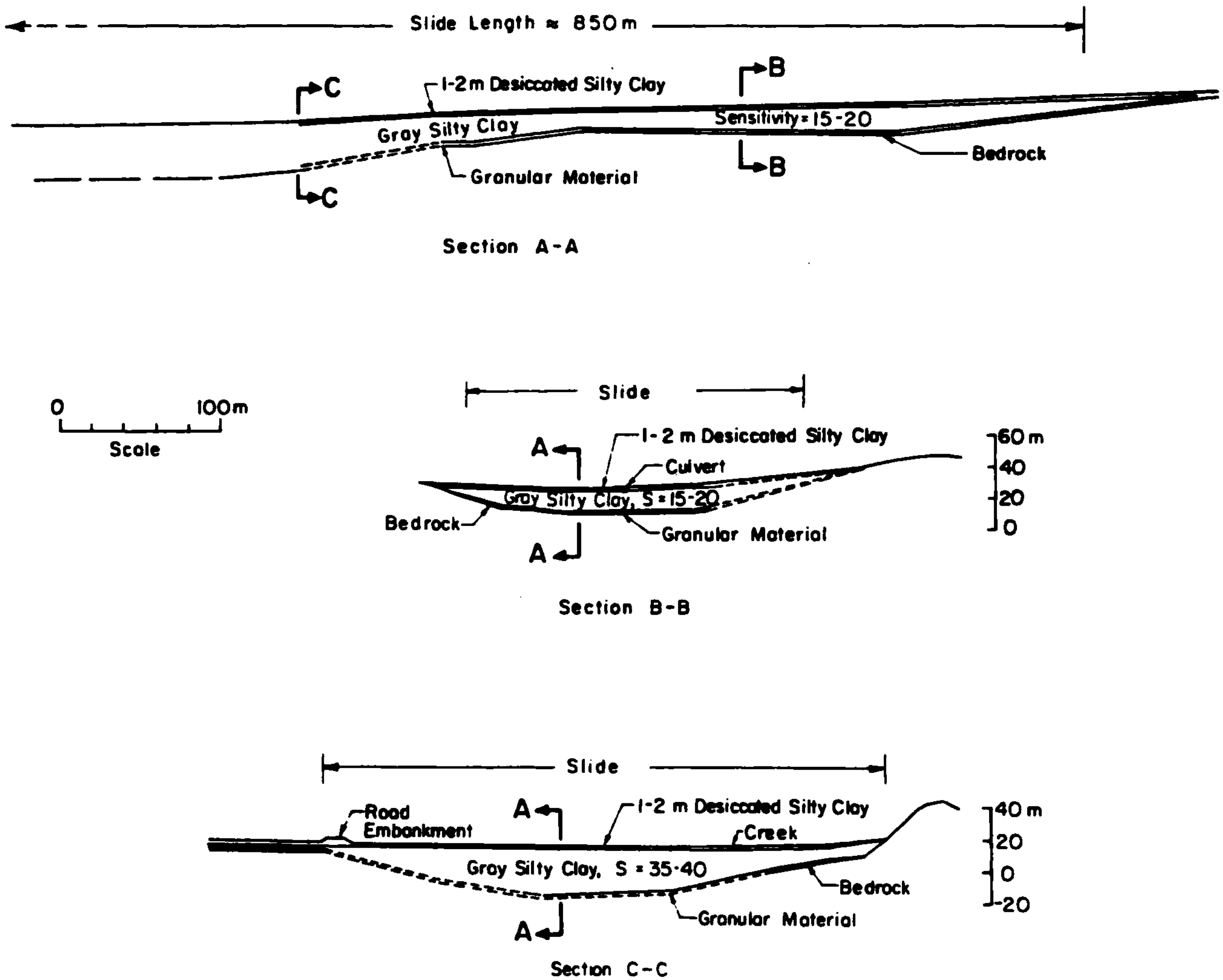

Fig. 7 Cross-sections through the slide area determined before the slide (see Figure 6).

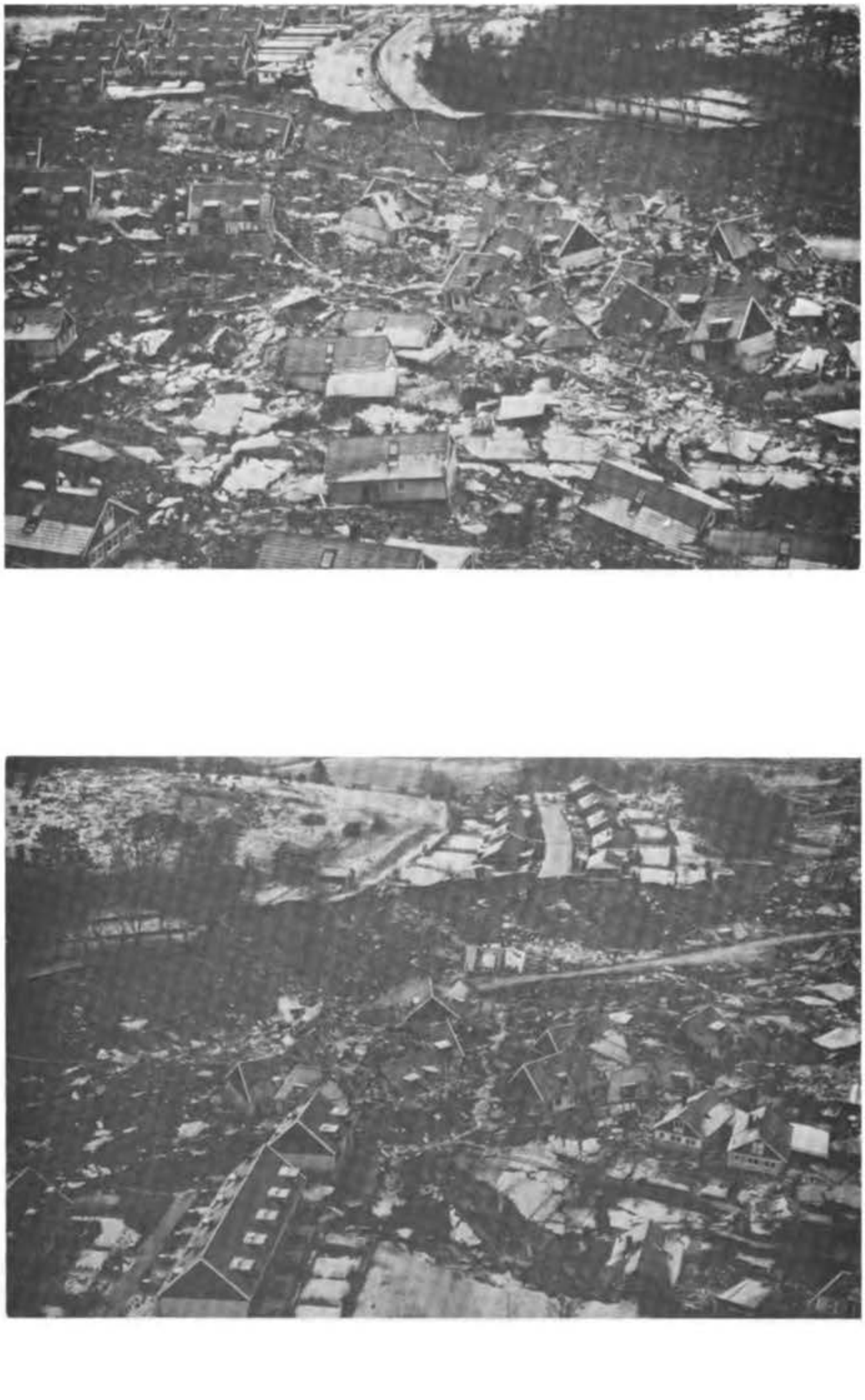

Fig. 8 Two views of the bowl formed at the upper part of the slide.

Fig. 9 Displacement of the road and heave and compression of the ground surface in the lower part of the slide.

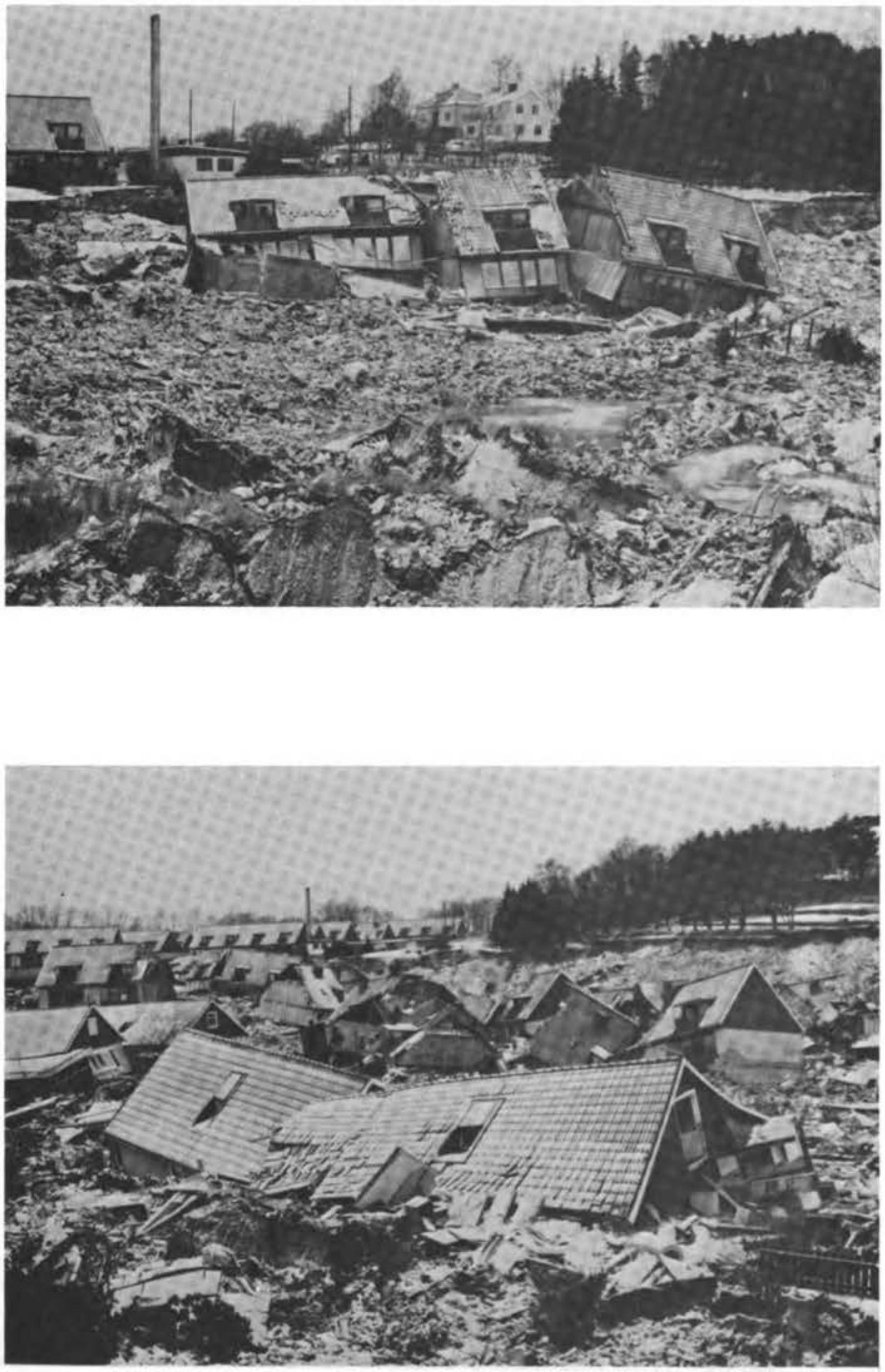

Fig. 10 Houses in the center of the slide area.

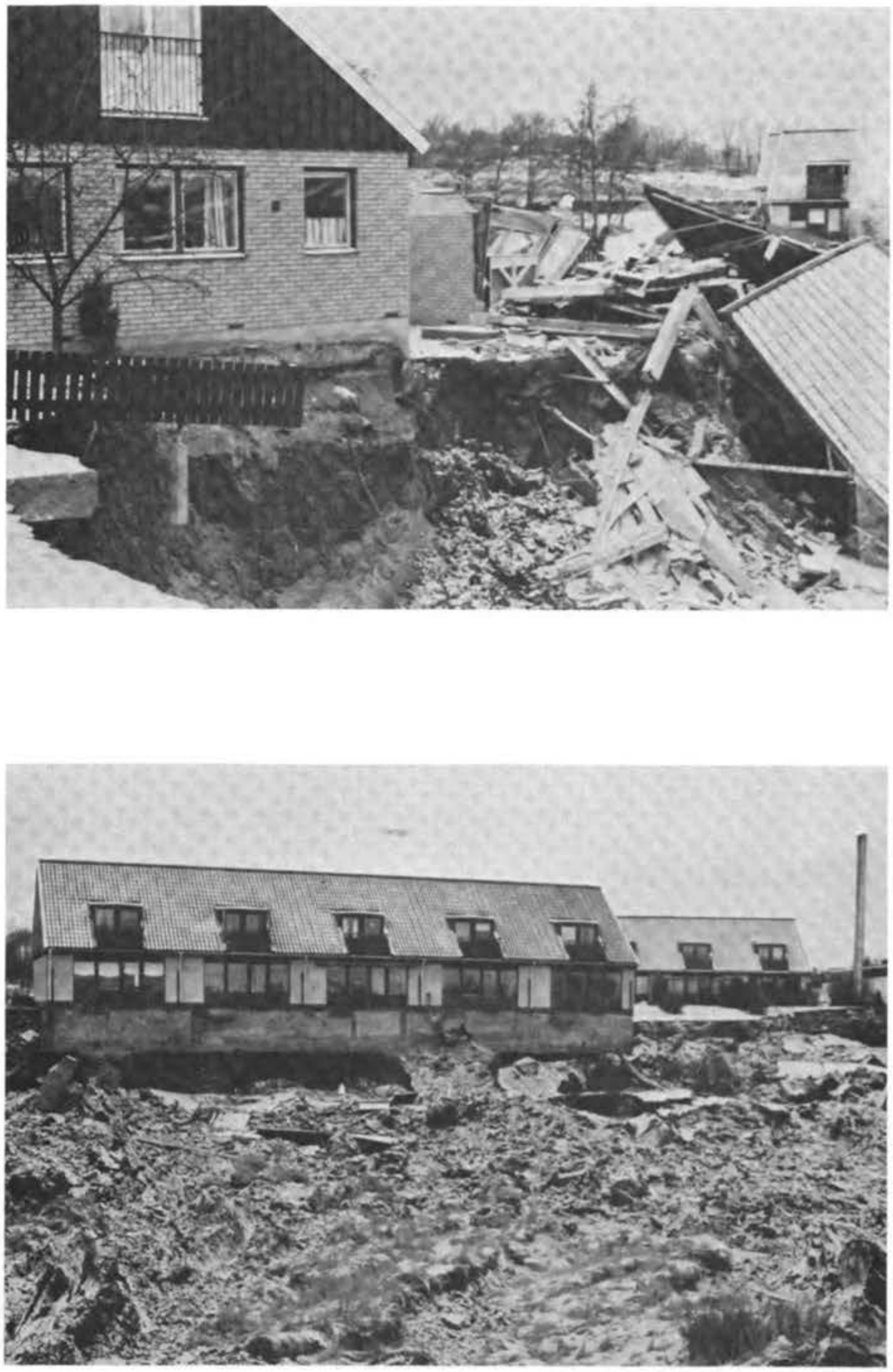

Fig. 11 Houses near the margins of the slide.

CAUSES OF THE SLIDE

It is clear that the Tuve landslide began with a relatively minor slope failure in the Tuve Kyrkväg embankment. Then, by retrogression, an increasingly larger area became involved. The head of the slide worked its way uphill as a succession of steep slide scarps were created and then failed, leaving other steep scarps, which failed in turn. As these failures occurred the soft clay was remolded by the movements, lost most of its strength, and flowed downhill. The dried crust that had capped the clay, and the houses it had supported, slipped along toward the bottom of the slope. As the head of the slide spread uphill and the amount of material slipping down became greater, the toe of the slide bulged outward further and further under the force of the material from above.

In discussing causes of this type of slide, it is useful to distinguish between two types of contributing factors: the first type includes those factors that led to development of the initial small slide, and the second type includes those that led to the spreading of the slide and its eventual involvement of such a large area.

Although there was general agreement among the witnesses that the slide began with a small slide in the Tuve Kyrkväg embankment, the cause of the first slide had not been determined at the time of the writers' visit. Two possibilities were discussed, both of which fit the known facts:

1. The stream flowing down the secondary valley in which the slide occurred emerged from a conduit under the Tuve Kyrkväg embankment (see Figures 2 and 12). Where it emerged from the conduit, the stream ran parallel to the embankment for about 50 m. On the morning of the slide, a resident of the area noticed unusually heavy flow in the stream, which might have resulted in erosion of the toe of the embankment or the stream slopes further downstream, thus triggering the initial slide.

2. The groundwater levels had been quite low in the Tuve area for several years before 1977. An intensely rainy period during the fall of 1977 had caused them to rise and return to more normal, higher levels. A piezometer above the head of the landslide indicated artesian pressures 1 m above the ground surface at that location, which would be consistent with larger artesian pressures at points downhill. This rise in the groundwater levels had the effect of reducing the strength of the clay at depth, where it rested on the underlying granular till materials, and might have caused the initial failure of the roadway embankment. These artesian pressures are believed to have played a significant role in the initiation and the regression of the slide.

SEQUENCE OF EVENTS

Through interviews with eyewitnesses who saw the slide develop, personnel of the Geologic Institute at Chalmers University of Technology and University of Göteborg have been able to determine the

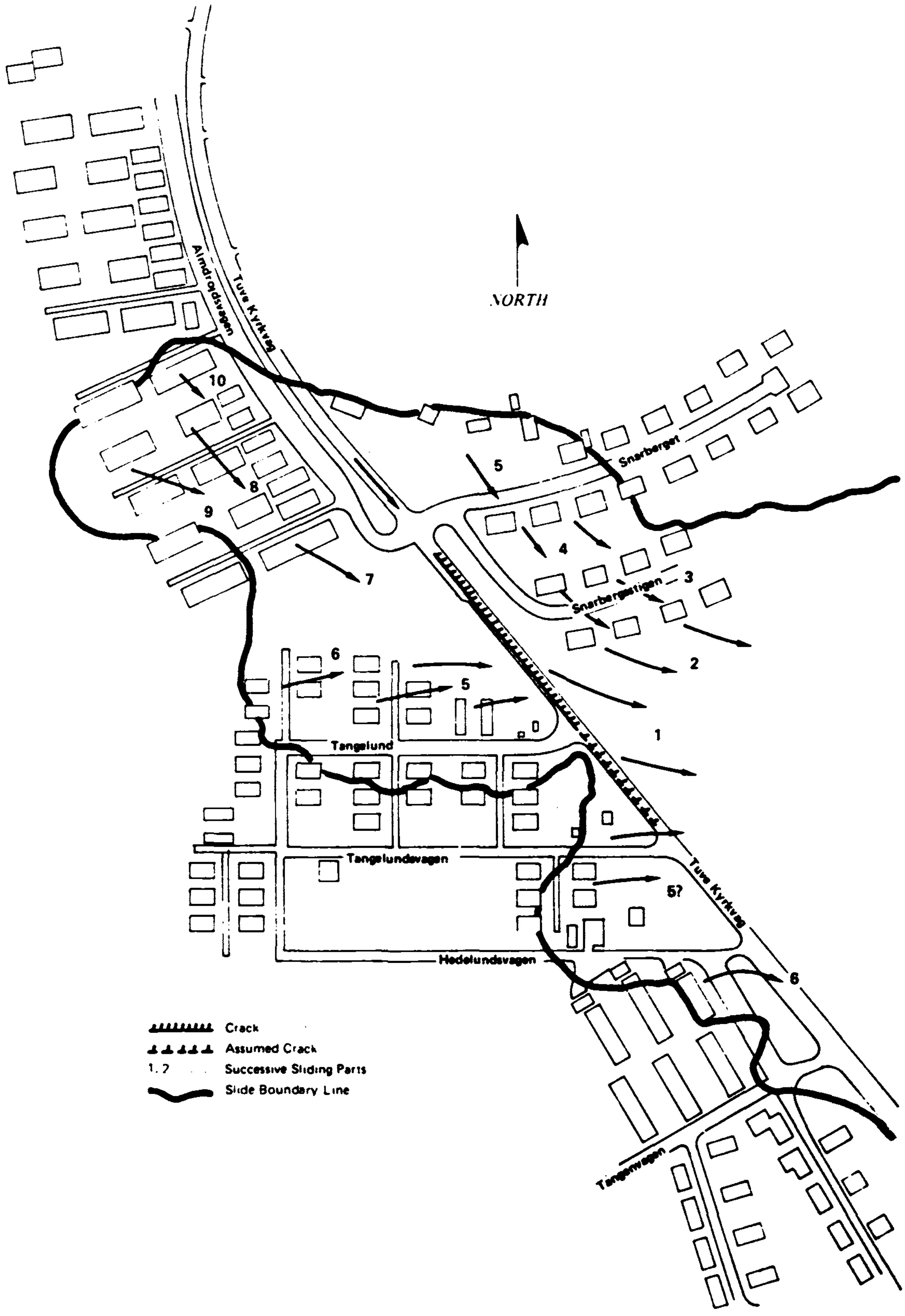

Fig. 12 Sequence of events in the Tuve landslide.

sequence of events involved in development of the slide. The order of the events, as shown by the numbers on Figure 12, was as follows:

1. Shortly after 4:00 p.m., a crack developed in the pavement of Tuve Kyrkväg. It ran from Snarberget to Tångelundsvagen. The crack propagated approximately at walking speed, about 2 m/second. When the crack formed, a small portion of the Tuve Kyrkväg embankment, with a surface area of 10 to 20 m^2, slid away toward the southeast.

2. The lower row of houses on Snarbergsstigen then slid out, approximately at walking speed, about 10 or 20 seconds after the crack developed in Tuve Kyrkväg.

3. The second row of houses on Snarbergsstigen slid out a few seconds later as the slide retrogressed to the north.

4. The row of houses on the lower side of Snarberget slid out a few more seconds later, following those from Snarbergsstigen down the hill.

5. Within about 20 seconds after development of the crack in Tuve Kyrkväg, the houses on the upper side of Snarberget, those north of Tångelund, and those north of Hedelundsvagen began to slide. By this time, the houses from Snarbergsstigen had moved about 50 m downhill.

6. Within a very short time, the houses further up Tångelund and those on Tangenvagen began to slide.

7-10. Subsequently, in a succession of slides, the houses to the west of Almdrojdsvagen slid away. From the development of the crack in Tuve Kyrkväg to the last of the slides, the total duration of the slides was estimated as 1-2 minutes.

EMERGENCY ACTION

Within minutes after the slide the fire department, police, civil defense, military, and volunteers were working in the area, under the direction of the fire chief, to locate survivors in the debris and to rescue them. The Red Cross and medical personnel from nearby hospitals were at the site, and city buses were mobilized to evacuate people from the area. Personnel of the Road Office and the Water and Sewage Office also assisted in the rescue operations, all of which had to be conducted under light from a police helicopter and emergency light poles erected by civil defense workers, owing to the early onset of darkness in Göteborg in December.

The slide disrupted electrical service to about 5000 inhabitants and disrupted water and sewage service to a smaller number of people. Electrical power was restored within 1-1/2 hours, and water and sewage service was restored to all residents remaining around the slide by the evening of December 1, about 24 hours after the slide. Temporary roads were constructed in the slide area using gravel, and in some cases fabric reinforcement, to provide access to the displaced houses. These temporary roads can be seen in Figures 4 and 5.

All of the dead were found by Friday afternoon, within about 48 hours after the slide. The final death toll was 8 persons, all of whom were women and children; most of the men residents of the area were not at home at the time of the slide, which occurred when many were at their jobs. Thirty persons injured in the slide required hospitalization.

Immediately after the slide, a fence was erected around the destroyed area and the undamaged houses believed threatened by possible further sliding, as shown in Figure 13. All of the houses within the fenced zone were evacuated. On Friday, December 2, a crack was discovered outside the fence, and 34 additional houses were evacuated. A total of 65 houses were destroyed and about 100 were evacuated.

The Social Welfare Department provided apartments for those people displaced by the slide, and on Friday morning, all sales of homes were halted to give persons from the slide area first choice in buying new houses.

The damage caused by the slide was estimated at 50 million Swedish crowns (about $10 million). Because of a change in insurance laws shortly before the slide, the homeowners were able to recover damages from their insurance companies. On Friday, December 7, the Minister of Internal Affairs announced that the Swedish government would ensure that none of the residents of the area would suffer financial loss from the disaster.

GEOTECHNICAL INVESTIGATION

On Thursday, December 1, two geotechnical engineering firms from the Göteborg area (J. W. and V.I.A.K.) were charged with defining the area of risk around the slide. These firms began immediately to perform soundings and vane shear tests to locate areas underlain by soft clay. On Friday, December 2, the community appointed a committee consisting of Mr. L. Andreason (director of the Swedish Geotechnical Institute), Dr. A. Bergfelt (professor at Chalmers University of Technology), and Mr. G. Berg (civil engineer from Göteborg), who were assigned the task of supervising the geotechnical investigations. On Monday, December 5, the governor of the county turned over to this committee full responsibility and authority for determining which houses should be abandoned permanently and which could be reoccupied.

The geotechnical investigation consisted of the soundings and vane shear tests mentioned previously, the installation of piezometers around the head of the slide to monitor trends in pore pressure, the use of geophones to detect small ground movements, and total stress stability analyses to assess the risk of further sliding. The final decision regarding which houses could be reoccupied was scheduled for Friday, December 9, 9 days after the slide.

On December 9, the Swedish government allocated 200,000 Swedish crowns ($40,000) to the Swedish Geotechnical Institute to study the Tuve slide. During the week after the slide, several communities in the Göteborg area requested that the government conduct geotechnical investigations to assess the risk of landslides in their localities. The Tuve disaster has revived widespread concern over the potential for landslides in Sweden, which had subsided after about 20 years without a major landslide.

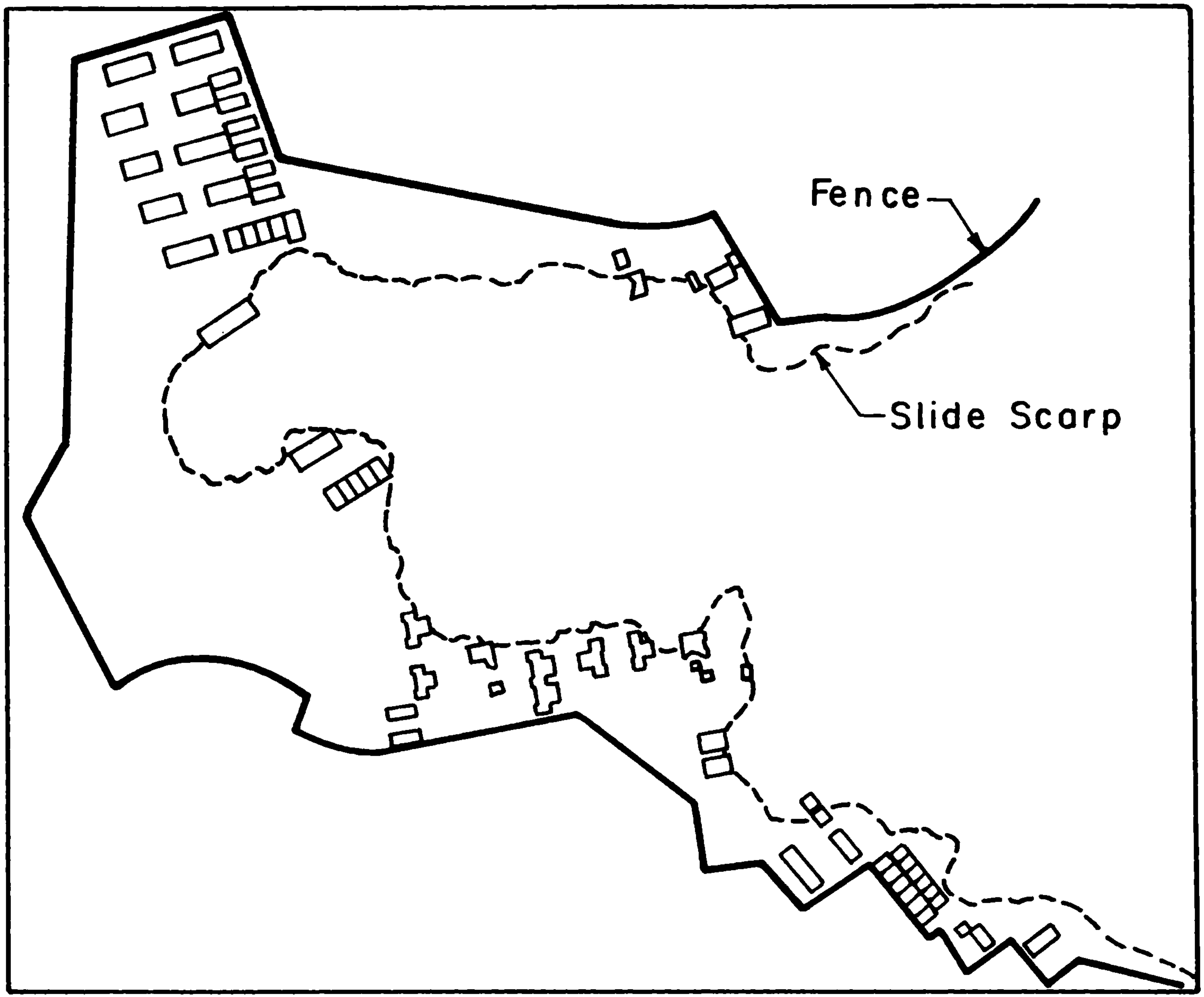

Fig. 13 Security fence around the evacuated houses.

APPENDIX

National Research Council Reports of Post-Disaster Investigations 1964-1978

Copies Available From Sources Given in Footnotes a, b, and c

Earthquakes

[a]The Great Alaska Earthquake of 1964:

Biology, 0-309-01604-5/1971, 287 pp ($21.95)
Engineering, 0-309-01606-1/1973, 1198 pp ($37.50)
Geology, 0-309-01601-0/1971, 834 pp ($35.00)
Human Ecology, 0-309-01607-X/1970, 510 pp ($29.50)
Hydrology, 0-309-01603-7/1968, 446 pp ($25.00)
Oceanography and Coastal Engineering,
0-309-01605-3/1972, 556 pp ($32.50)
Seismology and Geodesy, 0-309-01602-9/1972, 598 pp ($25.00)
Summary and Recommendations,
0-309-01608-8/1973, 291 pp ($16.00)

[c]Engineering Report on the Caracas Earthquake of 29 July 1967, by M. A. Sozen, P. C. Jennings, N. M. Newmark, 233 pp, (1968)

[c]The Western Sicily Earthquake of 1968, by J. Eugene Haas and Rober S. Ayre, 70 pp, (1969)

[b]The Gediz, Turkey, Earthquake of 1970, by Joseph Penzien and Rober D. Hanson, 88 pp, (1970)

[c]The San Fernando Earthquake of February 9, 1971, by a Joint Panel on San Fernando Earthquake, Clarence Allen, Chairman, 31 pp, (March 22, 1971)

[b]Destructive Earthquakes in Burdur and Bingol, Turkey, May 1971, by W. O. Keightley, 89 pp, (1975)

[c]The Engineering Aspects of the QIR Earthquake of April 10, 1972, in Southern Iran, by R. Razani and K. L. Lee, 160 pp, (1973)

[c]Engineering Report on the Managua Earthquake of 23 December 1972, by M. A. Sozen and R. B. Mathiesen, 122 pp, (1975)

[c]The Honomu, Hawaii, Earthquake, by N. Nielson, A. Furumoto, W. Lum, and B. Morril, 95 pp, (1977)

[b]Engineering Report on the Muradiye-Caldiran, Turkey, Earthquake of 24 November 1976, by P. Gulkan, A. Gurpinar, M. Celebi, E. Arpat, and S. Gencoglu, 67 pp, (1978)

Flood

[b]Flood of July 1976 in Big Thompson Canyon, Colorado, by D. Simons, J. Nelson, E. Reiter and R. Barkau, 96 pp, (1978)

Dam Failures

[b]Failure of Dam No. 3 on the Middle Fork of Buffalo Creek Near Saunders, West Virginia, on February 26, 1972, by R. Seals, W. Marr, Jr., and T. W. Lambe, 33 pp, (1972)

[b]Reconnaissance Report on the Failure of Kelly Barnes Lake Dam, Toccoa Falls, Georgia, by G. Sowers, 22 pp, (1978)

Landslide

[b]Landslide of April 25, 1974, on the Mantaro River, Peru, by K. Lee and J. Duncan, 79 pp, (1975)

Windstorms

[c]Lubbock Storm of May 11, 1970, by J. Neils Thompson, Ernest W. Kiesling, Joseph L. Goldman, Kishor C. Mehta, John Wittman, Jr., and Franklin B. Johnson, 81 pp, (1970)

[c]Engineering Aspects of the Tornadoes of April 3-4, 1974, by K. Mehta, J. Minor, J. MacDonald, B. Manning, J. Abernathy, and U. Koehler, 124 pp, (1975)

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[a]Available from Office of Publications, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418

[b]Available from Committee on Natural Disasters, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (Limited number of copies, without charge)

[c]Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161