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The October 28, 1979, Landsliding On Tutuila, American Samoa

by

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Abstract

In an apparently short time interval in the early morning of October 28, 1979, more than 70 landslides occurred on Tutuila Island, American Samoa. They were confined to the western end of the island from Asili on the south shore to Massacre Bay on the north. One of the landslides in Seetaga caused four fatalities; the others caused property damage and blocked the main transportation route on the west end of the island.

Although there were rumors of an earthquake immediately preceding the landsliding, an examination of the seismograph from Apia Observatory, Western Samoa, for the morning of October 28 shows no record of an earthquake. Heavy rains during the preceding few days coupled with the generally steep slopes and deeply weathered geologic materials appear to have caused the slope failures. There is abundant evidence both visually and on aerial photographs taken in 1941 and 1960 that landslides are frequent occurrences in the effected area.

It is recommended that an analysis be made of the regional slope stability relative to current and proposed land use practices. Such an analysis would include: 1) air photos taken at a scale of 1:24,000 for comparison with those taken previously to document areas of landsliding; 2) a study of the vegetative cover; 3) a slope map; and 4) a detailed geological and structural map.

Purpose and Scope

This report is based on a study of the available geologic literature and air photos of the area, and a brief reconnaisance made at the request of the Government of American Samoa through the U. S. Geological Survey, Water Resources Division, Honolulu. The purpose of the reconnaisance was to obtain information on the causes of numerous landslides which occurred on Tutuila Island, American Samoa, on October 28, 1979.

Field work was limited to two days, December 11 and 12, 1979. One day was spent on land examining as many landslides as possible to determine the types of slides, the materials comprising them, and any differences or similarities between slides that might help determine the causes of the sliding. On the second day, a boat trip was made around the island to determine the geographic extent and the location of landslides along an otherwise inaccessible section on the northwest side of the island.

Acknowledgements

The study was undertaken at the request of the Government of American Samoa. Edvin G. Remund, Director, Department of Public Works, provided support personnel and extended numerous courtesies during the investigation. Neil Scratch and Frances Thompson, Department of Public Works, were invaluable as guides and interpreters. Funding and transportation on Tutuila for the investigation was provided by the Hawaii District, Water Resources Division, U.S. Geological Survey. Kiyoshi Takasaki and Johnson Yee, also of Water Resources Division, Honolulu, assisted the investigation in many ways including undertaking a trip to Western Samoa to obtain a seismograph record made available to them through the cooperation of Seve Iosa of the Apia Observatory, Upolu. Transportation from Hawaii to American Samoa was provided by the Federal Aviation Administration on one of their inspection flights.

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Geographic and Geologic Setting

The Samoan archipelago is a chain of volcanic islands located nearly 3,700 km (2,300 mi) southwest of Hawaii between 13° and 15° south latitude and 168° and 173° west longitude (fig. 1). The islands trend nearly east-west for at least 300 km (180 mi) and are on the southwest edge of the Pacific Plate, less than 200 km (125 mi) north of the west-northwest trending limb of the Tonga Trench. The two westernmost islands, Savai'i and Upolu, form Western Samoa, an independent Polynesian nation. To the east lie the principal islands of American Samoa, Tutuila and the Manu'a Islands (Ofu, Olosega, and Tau). The smaller islands of American Samoa, Rose and Swains, are not shown on figure 1.

Until recently, the Samoan Islands were considered geologically anomalous for the Pacific Plate in that the progression of volcanism was thought to have occurred from east to west rather than west to east (e.g. Hawaiian, Society and Marquesas Islands). This was based on the fact that the youngest volcano with eruptions in 1760, 1902 and 1905 was on Savai'i, the westernmost island (Natland, 1980, p. 23). However, on the basis of chemical distinctions in the pre- and post-erosional lavas, Natland suggests that there is an eastward propagation of volcanism of the older shield volcanoes of the Samoan Ridge, an interpretation compatible with the generation of other volcanic island chains on the Pacific Plate. Natland (1980) interprets the recent volcanism of the chain to be related to a post-erosional rift zone resulting from the bending of the Pacific Plate into the Tonga Trench with subsequent shear melting at the base of the lithosphere.

Geology of Tutuila

Tutuila is the largest island of American Samoa (fig. 2) with an area of 137 sq km (53 sq mi) (Davis, 1963, p. 3). It is nearly 32 km (20 mi) long trending generally east-west, and ranges in width from a kilometer at Pago Pago harbor to a maximum of 8 km (5 mi) at the Tafuna-Leone plain. Matafao Peak is the highest point with an elevation of 650 m (2,142 ft).

Stearns (1944) has identified five eruptive centers that built Tutuila (the Taputapu Volcanics, the Pago volcanic series, the Olofau Volcanics, the Olomoana Volcanics, and the Masefau dike complex; see fig. 2) during Pliocene to late Pleistocene time (7 million to 2 million years ago respectively). These episodes of volcanism were followed by a long period of noneruption and vigorous erosion, which resulted in steepsided mountains and exposed the dike systems that built the volcano. This period of erosion was followed by another episode of volcanism during Holocene time (the last 10,000 years) that produced both the post-erosional Leone lavas of the Tafuna-Leone plain, a broad plateau on the south side of the western part of the island, and the lavas capping the Taputapu Volcanics (not shown on fig. 2).

The Taputapu Volcanics, the geologic unit to which landsliding was confined, form the western end of the island, and are Tutuila's oldest lavas. This unit comprises lava flows, dikes, cones and tuff deposits about 500 m (1,500 ft) thick. The flows are mostly olivine basalt, 2 to 15 m (6 to 50 ft) thick, and commonly have interbeds of red vitric tuff several centimeters to about a meter thick and lenses of cinder. These deposits dip 5° to 10° to the north and south away from the generally east-west trending ridge crest (Stearns, 1944, p. 1305).

Landslides

One of the major processes that has shaped and reshaped the topography of Tutuila is landsliding. According to Stearns (1944, p. 1310), hundreds of landslides are triggered by each hurricane that hits the island. However, the scars are rapidly covered by vegetation so that the frequency and distribution of past landsliding is obscure.

The latest episode of landsliding occurred during the early morning hours of Sunday, October 28, 1979 (Edvin G. Remund, oral comm.), when more than 70 landslides developed in an area west of a NE-SW line from Massacre Bay to Asili (fig. 3). It is estimated that more landslides occurred but were not observed due to the thick vegetative cover, poor light, and small amount of field time available . The exact times of the landsliding are not known but those in several of the villages were reported to have occurred between 0600 and 0700.

The landslides took place within the Taputapu Volcanics, in various kinds of deeply weathered geologic materials - bedded lavas, tuff and lava interbeds, cinder and saprolite deposits (decomposed rock formed in place through chemical weathering) - that moved down slope under the force of gravity. Most of the landslides were shallow, narrow slump failures in the crown of the slide, that continued downslope as debris flows (fig. 4; Varnes, 1980, p. 13). Many of the slides were 60 m (200 ft) or more in length, while none was greater than 30 m (100 ft) in width and few were greater than 15 m (50 ft) wide (fig. 5a, 5b, 6a and 6b; see fig. 3 for locations). More than half of the slides took place from elevations estimated between 8 and 120 m (25 and 400 ft), although some slides occurred at higher elevations. Due to the generally steep slopes, many slides formed chutes as they moved downward. A few occurred on slopes so gradual that vegetation remained upright during the sliding. Of the total number of observed landslides a small percentage had their headscarps in grassy areas that were obviously old landslide scars on which the jungle had not had sufficient time to re-establish itself. The headscarp of the widest landslide may have comprised old landslide material (fig. 7a and 7b). A few landslides occurred in areas used for agriculture.

All of the villages on the west end of Tutuila lie along the coast nestled in embayments where stream erosion and delta formation have produced flat areas suitable for building. Most of these villages were damaged to some degree by the landslides.

At Seetaga, Agugula and Fagamalo, landslides entered drainages and entrained stream water which fluidized the slide material changing it to debris flows that inundated the villages. Water catchment systems were damaged at these and other villages when slope failures occurred above the small-capacity impounding ponds, removing the reservoirs and adding water to the landslides as they moved down slope.

The severest consequences occurred at Seetaga where four people were killed. Eyewitness accounts from survivors at Seetaga indicated that the villagers were awake and moving about when they heard a loud boom. Within seconds, a debris flow entered their village, engulfed four people, and flowed to the sea (fig. 8a and 8b). They reported that the rain had not been unusually heavy the previous night nor that morning. The lateral force exerted by the flow apparently was not great. No houses were destroyed, although some were damaged, and coconut trees in the path of the debris flow were left standing (fig. 8b; field investigations took place nearly two months after the landsliding and the deposits within the villages had been modified by bulldozers). On two sets of vertical air photos, one taken in 1941 and another in 1961, a debris flow deposit can be seen at the confluence of the streams near Seetaga. On the 1941 photos, this deposit has a very fresh appearance and may have occurred during the hurricane of 1940. On the 1961 photos, the debris flow is still obvious although vegetation has been established on it.

The road along the southwest shore of the island was apparently not damaged by the slides, although debris had to be removed from it at many localities. However, a newer, unpaved road at approximately the 75 m (250 ft) elevation from Amanave on the south shore to Fagamalo on the northwest coast, was damaged at many localities by slides occurring both in the cut slope and below the road. By December, the road was passable only as far as Maloata.

Cause

The short-term factor which caused the landsliding is believed to be the heavy rains that fell on the western end of the island during the few days immediately preceding the event, as well as during the night of October 28. The generally steep slopes, the downslope dip of the rock units away from the ridge crest, the nature of the geologic materials and their deeply weathered character, are the long-term causes contributing to slope instability. The possibilities that (a) a small earthquake occurred a few days before the landsliding episode, weakening the slopes without causing immediate sliding until the equilibrium was disturbed by the heavy rains, or (b) an earthquake occurred on the morning of October 28 triggering the slides, were investigated. The seismic records of the National Earthquake Information Center, Golden, Colorado, and the Apia Observatory in Western Samoa, were examined but no seismic event in this part of the Pacific was recorded during the time of interest.

Rainfall data collected on October 26, 27 and 28 at Malaeloa, 3 km east of the disaster area, show 24-hour totals of 5.59, 2.57 and 11.40 cm (2.20, 1.01, and 4.49 in), respectively, while at the Pago Pago International Airport gauge, 6 km east of Malaeloa area, for the same time period, the totals were only 1.98, 1.85, and 6.10 cm (0.78, 0.73, and 2.40 in) (fig. 2). U.S.G.S. stream gauge records also show that the western part of the island had higher rainfall than the eastern part (Table 1). Gauges at Atauloma Stream, within the landslide area and Asili Stream, 0.35 km (0.4 mi) east of Atauloma Stream, show gauge heights slightly over the historic peak during the early morning hours of October 28. Several kilometers further east records from Afuelo, Pago and Leafu (near Auasi) streams, show much lower gauge heights for the same period of record (figs. 2 and 3). Thus it seems likely that the large quantity of rain that fell on portions of the western end of the island added substantial weight to the slope materials, decreased the internal friction between particles, and decreased the cohesive forces that bound the clay minerals together. These combined factors apparently were sufficient to induce local mass movement of material downslope under the force of gravity.

Certain geologic factors, including long-term, deep weathering, have resulted in a widespread deterioration of slope stability. The Taputapu Volcanics, which underlie the western end of the island, originally consisted of interbedded resistant lava beds and poorly consolidated tuff beds. The basalts are severely decomposed and the interbedded tuffs are altered to red, clay-rich residual products. Spheroidal weathering leaves boulder-shaped remnants of lava flows within thick, well developed saprolite. This saprolite, consisting of a soft, earthy, clay-rich material, typifies the substantial weathering the rocks have undergone.

The chemical weathering resulted from Tutuila's tropical climate with an average temperature range of 21° to 32°C (70° to 90°F), an average humidity of 80%, and an average annual rainfall at Pago Pago of nearly 5,000 mm (200 in) (Pacific Island Yearbook for 1977). The weakening of the geologic formations by time and climate combined with oversteepening of the slopes by both natural and, more recently, by human agencies has greatly reduced slope stability. Vigorous stream erosion from the frequent heavy rainfalls probably removes material from the base of the slopes, locally oversteepening them by undercutting and contributes to the failure potential. Road and water catchment construction also are relatively recent contributors to slope instability by cutting the slopes, increasing the slope angle and removing supporting material. Some of the landslides examined along the north-south road near Amanave were the result of road construction and occurred prior to October 28 (Neil Scratch, oral comm.).

Conclusions and Recommendations

Landslides occur frequently on the steep slopes of Tutuila's weathered and altered volcanic rocks. Weathering, erosion, and heavy rainfall modify the slope angle, remove supporting material and/or weight the slope materials eventually causing downslope movement. These natural processes are sometimes augmented locally by human activities that unwittingly undermine the equilibrium of the slopes. Relatively stable areas can be converted to unstable ones by cutting into and oversteepening the slopes by construction activities.

Knowledge of the past history of geologic events is an important tool in understanding and predicting future landsliding. With such knowledge, sound land-use planning decisions can be made and the geologic consequences resulting from construction projects can be minimized. In December when the field investigation was underway, a recommendation was made to the Director, Department of Public Works, that vertical air photos at a scale of 1:24,000 be flown of the island to document the October disaster and provide an additional data base to be used for short-term geologic studies. These photos should be used for comparative studies with the existing 1941 (U. S. Army, scale 1:16,500), and the 1961 (U. S. Coast and Geodetic Survey, scale 1:24,000), photos. The comparison should stress:

1. documentation of areas of landsliding within the last 40 years
2. identification of the relationship between the different types of vegetative cover and slope stability
3. examining the relationship between land use and slope stability
4. identification of the geologically most unstable areas.

In addition, a map showing degree of slope (the relationship between a given horizontal distance and its vertical component) should be produced. The slope map should be supplemented by field work directed at evaluating the depth of erosion and types of weathered materials that underlie the slopes.

Finally, for long-term planning, a detailed geological and structural map of the island should be made. With an expanding population and the resulting increase in human impact on the terrane, such a map would provide information on many geologic parameters that would be valuable for making intelligent and informed land-use decisions.

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FIGURE CAPTIONS

Figure 1. Location of Samoa Islands (modified from Bentley, 1975)

Figure 2. Generalized geologic map, Tutuila Island, American Samoa (adapted from Stearns, 1944)

Figure 3. Topographic map of west end of Tutuila Island showing general locations and estimated elevations of landslides.

Figure 4. Schematic drawing of typical slump failure and resulting debris flow deposit (not to scale). Slump material from crown of slide erodes slope immediately downhill forming a chute. Due to the high fluid content of the slide material, it can flow for substantial distances beyond the base of the slope.

Figure 5a. Head scarp of slide at Utumea. Height of scarp approximately 5.5 m (18 ft). View towards northeast.

5b. Westward view taken from road of landslide shown in 5a.

Figure 6a. View towards north of landslides along a portion of the south coast. Slide to far right is in Agugula.

6b. Close up of landslide at Agugulu shown in 6a. View to northeast.

Figure 7a. Widest landslide (approximately 24 m [80 ft]) occurred near Vaoaga Point on the north coast. View towards south.

7b. View to southwest of slide shown in 7a. Rounded boulders and lack of sorting suggests an old landslide deposit at head of new slide.

Figure 8a. Landslides in Soonapule Stream above Seetaga. View towards west.

8b. Debris flow material in Seetaga (modified by bulldozer) in part derived from landslides shown in 8a. View towards north

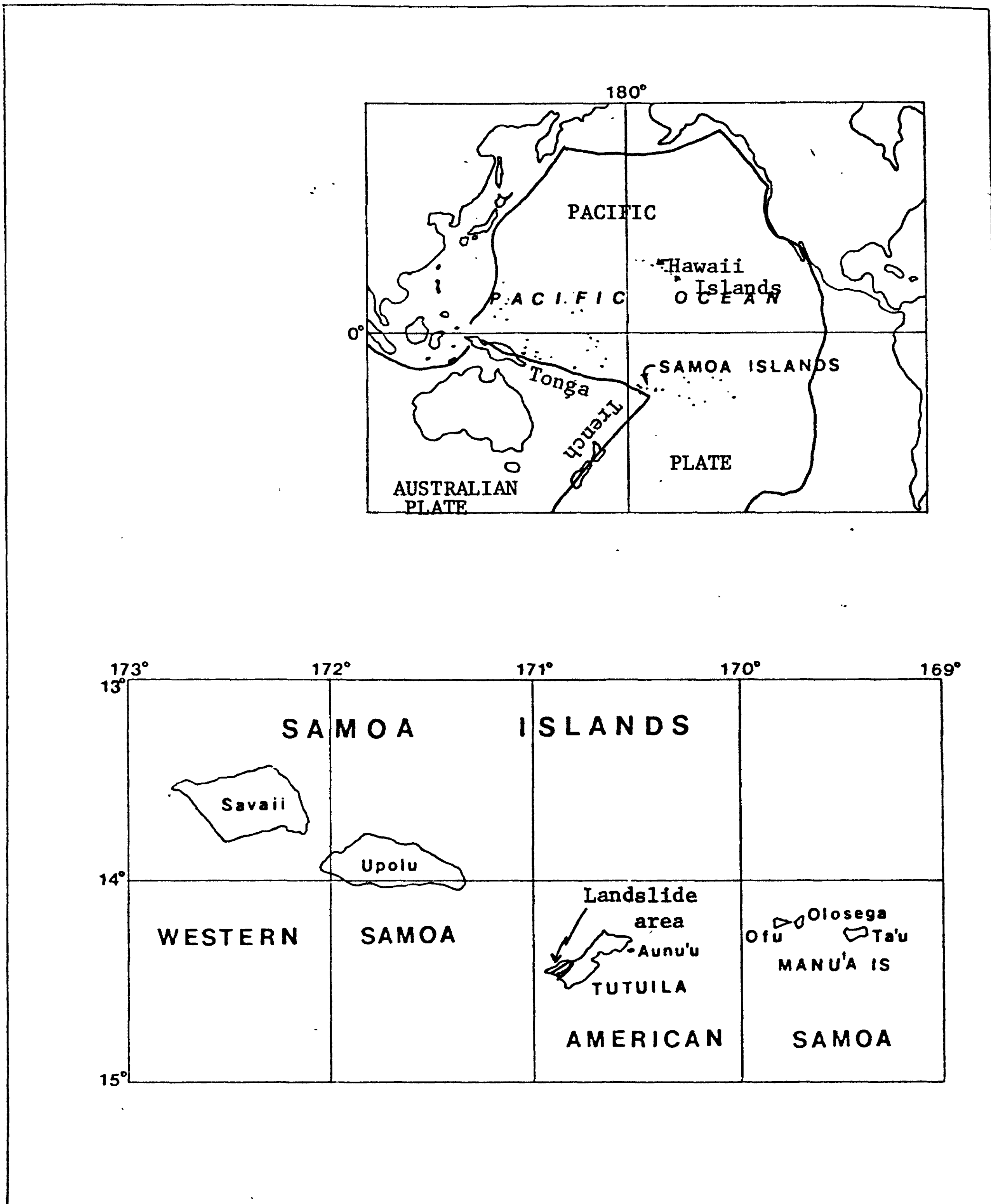

FIGURE 1. LOCATION OF SAMOA ISLANDS (modified from Bentley, 1975)

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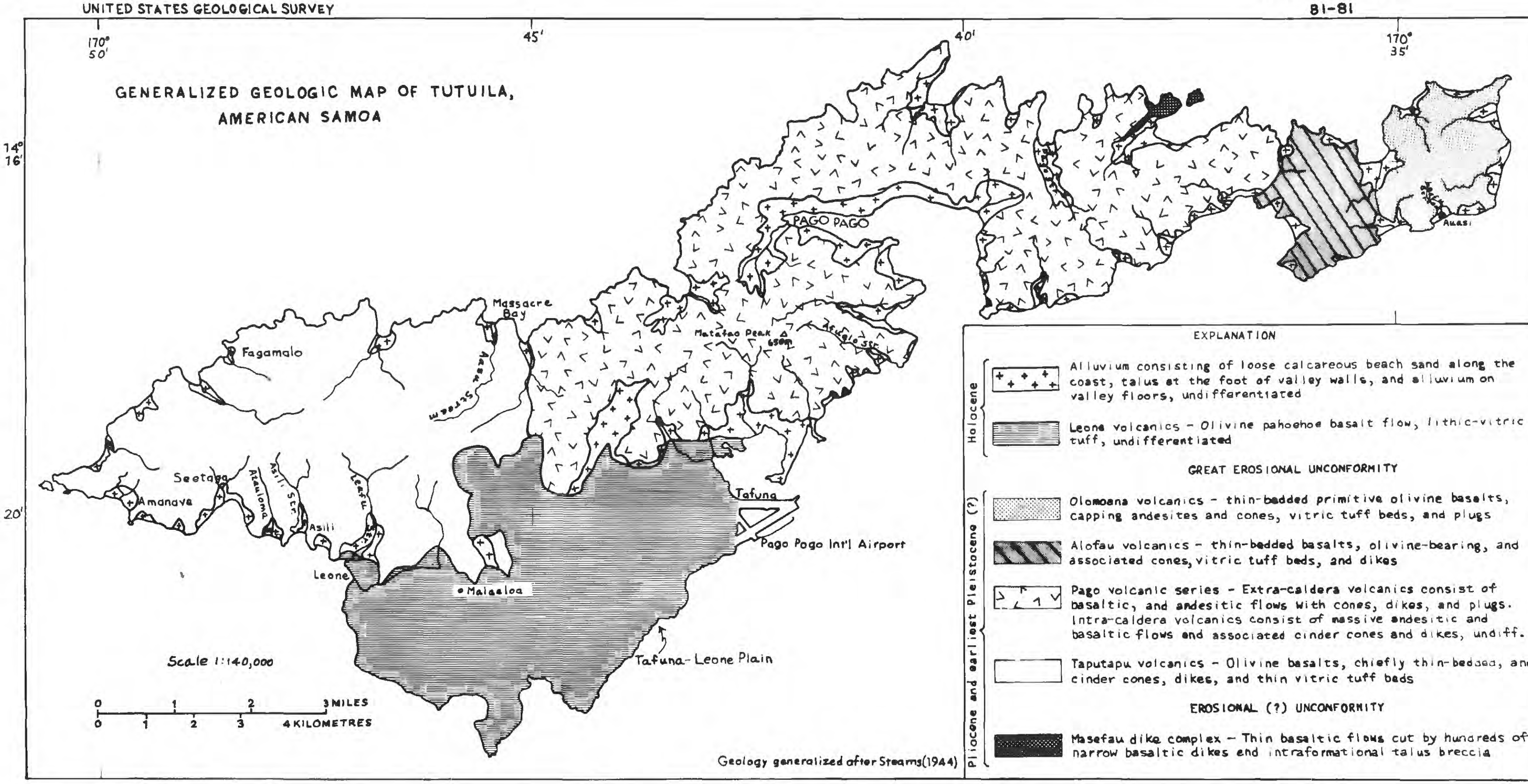

Figure 2

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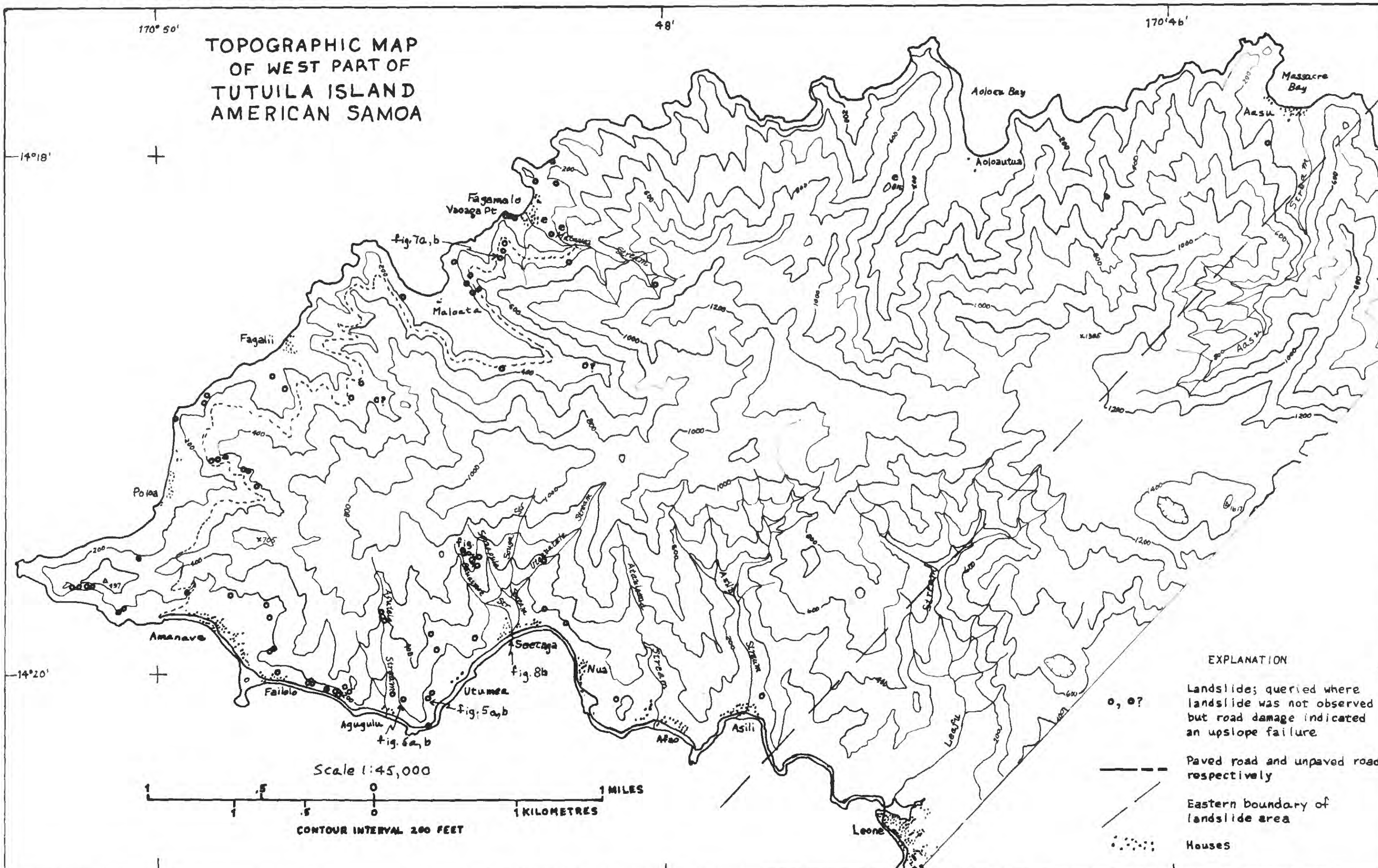

Figure 3

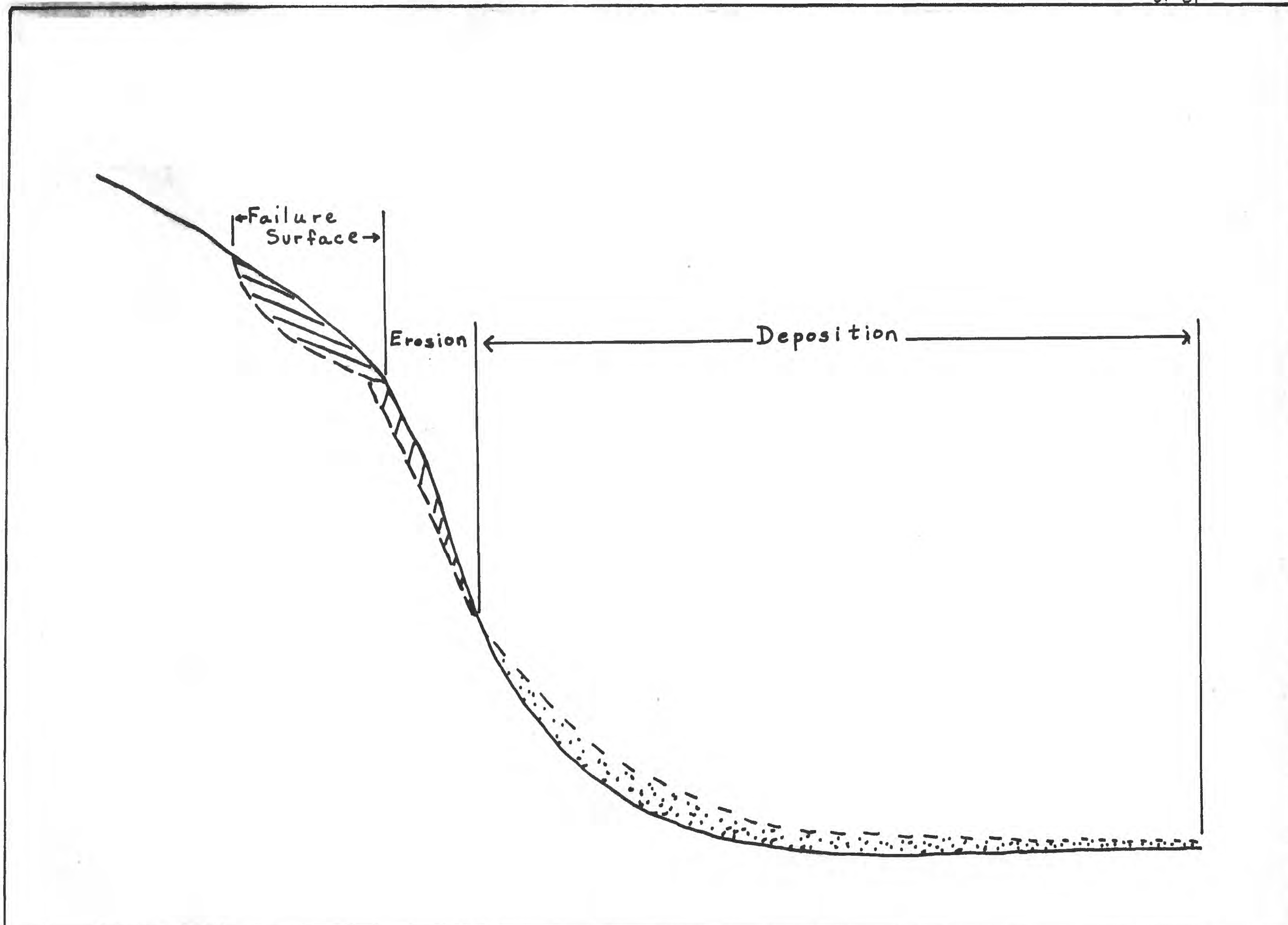

Figure 4

Fig 5a

Fig. 5b


Fig. 6a


Fig. 6b

Fig. 7a

Fig. 7b

Fig. 8a

Fig. 8b

Table 1. Peak gauge height recorded at U.S.G.S. stream gauges, Tutuila Island

		Station Name	Peak Gauge Height 10/28/79 (in feet)	Time of Peak (approx.)	Peak Gauge Height of Record (in feet)	Date	Period of Record Years
	E	Atauloma Stream at Afao	4.47	0730	3.99	8/10/67	20
South		Asili Stream near Asili	4.73	0645	3.92	9/ 1/79	2
Coast		Leafu Stream near Leone	4.53	0700	4.58	9/ 1/79	2
		Afuelo Stream at Matuu	2.59	0715	4.59	4/29/75	21
	W	Leafu Stream near Auasi	2.04	0730	2.56	7/29/73	7
North	E	Aasu Stream at Aasu	4.71	0610	5.16	8/ 7/72	20
Coast	W	Pago Stream at Afono	3.28	0740	5.49	7/ 5/69	20