DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

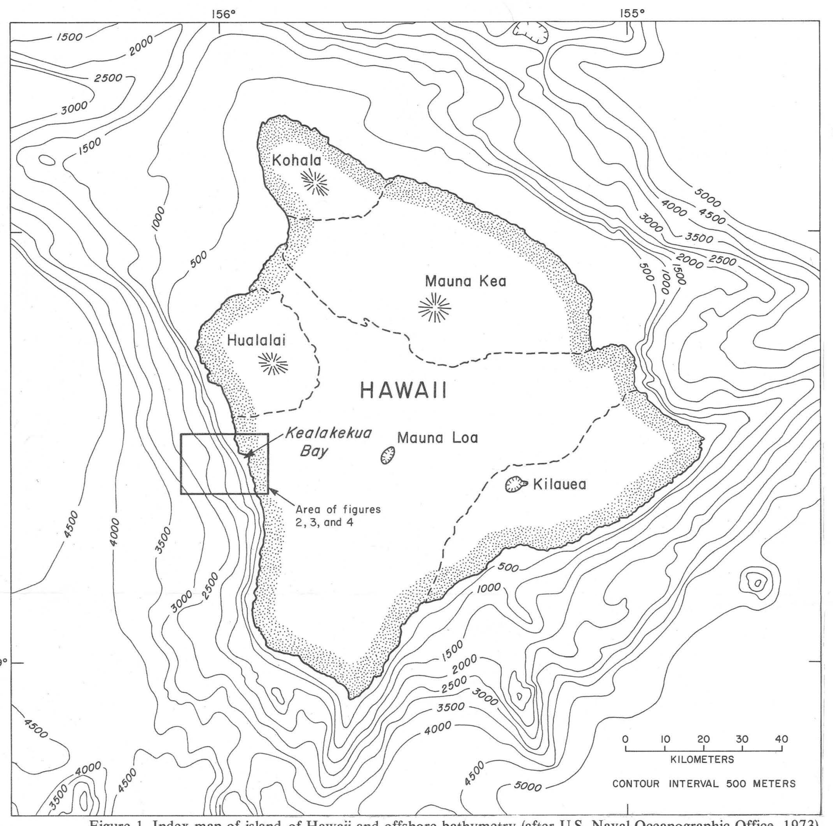

Figure 1. Index map of island of Hawaii and offshore bathymetry (after U.S. Naval Oceanographic Office, 1973). Dashed lines are boundaries between volcanoes.

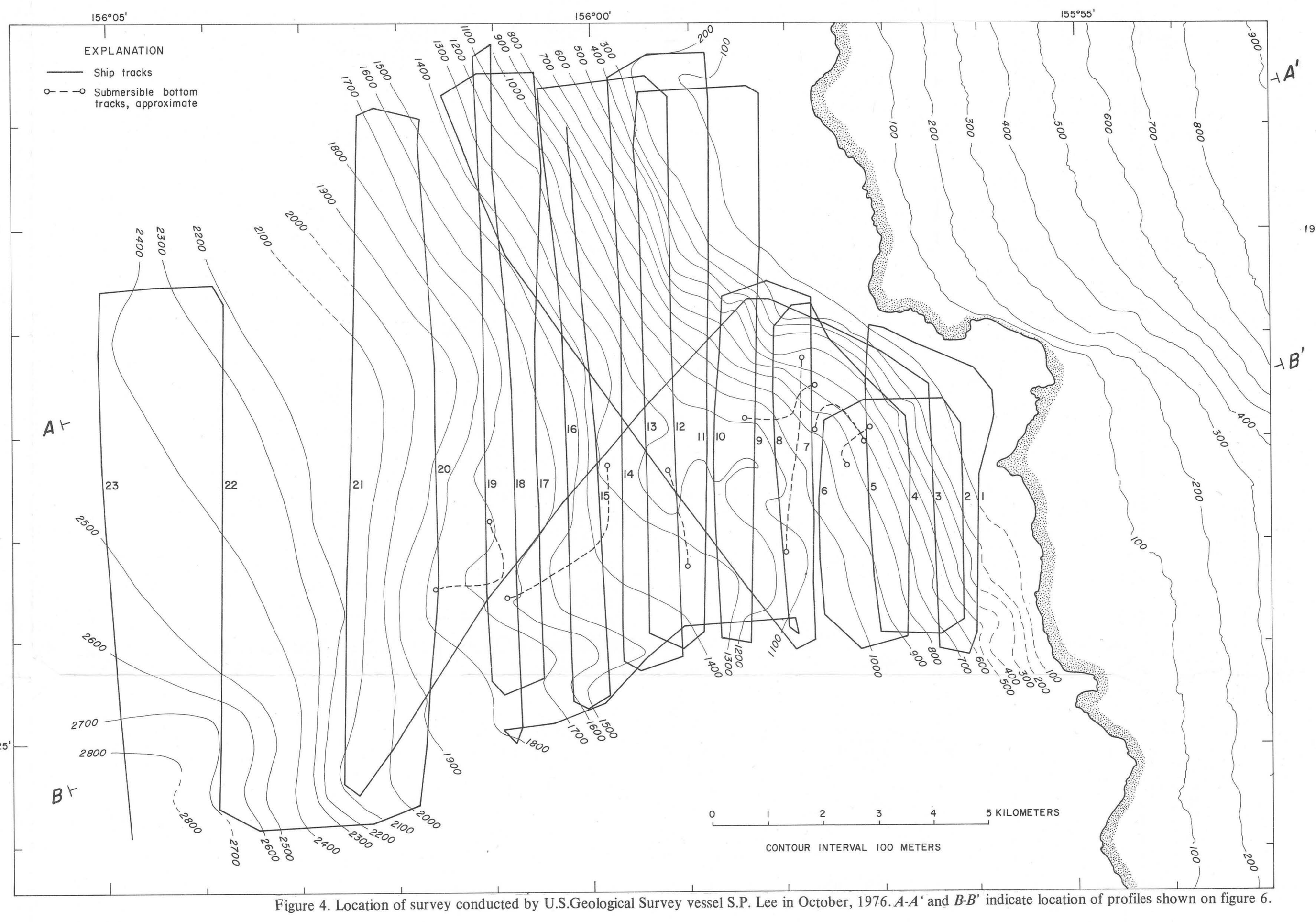

Figure 4. Location of survey conducted by U.S.Geological Survey vessel S.P. Lee in October, 1976. A-A' and B-B' indicate location of profiles shown on figure 6.

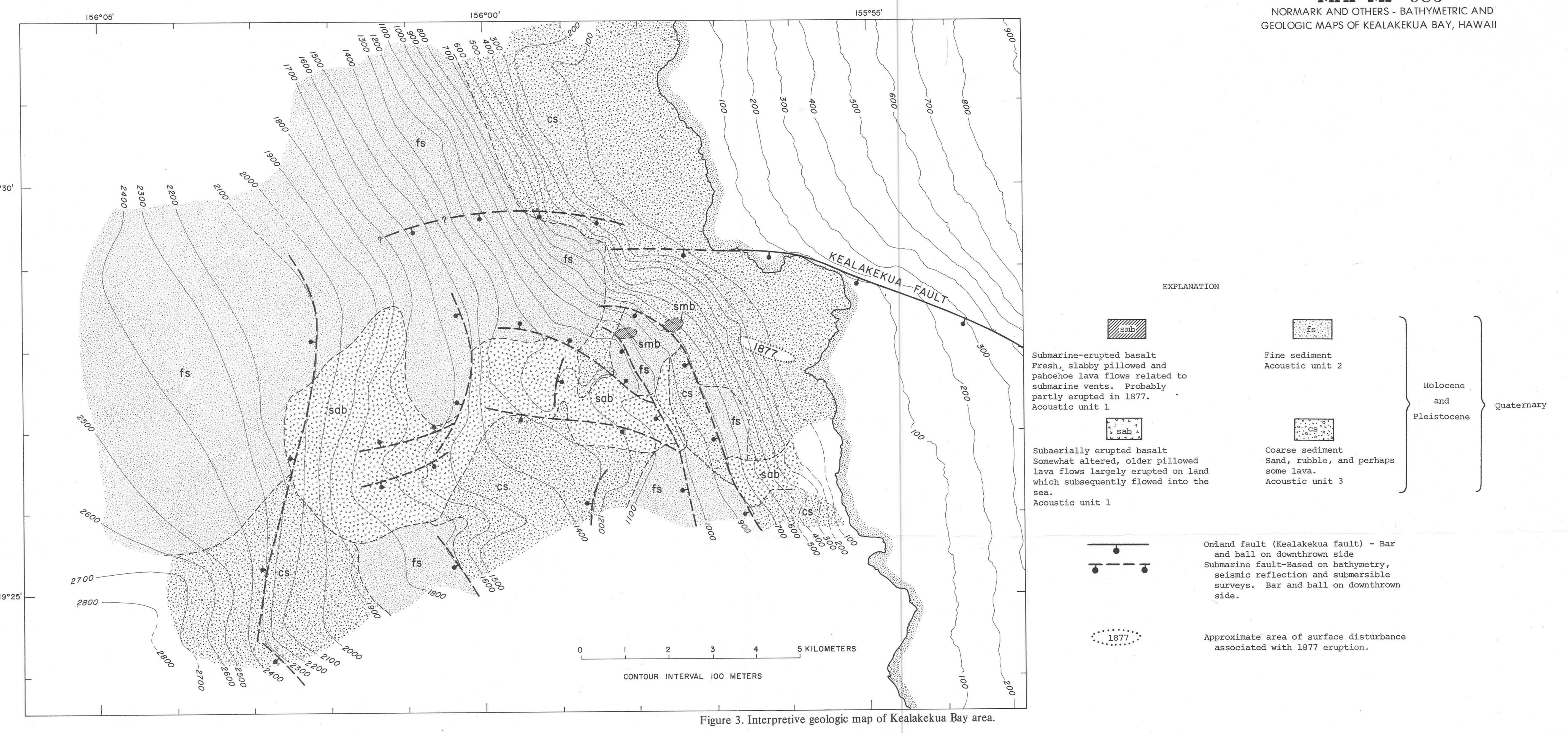

Figure 3. Interpretive geologic map of Kealakekua Bay area.

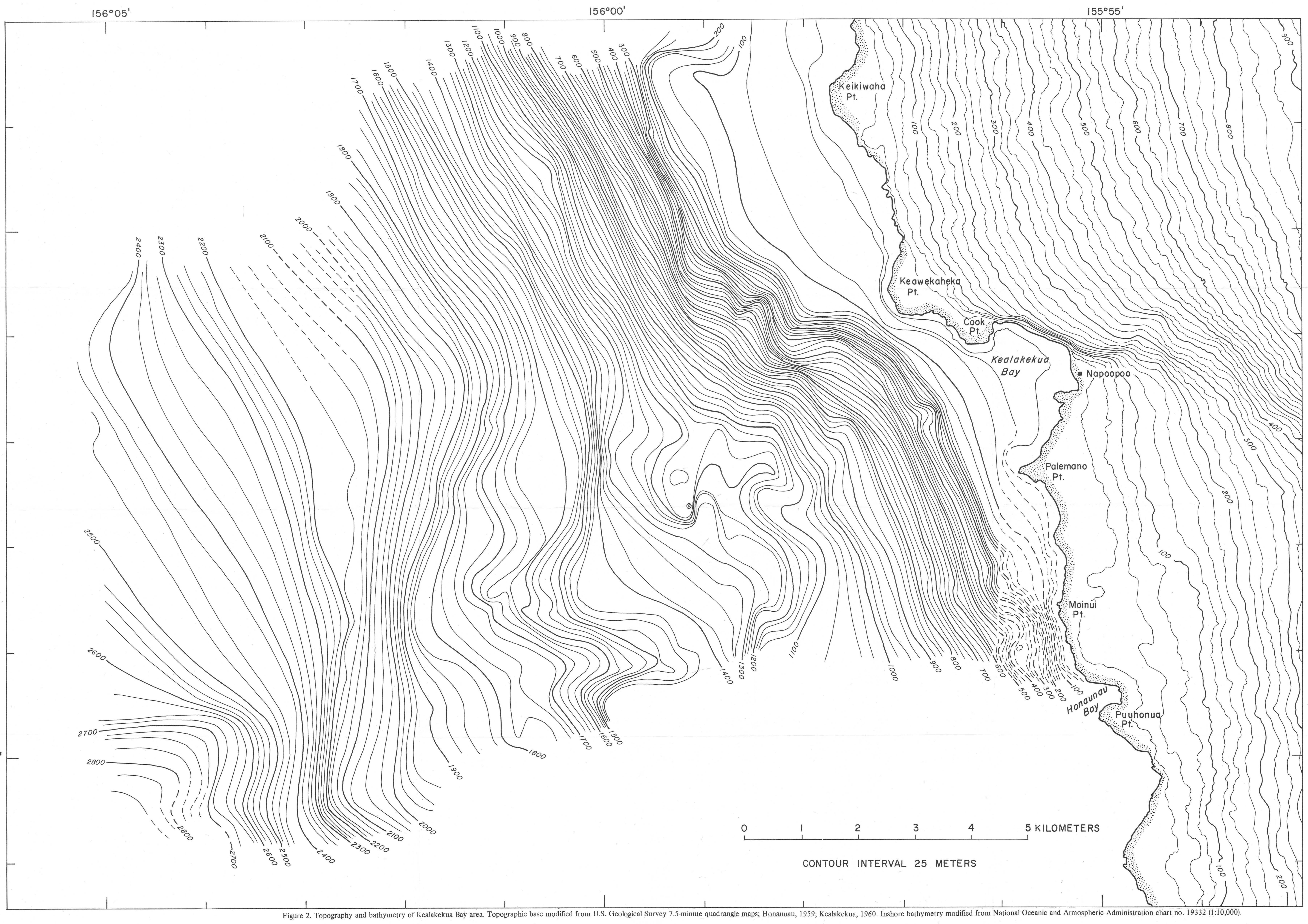

Figure 2. Topography and bathymetry of Kealakekua Bay area. Topographic base modified from U.S. Geological Survey 7.5-minute quadrangle maps; Honaunau, 1959; Kealakekua, 1960. Inshore bathymetry modified from National Oceanic and Atmospheric Administration chart no. 19332 (1:10,000).

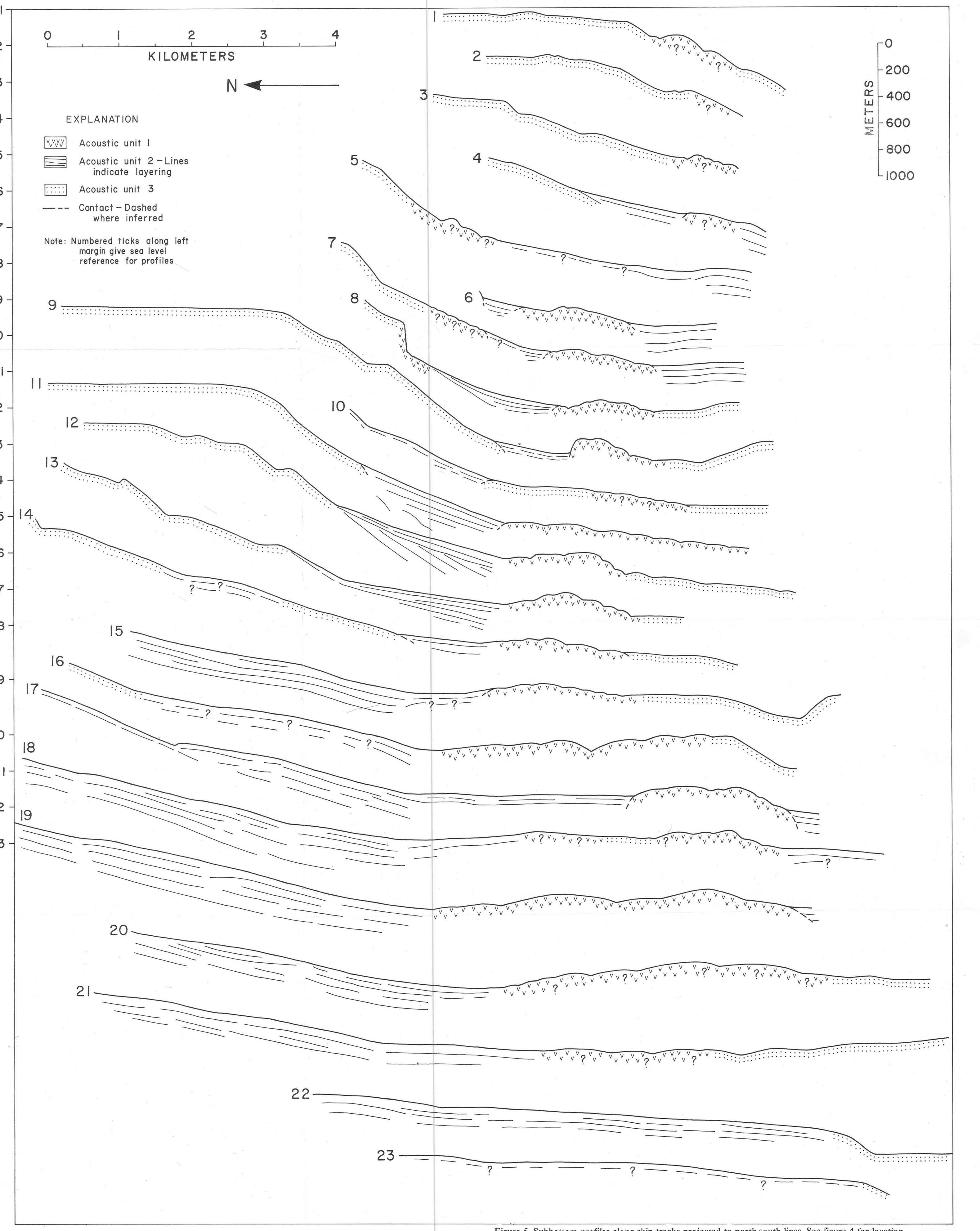

Figure 5. Subbottom profiles along ship tracks projected to north-south lines. See figure 4 for location.

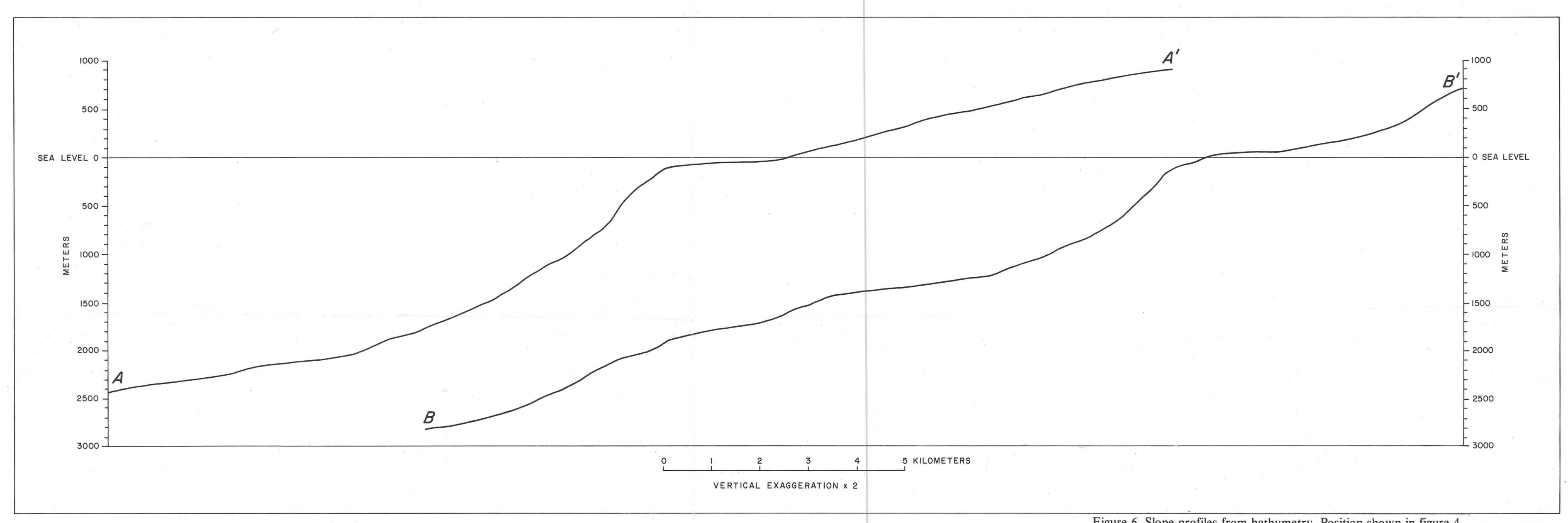

Figure 6. Slope profiles from bathymetry. Position shown in figure 4.

INTRODUCTION

Kealakekua Bay is shaped largely by the Kealakekua fault, a major arcuate normal fault along which part of the seaward flank of Mauna Loa volcano has been downdropped (fig. 3). The on-land fault scarp has topographic relief greater than 250 m, even though it is extensively draped by prehistoric (pre-19th century) lava flows from Mauna Loa. A young lava delta from one of these flows built Cook Point (fig. 2), where Captain James Cook first landed in 1778. In 1951, a major earthquake (M = 6.1), accompanied by a local tsunami, had its epicenter on the seaward end of the fault, although there was no known surface rupture. Aftershock epicenters were distributed along the curving landward extension for a distance of about 25 km. The overall seismic-tectonic pattern demonstrates south-side-down normal faulting (Macdonald and Wentworth, 1954).

A submarine eruption occurred offshore in the mapped area on February 24, 1877 (Anonymous, 1877) (fig. 3). This eruption reportedly occurred along a west-northwest-trending line extending out 1.7 km from Palemano Point, and no active fissure vents or lava appeared on land. The submarine activity was manifested by boiling water, a strong sulfurous odor, appearance of incandescent scoriaceous basalt blocks at the sea surface, and fish kills.

MARINE SURVEY METHODS

The bathymetric survey was conducted with the U.S. Geological Survey vessel S. P. LEE in late October, 1976. Fixes were obtained every five minutes or less, using a C-band radar transponder navigation system. Most fixes utilized range data from three or four precisely located land-based transponders; the average range error for the 295 fixes of the survey was 8 m. Ship speed was maintained at 10-11 km/hr, with a general line spacing over the eastern part of the mapped area of approximately 0.5 km (fig. 4).

The bathymetric map (fig. 2) was derived from conventional 3.5-kHz reflection profiles. Depths were taken at all inflection points along the profiles and converted to corrected meters, utilizing sound velocity tables from Matthews (1939). In addition to subbottom information on the 3.5-kHz profiles, single-channel seismic-reflection profiles were generated with an 80-kilojoule sparker sound source.

Records from both the 3.5-kHz and sparker-reflection systems define three acoustic units, which have been utilized (with submersible observations and samples) to construct the geologic map (fig. 3):

1. Discrete zones of acoustic basement with very rough local relief that appear as numerous overlapping hyperbolic echoes. Units smb and sab.
2. Sediment-smoothed slopes with limited subbottom acoustic reflectors. Unit fs.
3. Relatively low-relief sea floor of acoustic basement; no coherent subbottom reflectors are visible. Unit cs.

Figure 5 presents most of the profiles from the survey projected normal to north-trending lines. This projection standardizes horizontal distance along the profiles; as a result, the subbottom information is interpretive and does not represent actual signal tracings. Although not clear from the record traces, submersible observations indicate that the sediments bank against, overlap, or are in fault contact with outcrops of the rough acoustic basement (acoustic unit 1). Acoustic unit 1 is believed to be largely lava flows. Acoustic unit 2 is associated with a smooth sea floor underlain by fine sand and mud, common in areas of low relief predominating further offshore. Evidence for folding and faulting is rare, although several unconformities are present. Acoustic unit 3 occurs on the narrow coastal shelf and on steeper slopes. It probably represents coarse volcanic sand and rubble generated by disintegration of lava flows near the shoreline and may also include some lava flows.

Several dives were made in the mapped area (see approximate tracks, fig. 4) by the U.S. Navy Submersible DSV #4 SEA CLIFF during 1974 and 1975. Bottom submersible navigation was by dead reckoning, controlled by radar fixes for the surface tender at the start and end of each dive; consequently, it is of lower reliability than the surface ship survey of the S. P. LEE. The results of these dives will be reported in detail elsewhere, but they have been utilized in refining the geologic interpretation reported here.

SUBMARINE LITHOLOGIC UNITS

Four submarine lithologic units are depicted on the geologic map (fig. 3). They have been defined by the acoustic signatures supplemented by submersible observations and examination of submersible-collected samples.

Submarine-erupted basalt (smb).--Two small areas of fresh basaltic lava flows were seen on two submersible dives about 1.8 km south of the seaward extension of the Kealakekua fault. The area covered by these flows is not well established, because of uncertainties in submersible navigation and because of the irregular reflection signal obtained from the surface ship due to the steep slope.

Inspection of these flows from the submersible revealed fresh hollow broken pillows and slabby pahoehoe lava, lightly mantled with a few millimeters of white biogenic sediment in depressions. The flows are apparently derived from local submarine fissure vents with an estimated N70°E trend; they cover a surface of fine sediment and rubble. The lava is extremely fresh; palagonitic alteration of glassy pillow rims is less than 5 µm thick, and encrustations of MnO are absent. Relatively high sulfur concentrations in samples of basalt glass indicate that the flows were erupted underwater and have not degassed, as would be expected for subaerially erupted lava (Moore and Schilling, 1973). These data suggest that these fresh flows may be related to the 1877 eruption, which was observed at the sea surface about 1.5 to 2.5 km east of the mapped lava (Anonymous, 1877, p. 1; Hitchcock, 1911, p. 115-117; Westervelt, 1963, p. 182-184).

Fine sediment (fs).--Fine sediment, showing acoustic unit 2 signature, is present in areas of low relief and predominates in the western part of the mapped area in deep water. Such sediment is also ponded several hundred meters thick on the north side of the west-trending ridge of subaerially erupted basalt (sab). It probably represents fine material carried by prevailing southerly currents along the west coast of Hawaii.

Subaerially erupted basalt (sab).--An irregular 2 by 9 km area of acoustic unit 1 occurs along a broad irregular ridge which extends downslope to depths of more than 2000 m. Submersible observations indicate it is built of basaltic pillow lava lightly mantled by sediment. The lava pillows appear older than the submarine flows to the northeast, as they show a greater degree of weathering and are covered with more sediment. The pillows are encrusted with 10-40 µm of both palagonite and MnO. They are much more solid than the pillows in submarine-erupted basalt, central cavities are smaller or absent, and vesicularity is lower. Basalt glass shows low sulfur concentrations, indicating degassing during subaerial eruption before entering the sea.

A second smaller area displaying acoustic signature 1 occurs near shore in the southeast corner of the map. It probably represents a lava flow that originated on land, but it has not been related to any particular subaerial flow and has not been visited by submersible.

Coarse sediment (cs).--Coarse sediment and rubble with rare subbottom reflectors (acoustic unit 3) are present primarily on the narrow shelf and steep slopes adjacent to it. Such material also occurs in deeper water primarily south of the west-trending lava ridge. It is largely volcanic-derived sand and rubble, generated by quench-induced disintegration of lava flows crossing the shoreline, as well as erosion and breakdown of lava in the surf zone. Some partly buried lava flows may be included.

BATHYMETRY AND GEOLOGY

The Kealakekua fault, trending roughly east-west and downthrown to the south, has greatly modified the west slope of Mauna Loa in the mapped area. South of the fault is an eastern stepback of the coastline and an anomalously flat coastal bench. The submarine shelf is about 2.5 km wide north of the fault and 1 km wide south of the fault (figs. 2, 6). The submarine slope north of the fault falls rather smoothly from the shelf edge to abyssal depths (fig. 6, A-A'). It is steepest just beyond the shelf edge (25°) and averages 18° 5 km seaward of the shelf edge. South of the fault, the bathymetry and geology are complex (fig. 6, B-B'), apparently modified by extensive secondary faulting.

These relations suggest that the Kealakekua fault bounds the north side of a large slump structure, and that the landward end of the fault curves south, bounding the east side of the slump on the higher subaerial slopes of Mauna Loa. Topographic expression of the fault is indistinct here because of extensive mantling by young flows erupted from the summit and southwest rift zone of the volcano. Historic activity of this seaward-moving slump is verified by: (1) the major earthquake episode in 1951 on the Kealakekua fault, (2) the 1877 submarine eruption adjacent to the fault, (3) the recurrence of a swarm of shallow earthquakes off the west-central Hawaiian coast (Koyanagi and Okamura, 1966), and (4) the historic subsidence of the coastline at Honaunau (fig. 2) at the southeastern corner of the mapped area, at a rate of 3 mm/yr (Apple and Macdonald, 1966); much of this subsidence is the result of eustatic and isostatic processes, but some may be due to large-scale slumping (Moore, 1970).

The effects of large-scale downdrop of a coastal block, in addition to shifting the coastline eastward, would be the rapid construction of a coastal bench by coalescing lava deltas where lava flows tend to widen at the shoreline rather than flow actively into the sea.

The form of the offshore shelf provides information on the timing of offset on the Kealakekua fault. North of the fault, the shelf is 2.1-2.7 km wide with its outer edge at a depth of 122 ± 15 m. South of the fault, the shelf is about 1 km wide with its outer edge at a depth of 150 ± 10 m. This shelf probably formed as a subaerial coastal flat by grading of subaerial fluid lava flows to sea level during one or more of the Pleistocene eustatic lowerings of the sea. Similar benches occur on Oahu at an average depth of 105 m (Ruhe and others, 1965) and on Molokai at 115 to 157 m depth (Mathewson, 1969). The last major emergence of the island occurred during the Wisconsin Glaciation, which peaked approximately 17,000 years ago with a worldwide sea-level lowering of about 100 m (Dillon and Oldale, 1978). Since that time, the shelf has been narrowed south of the fault, probably by coalescing lava deltas advancing the coastline seaward. The reason that lava flows have not advanced the coastline seaward north of the fault is that the fault scarp on land tends to divert flows to the south.

Consequently, the vertical offset of the Kealakekua fault on land which has produced a cliff and steepended slope over 250 m high appears to have occurred primarily more than 17,000 years ago. Perhaps about 28 m of downdrop south of the fault has occurred since formation of the bench. South of Moinui Point (fig. 2), the shelf has apparently been substantially modified, although bathymetric data are incomplete. The greater depth of the shelf break north of the fault (-150 m) as compared with the Wisconsinan minimum stand of sea level (-100 m) partly records regional subsidence of the island. Fifty meters per 17000 years amounts to 2.9 mm/yr, which compares to the present rate of subsidence as measured at the Hilo tide gage of 4.1 mm/yr (Moore, 1970).

The submarine slope south of the Kealakekua fault is irregular when compared with the generally uniform slope to the north. In gross aspect, this irregularity is caused by a broad amphitheater shallower than about the 1,400 m contour and by a welt that can be traced from the 1,400 m contour nearly 15 km offshore to at least 2,600 m depth. Only about the northern 6 km of the amphitheater and welt are defined on the map, but regional bathymetry (fig. 1) indicates that this feature has a north-south width of about 15 km and extends south to lat. 19°21'N, which is also the southern limit of the flat subaerial coastal bench.

This large feature is regarded as part of landslide or slump which has modified the steep flank of the volcano, extending at least 15 km offshore and reaching inland about 5 km. The irregular bathymetry in its central part is interpreted as the result of faulting. An attempt has been made to map the larger faults on the basis of bathymetric scarps and subbottom irregularities, as well as by utilizing submersible observations (fig. 6). Individual scarps, observed from the submersible, are as much as 150 m high, ranging in slope from 45° to near vertical.

ACKNOWLEDGEMENTS

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BATHYMETRIC AND GEOLOGIC MAPS OF KEALAKEKUA BAY, HAWAII

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