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Woods Hole Oceanographic Institution



Cable Failures off Oahu, Hawaii Caused by Hurricane Iwa

by

Charles D. Hollister

August 1984

Technical Report

*Funding was provided by the International Cable Engineering Division
of A T & T Communications under contract number 47-5697.*

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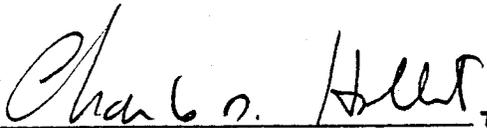


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Charles D Hollister

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CABLE FAILURES OFF OAHU, HAWAII, CAUSED BY HURRICANE IWA

by: Charles D. Hollister

ABSTRACT

Six submarine telecommunications cables on the steep insular slope off southwest Oahu were damaged or broken by a combination of debris slides and large-block talus movement or, for the shallowest cables, wave induced chafe.

These problems were caused by the sea floor's response to high surface energy produced by Hurricane Iwa. An examination of all available data does not support the concept of failure by turbidity currents.

BACKGROUND

By and large, most telecommunications cables laid on the sea bottom continue to serve their purpose for decades, without any signs of trouble. But there are some notable exceptions. Perhaps the most famous-- at least from a scientist's perspective-- occurred in 1929 when an earthquake on the Laurentian fan east of Nova Scotia triggered a series of turbidity currents that severed a dozen telecommunications cables (Heezen and Ewing, 1952). The intriguing aspect was not that they broke, but when and where they broke: in an apparently progressive downslope sequence. This allowed for some strong inferences about the velocity of downslope processes.

There have been only two known multiple (4 or more) cable failures. The first, which occurred in 1929, was investigated by the late Bruce C. Heezen, who linked the downslope sequence of cable breaks to turbidity currents. Heezen's interpretation is still controversial, although many other cables have broken (but not in a sequence) with some evidence that turbidity currents were to blame (e.g. off the Magdalena and the Congo Rivers).

The only other multiple cable failures reported in the literature happened in November 1982, when Hurricane Iwa moved over the Hawaiian Islands.

My interests over the past 20 years have focused not on the fast-moving (e.g., tens of knots) turbidity currents, but on processes of a gentler kind: the transport of deep-sea sediment by comparatively slow-moving (order of one-half to two knots) deep-sea storms (Hollister, et al., 1984, and Hollister and McCave, 1984). Nevertheless, the possibility of obtaining a new data set about turbidity currents was very appealing. The following report resulted from a consulting contract from the International Cable Engineering Division of A T & T Communications to assess the available data and provide recommendations that might aid in the security of cables yet to be laid.

AVAILABLE DATA

The Storm

The eye of Hurricane Iwa passed near the islands of Oahu, Kauai and Niihau during the early evening hours (between 1600 and 1900 hours Hawaiian Standard Time - HST) of 23 November 1982. (For details on the storm, see Noda, 1983). The low-pressure center, combined with high onshore winds, produced devastating high-water and wind damage along the islands' south-facing properties. The maximum wind speed (50 to 70 knots, gusts to 80 knots) and high

water (36 inches above MLLW) occurred at about 1900 to 2200 HST. During the hurricane's passage, maximum wave height was calculated at about 10 m; this is commonly referred to as the "storm surge", which happened at about 1630 HST.

Current Meter Data

An array of current sensors off the southwest coast of Oahu, Hawaii recorded successive episodes of downslope movement of the moorings associated with high-speed, near-bottom currents of up to 200 cm/sec and elevated water temperatures (see for details, Dengler & Wilde, 1983 and Dengler, in press). These episodes occurred at about 2000 HST on 23 November 1982, coincident with the maximum storm effects of Hurricane Iwa. The total array consisted of 15 current sensors on 11 moorings between 30 and 760 m depth. One of the deeper sensors broke loose during the storm and washed ashore. Two sensors were recovered substantially seaward of their deployment sites. Three moorings could not be found during the scheduled recovery but were recovered several months later. Four sensors on three shallow-water moorings (50 m) are still missing.

Sensors from four moorings in water depths of 119 m (#6), 424 M (#5), 614 m (#4) and 766 (#2) recorded increases in depth of up to 220 m and implied downslope movement as far as 2.4 km. Mooring #6 apparently tumbled down an unstable and steep escarpment face (Fornari, pers. comm.). Pressure, temperature, and current speed records of these sensors show four separate events. Comparing the depth change of the sensors with the arrival time of each episode at successive meters gives downslope speed up to 300 cm/sec. Temperatures at three deeper sensors were 2 to 3 degrees centigrade above ambient conditions.

Cable Damage

Two cables suffered tension breaks; one broke by chafe and four more suffered damage on the evening of 23 November 1982 HST. Some of the breaks and cable damage (see Table I) occurred in an area (15 km square) immediately offshore of Kahe Point in water depths of 600 to 1600 fms over a relatively short period of time (0518 to about 0610 GMT on 24 November, or 1918 to 2010 HST on 23 November). Cable damage also occurred about 15 km north of these breaks during the storm period (at 0540 GMT on 24 November on the Keawaula-Fiji Section of the COMPAC cable and at 1610 GMT on 25 November on the Keawaula--Port Alberini COMPAC cable). This damage occurred in much shallower water (300 fms) than where chafe and eventual breakage of the Keawaula-Fiji Section occurred. The spatial distribution of cable damage (Fig. 1A) shows that two cables (Guam 2 and Fiji compac) passing through the region of cable breaks did not fail there. (They did fail, however, in shallow water).

Visual Observations

Observations from a U.S. Navy submarine (DSV TURTLE) in the region of the current meters was reported by Dr. Daniel J. Fornari (1983). His extensive visual data (I previewed the video tapes) shows that the whole region where the current meters were originally moored is covered with unconsolidated, coarse coral debris and rubble on steep local slopes up to 70°-90°. Sediment cores taken in March 1984, show 50 to 100 centimeters of hemipelagic sediment overlying a coarse coralline and volcanic rubble horizon. This is an ideal condition for downslope sliding of a traction carpet of loose material on slopes that were measured close to the angle of repose.

Bottom photographs taken during a recent submarine cable survey in this area in the region nearest the cable failures show boulders in 20 of the 24 pictures (Lowe, 1983).

Microphysiography From Side-Scan Sonar

Data from 12 khz side-scan sonar in this region yields significant insight into dynamic sea-floor processes (Fig. 1 and Map-1, and Figs. 2A, 2B and Map-2). The details of this come from another report by Dr. Daniel J. Fornari. The SEA MARC II is a swath-mapping, side-scan sonar system which produces "shadow-gram" images of the seafloor. The system operates at a frequency of 12 khz and is towed near the sea surface, thereby allowing a fast tow speed (as high as 10 knots) and rapid data acquisition. Map-1, attached to this report, shows the interpretation of side-scan sonar in the region of interest.

There are several prominent morphological features in this area, including: 1) the continuous, steep carbonate escarpment which marks the western edge of a relic carbonate platform; 2) the shelf terrace area which lies between the shoreline and the top edge of the carbonate escarpment; 3) the reflective ridge and gully terrain that lies seaward of the escarpment base; 4) highly reflective across-slope swaths of terrain seaward of the escarpment base; and 5) digitate lobes of alternating high and low reflectivity seafloor, located near the break in slope between 800 and 1200 fathoms at the downslope ends of the highly reflective regions.

As can be seen, a lot of the region is covered by carbonate cobbles and large blocks. Thus, the side-scan data display several interesting features which bear directly on the identification of major geologic pro-

cesses occurring in this seafloor area (Ryan, 1982). In addition, because this area was the site of multiple seafloor cable breaks and associated displacements of a few current meter arrays, the side-scan sonar records are critical in assessing what seafloor processes are most likely to have caused the damage. When the deep-water cable failures were plotted on the map showing "acoustic facies" (Map-1), it became clear that the breaks were located in areas of rubble streams and landslide lobes. These zones contain cobbles and gravelly lag deposits (sampled in March by Fornari) on steep slopes that can become easily unstable by hydraulic pumping. This well-known process causes rapid changes in internal pore pressure which lead to internal grain-fabric realignment and then to slope failure. Various observers (see Noda 1983) reported 30 foot high waves, i.e., the "storm surge", which would provide ample energy to liquify and thus destroy the fabric of underlying sediment by causing localized rubble flows (Heezen, 1959).

Other prominent features are the landslide lobes. These finger-like acoustic features have positive relief over the surrounding seafloor as evidenced by the prominent acoustic shadows which are cast to the south of the tips of these features. It should be noted that these features are located in the same region mapped earlier by Normark et al., 1982, who suggested that this deep-water area off Kaha Point may have been subjected to frequent landslides in the geologic past, based on the presence of inferred chaotic terrain recorded on geophysical records.

The general area mapped by Normark et al., 1982, also corresponds to the deep-water cable breaks. It should be noted that a new (February 1984) set of overlapping side-scan sonar records, obtained by R. J. Brown and Associates, fully confirms (2 April 1984 pers. comm. Fornari) the correlation

between reflectivity and sediment character of this part of the seafloor, once again suggesting that this steep area is one of landslide and boulder fans interspersed with regions of relatively undisturbed and unreflective sediment cover.

Temperature Data from Current Meter Moorings

According to Cacchione (pers. comm., 1984), there appeared to be two thermocline zones, one from about 70 m to 400 m (A), and one from 400 m to at least 750 m (B). In (A), the thermal gradient is about 0.05 °C/m; in (B) about 0.01 °C/m. Assuming a constant salinity of 35‰ (for lack of a better estimate), the Brunt-Vaisala frequency for layer (A) will be about 1.076×10^{-2} rad/sec or about 6 cph (the equivalent period will be about $T_n \approx 10$ minutes). This is assuming that $N = (g/\rho \partial\rho/\partial z)^{1/2}$ and calculated density (ρ) from the temperature and $S = 35‰$. One interesting simple computation is to estimate the internal wave frequency (or period) that is "critical" for the proximal bottom slope. That is, what internal wave frequency has energy propagating parallel to the bottom, so that there is a predicted large velocity shear at or near the bed and upslope amplification. That is found in 2-D linear theory (Cacchione and Southard, 1974) as:

$$C^2 = \frac{\sigma^2 - f^2}{N^2 - \sigma^2}$$

where C is the slope of the energy vector relative to horizontal; f is local inertial frequency; N is as above; and σ is the unknown wave frequency.

For $C = Y = \text{bottom slope} = \tan(7^\circ) = 0.123$,
 $f = \sin \phi/12$ where $\phi = 21^\circ$, and $N = 6$ cph,
 then $\sigma = 0.75$ cph or $T = \underline{1.33 \text{ hrs.}}$

Based on this, internal waves with that periodicity, if generated by the storm, would produce large shears near the sea floor. In fact, ... "the current episodes observed at mooring 5 is a periodicity on the order of 1 hour" (Dengler, et al, in press, 1984.), which is very close to the 1.33 hours predicted by Cacchione.

INTERPRETATION AND DISCUSSION

Clearly the excitement, at least within the scientific community, over the cable failures arose from the real expectation that another turbidity current like the one off the Grand Banks had occurred and that the cable failures could provide a confirmatory record of the velocities inferred by those cable break sequences. An uncritical conclusion that turbidity currents were caused by the hurricane has already been made by some investigators who did not take into account all available data like the cyclic nature of the current meter data, the bottom morphology and cable failure sequences (Dengler, et al, in press, 1984.)

Unfortunately, the Hawaiian cable breaks and damage cannot be of much help to us. But the cable failures and current meter displacements were obviously related to the hurricane. The real question is: how is the bottom activity related to the storm? Without before-and-after, precisely navigated near-bottom observations, one will never really know. In this case, however, certain zero-order facts have to be reckoned with in any explanations that are offered:

- 1) Some cables clearly within the only probable path of a turbidity current were not broken.

2) The moored current meters were not swept completely out to sea, entangled in the cables or incorporated into a massive turbulent avalanche like other structures that have been transported by turbidity currents, e.g., grass and twigs (see Heezen and Hollister, 1971). Having muddy water in flotation spheres, (see Dengler et al., 1983) is a common occurrence in high energy field experiments.

3) No retrograde failure of the escarpment face was observed or is plausible given the massive nature of the carbonate rock. It is unlikely that large carbonate blocks falling down the escarpment would generate turbidity currents.

4) Each shallow mooring had a concrete clump with about 270 lbs. net weight; the deeper moorings had chain anchors with only 83 lbs. negative weight. The downslope drag on the buoyant packages and current sensors at a 1 knot current with these low weights will induce down-slope sliding. In addition, any turbulent lift provided by near-bottom eddies would aid the downslope sliding.

5) There was no clear, documented evidence for any subsequent change in the bottom morphology although there were some reports of "bottom changes". Even very slight (1%) deviations in navigation on such steep slopes result in much apparent change in subsequent trips across the same region. The surface ship observations are simply not precise enough for this level of discrimination. Computerized comparisons of before and after bathymetric data do not reveal any significant change (Noda, 1983).

6) Three current meter moorings upslope of the cable damage area slid in a sporadic fashion over 2 km downslope while experiencing temperature fluctuations of unexpectedly warm water.

7) Cables did break and the current meters were translated across the bottom during the storm; the current meters moving after the cables were broken.

In my judgment, all of these events were the result of the storm but in very different ways.

CONCLUSIONS

1. The substrate beneath the current meter moorings consisted of loosely packed coral debris of sand and gravel size, resting on a slope approaching the angle of repose of this type of incohesive material. The storm surge and resulting very high waves occurred at the height of the storm when maxima in variations of interstitial pore pressure would be expected. These pore pressure variations have long been known to initiate slope failure and thus the most probable explanation for the current meter movement is a combination of the sliding of a traction carpet of loose debris downslope, much like the classic sand flows in the California canyons reported on by Francis Shepard over the past 20 years, combined with large downslope shear produced by shoaling and, perhaps, breaking internal waves.

2. The cyclic nature of the warm water measured by the sensors on the three deepest current meter moorings probably reflects the activity of shoaling and breaking internal waves that are often observed propagating along sharp density contrasts in any layered fluid. Internal waves produce high shear when they encounter steep slopes. The seasonal thermocline thus produces a sharp density gradient in this area at about the same depth and temperature as the meters were when they measured the fluctuation (Cacchione, D.A. and Southard, J.B., 1974 and Cacchione and Wunsch, 1974).

3. The deep water cables were broken, buried or damaged by debris slides, rubble and talus streams triggered by rapid fluctuations in pore pressure in the unconsolidated sediment lying beneath the more massive debris. The side-scan sonar data shows that the cables were laid across steep, scarp-like, regions exhibiting a myriad of channels, rubble piles and talus aprons of large boulders. The cables that suffered least damage were fortuitously laid atop relatively flat sediment-covered benches.

4. The shallow-water cable breaks were caused by chafe on sharp coralline outcrops. Strong surface, wave-induced, oscillatory bottom currents were the cause of these breaks/damage.

5. There is little or no evidence, in my opinion, that any of the cable failures or current meter dislocations was due to a turbidity current. This conclusion is obviously in direct conflict with the consensus of a number of workers who have already published reports stating categorically (and to me uncritically) that turbidity currents caused all of the above mentioned bottom activity (see all references to Dengle, Normark, Wilde, Noda referred to above).

RECOMMENDATIONS

After a disaster, hindsight often allows for bold statements, and mine follow:

1. Never lay cables parallel to contours on steep slopes.
2. Never lay cables across active channels or debris-covered steep slopes that exhibit rubble aprons and talus-covered slopes.

3. Use state-of-the-art bathymetric techniques (e.g. multi-channel SEA BEAM) for entire route survey, and use state-of-the-art side-scan sonar systems (now SEA MARC) to survey the continental margin, seamount, ridge-crest and other steeper portions of proposed cable routes.

4. Don't be surprised if hurricanes, earthquakes and other acts of God foul up the best laid cables.

ACKNOWLEDGEMENTS

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TABLE I
TABLE OF HURRICANE IWA-CAUSED CABLE TROUBLES

<u>Cable System/Section</u>	<u>Year Laid</u>	<u>Installed By</u>	<u>GMT Break Time & Date</u>	<u>GMT Damage Time & Date</u>	<u>Comments</u>
1. HAW Tie Hawaii Tie Cable Makaha - Hanauma Bay	1964	A T & T	0520 24 Nov. 1982	0518 24 Nov. 1982	Tension Break
2. TPC-2 (Transpacific 2) Hawaii-Guam 2 Makaha-Guam	1975	A T & T		0520 24 Nov. 1982	"Outer sheath damage in vicinity of cable breaks ... repeater fault 5 km to the north".
3. COMPAC Hawaii-Fiji Keawaula-Fiji	1963	Cable & Wireless Ltd.	0540 24 Nov. 1982		Not damaged in this area, however, damaged in shallow water further north when at 0540 it broke and was partially buried.
4. HAW-3 Hawaii- California 3 Makaha- San Luis Obispo	1974	A T & T	0551 24 Nov. 1982		Tension Break
5. WETWASH (USAF) Hawaii- Johnston Island Makua- Johnston Island	1966	U.S. Underseas Cable Corp		0600 Approx. 24 Nov. 1982	"Suffered haul and twist damage in the vicinity of the other cable breaks. Low voltage."
6. COMPAC Hawaii- Canada Keawaula- Port Albern.	1963	Cable & Wireless Ltd.		1610 25 Nov. 1982	Damaged next day. "Principal damage due to outer sheath and outer conductor chafe which had occurred over an extended period."

TABLE I (cont'd.)
CABLES WHICH DID NOT FAIL

<u>Cable System/Section</u>	<u>Year Laid</u>	<u>Installed By</u>
1. HAW-2 Hawaii-California 2 Makaha-San Luis Obispo	1964	A T & T
2. TPC-1 Hawaii-Guam 1 Makaha-Guam	1964	A T & T

CABLES INSTALLED AFTER HURRICANE IWA

<u>Cable System/Section</u>	<u>Remarks</u>
1. ANZCAN Hawaii-Canada Keawaula-Port Alberni	Installed in the summer of 1983.
2. ANZCAN Hawaii-Fiji Keawaula-Fiji	Installed in the summer of 1983

Figure Captions and Discussion of Figure 1 and Map 1
Covering the Cable Failure Region off Oahu

Figure 1 shows the complete side-scan mosaic, as supplied by the Hawaii Institute of Geophysics (HIG). MAP-1 is an interpretative overlay of Figure 1 which portrays a variety of data including: acoustic reflectivity facies; DSV TURTLE dive locations (Fornari, 1983); current meter data (Noda, 1983); cable-break information; and major morphological features of the seafloor in this area.

There are several prominent morphological features in this area including: 1) the continuous steep carbonate escarpment which marks the western edge of a relict carbonate platform; 2) the shelf-terrace area which lies between the shoreline and the top edge of the carbonate escarpment; 3) reflective ridge and gully terrain that lies seaward of the base of the escarpment; 4) highly-reflective, up-and-down slope trending swaths of terrain seaward of the base of the escarpment; and 5) digitate lobes of alternating high and low reflectivity seafloor, located near the break in slope between 800 and 1200 fathoms (uncorrected), at the downslope ends of the highly-reflective swaths.

Because the survey track is located west of the escarpment (Note: track line of survey is grey center swath within the side-scan records), the character and trend of the carbonate escarpment were easily resolved. The plan-view width of the seafloor covered by the relief of the escarpment is fairly uniform and in the range between 100 m and 250 m. A small, arcuate reflector south of the Kahe Point area and west of the escarpment has been tentatively identified as a patch reef.

Seaward of the base of the escarpment, there are numerous zones of slightly higher reflectivity which form crudely, fan-shaped swaths that are interpreted to be more cobbly seafloor within the ridge and gulley terrain identified on TURTLE dives (see Fornari, 1982). These swaths of seafloor generally exhibit linear patterns on the side-scan records which trend into the axes of the bathymetric re-entrants which are prominent along this southwestern coast of Oahu. Seaward of these acoustic reflectivity zones there are swaths of terrain with much higher reflectivity that are likely to be associated with areas of sea bottom that are either gravelly or hard.

Near the southwestern edge of the side-scan mosaic in Figure 1, there are several finger-like zones of seafloor which are characterized by narrow, alternating swaths of high and low reflectivity which create prominent acoustic shadows.

MAP-1

MAP-1 contains all cable break data available for the outages which occurred during the Iwa off southwestern Oahu. A sequential, time progression for the breaks in these cables is apparent as one moves offshore. However, the Guam-2 A.T. & T. cable, which is the third cable out from shore (see MAP-1), was not broken.

As discussed in this report, the movement of the current meter arrays was sporadic and occurred over a large time interval between 0500Z and 0610Z, with the major displacement taking place between 0600Z and 0610Z. This time interval is much later than the times when the Oahu Tie and California-3 cables (ones closest to shore and the current meter positions, see MAP-1) parted. In addition, the break times for these two cables is very well constrained based

on the drum recorder records and is well within a few minutes of the times shown on MAP-1. Consequently, it is difficult to conceive of these two events being related by a single event.

When one overlays MAP-1 on Figure 1, it is clear that the cable breaks are located in areas of high-reflectivity, especially the Oahu Tie and California-3 cable breaks which occur in high-reflectivity zones. Highly-reflective echo returns are typical of localized rubble/debris flows which were probably generated in the 400 fathom to 500 fathom area; this material was probably responsible for abrading and breaking the cables.

The most prominent feature in the deeper water area along the western edge of Figure 1 is the zone of landslide lobes. These finger-like acoustic features have positive relief over the surrounding seafloor as evidenced by the prominent acoustic shadows which are cast to the south of the tips of these features (MAP-1). In addition, it should be noted that these features are located at the break in slope between approximately 800 fathoms and 1200 fathoms where Normark et al (1982) suggests that this deep-water sea off Kahe Point may have been subjected to landslides in the geologic past, based on the presence of inferred chaotic terrain recorded on geophysical records.

The patterns of high-reflectivity seafloor as mapped on MAP-1 appear to coalesce and bifurcate principally in an up-and-down slope direction and the deeper water high-reflectivity zones seem generally continuous with narrower zones of highly-reflective seafloor in shallower depths. While the contrast between the right and left-hand sides of each side-scan record is influenced by whether the instrument is insonifying an upslope or downslope area of seafloor, it is clear that the most highly-reflective zones occur in water deeper than approximately 500 fathoms (uncorrected).

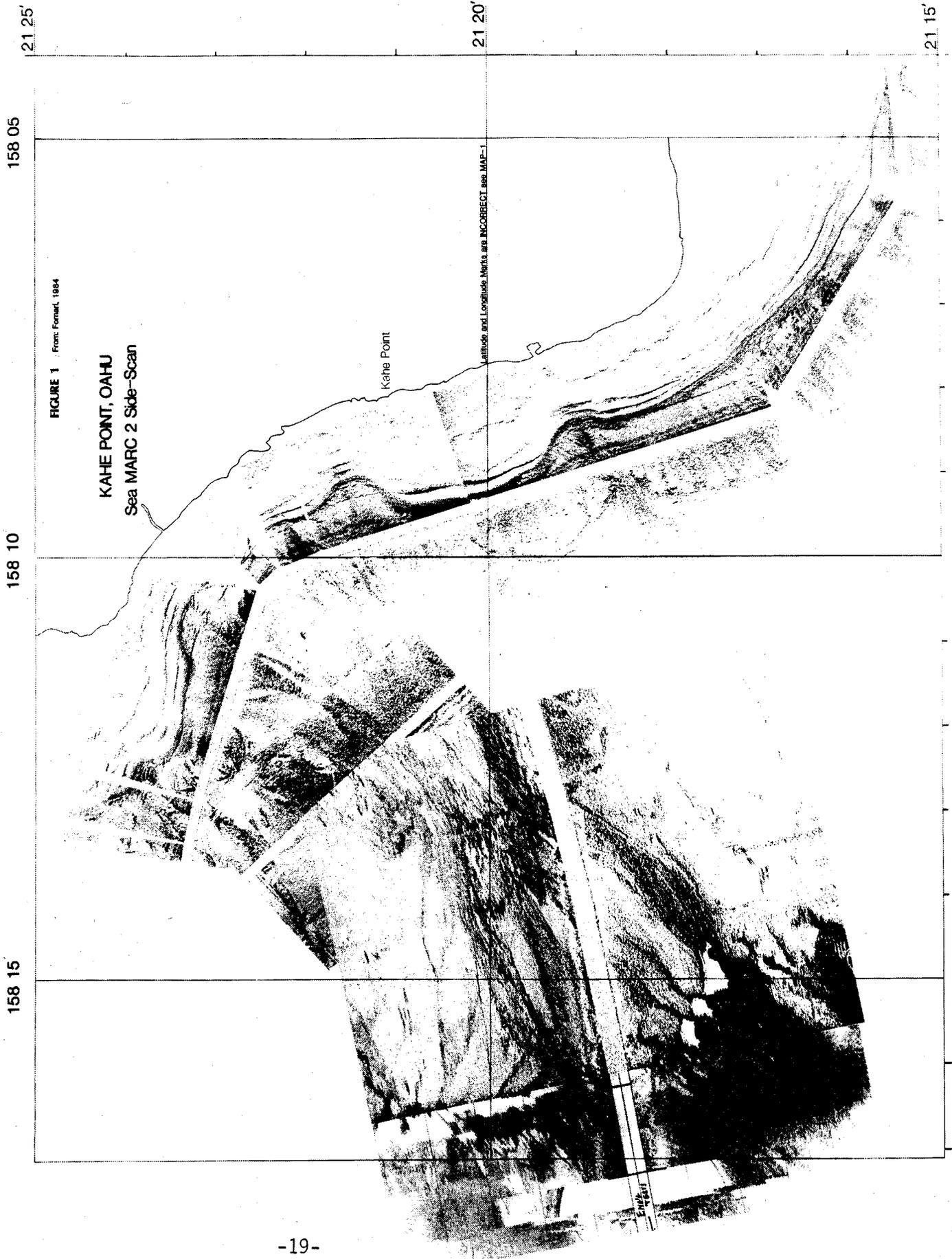


FIGURE 1 From Formel, 1984

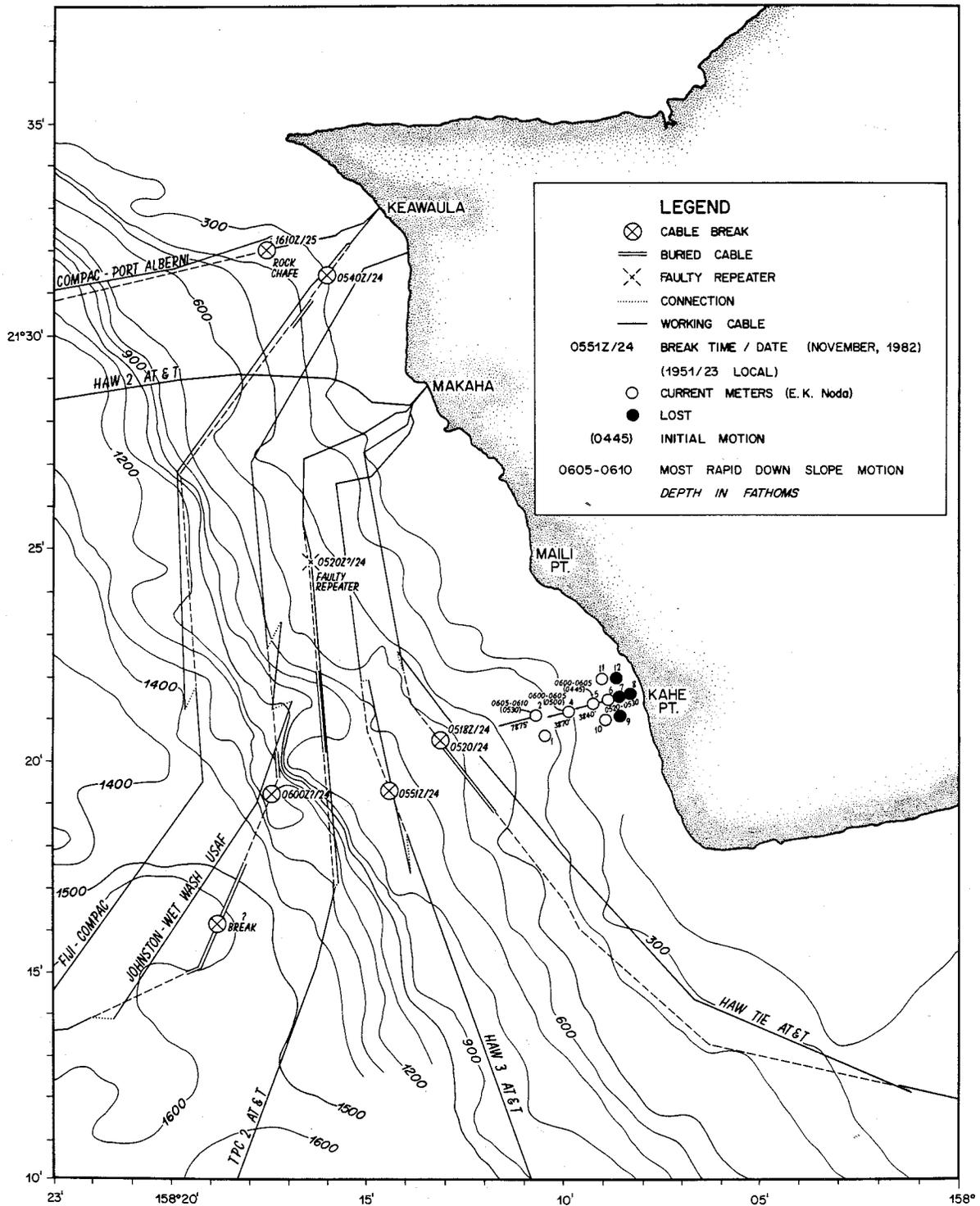
KAHE POINT, OAHU
Sea MARC 2 Side-Scan

Kahe Point

Latitude and Longitude Marks are INCORRECT see MAP-1

Fig. 1

Fig. 1A - Index Map Showing Cable Failures and Current Meters Referred to in Text



KAHE POINT, OAHU SeaMARC-2 PRELIMINARY

SCALE 1:18000

INTERPRETATIONS

- ACOUSTIC FACIES**
- N Non-reflective Seafloor
 - C Cobby, Reflective Seafloor
 - R Possible Rubble Streams, High-Reflective Seafloor
 - L Possible Landslide Lobes

- CABLE BREAK DATA**
- 0600Z Location of Cable Break and Time (GMT), 24 Nov. '82
 - - - Trace of Previous Cable Position
 - [] Estimated Length and Position of Buried (?) cable
 - Connection Between New and Old Cable (length of dotted line reflects navigational errors)

- TURTLE DIVES**
(from Fornari, 1983)

- CURRENT METER POSITIONS**
(arrow denotes extent and azimuth of displacement, from Noda, 1983)

- DEPTH IN FATHOMS**
Uncorrected

Lat. and Long. based on TURTLE Dive Nav. Data (see Fornari, 1983)

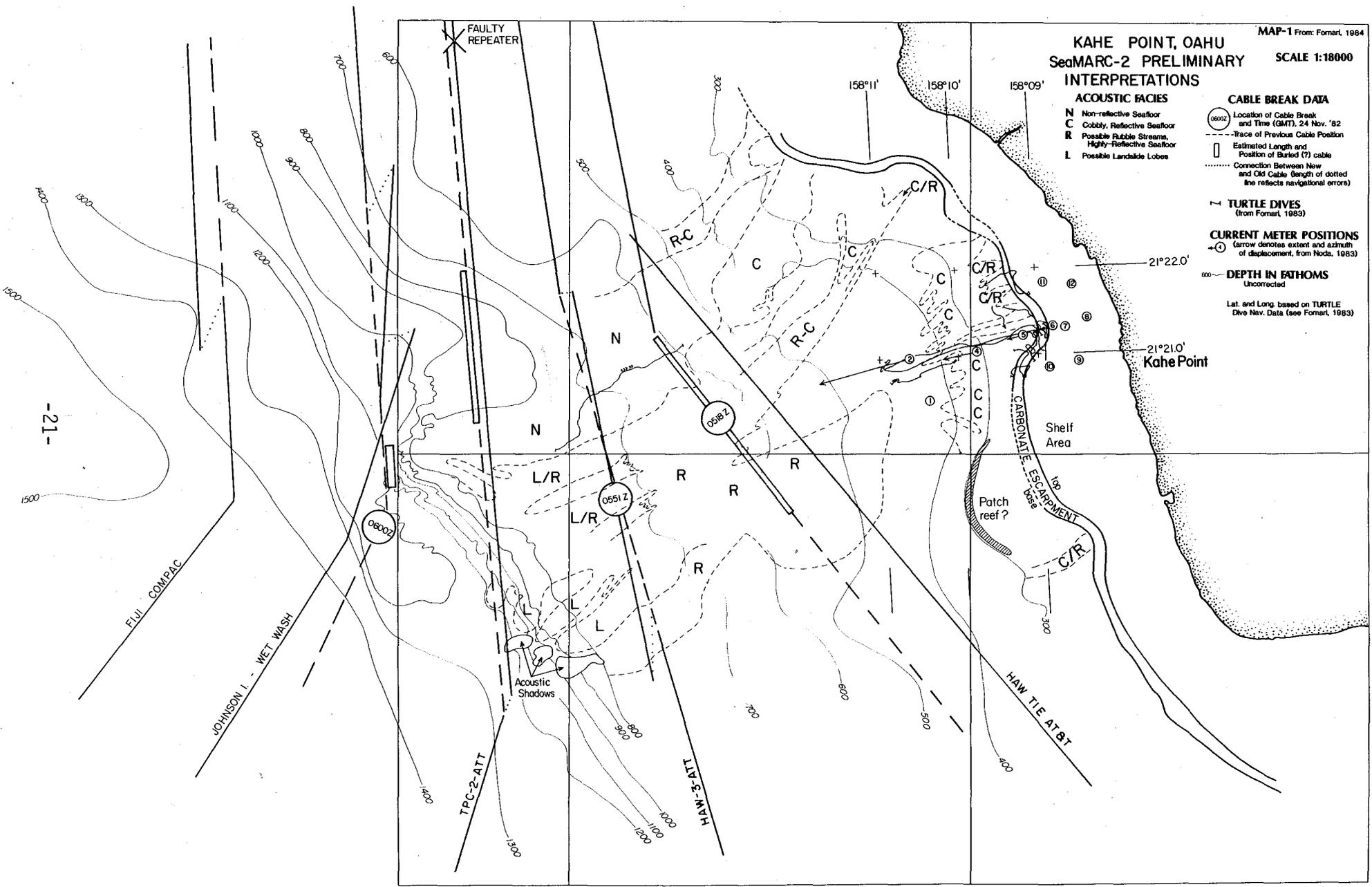


Figure Captions and Discussion of Figure 2 and Map 2

Covering Area just west of Kahe Point

Figure 2 is an enlarged section of the side-scan mosaic that covers the seafloor west of Kahe Point and is of primary interest with regards to the deployment of an OTEC cold-water pipeline. MAP 2 is the corresponding interpretative map for this record section. The pattern of the fan-shaped reflectivity zones shows a general funneling into the axis of the Kahe Point re-entrant.

The seafloor observed there (TURTLE, Fornari, 1983) is largely sediment-covered with only minor rippled bedforms and no indications of large cobbles or other seabed features that would render the terrain highly-reflective. In the northern part of Figure 2, there is another swath of terrain that appears to follow the axis of the bathymetric re-entrant. The location and character of these more reflective zones could indicate that the axes of the re-entrants act to channel tidal swashing thereby winnowing fine-sediments and leaving behind a gravelly lag deposit that is more reflective.

The trend and character of the carbonate escarpment is easily seen on Figure 2. The width of the escarpment terrain (plan-view map area) is relatively constant. At the southern end of the re-entrant, the width is about 150 m, in the middle it is approximately 200 m, and at the northern end it is only 100 m wide. The base and top of the escarpment are marked by abrupt changes in acoustic reflectivity. The trend of the escarpment top and base on Figure 2 are in excellent agreement with the discrete portions of the escarpment top and base which were mapped with TURTLE (Fornari, 1983).

Although there are problems with multiples on the shelf area, a tentative pick has been made for a terrace step which marks a brief low-stand of sealevel in the Quaternary. There is also a zone of slightly higher reflectivity along the base of the escarpment which, with the aid of TURTLE dive data, has been mapped in as the seafloor area covered by carbonate cobbles and large blocks (shaded area on Figure 2) (Fornari, 1983). During TURTLE diving, the base of the carbonate escarpment was found to merge with the shoreward limit of the boulder zone. The character of the side-scan record in this area supports this interpretation and suggests that it is indeed the case for much of the length of the escarpment in the Kahe re-entrant. Also the tapering of the boulder zone is apparent on the side-scan records and corroborates the findings of dive 423-20 which traversed a much narrower boulder zone than that observed by the dives further to the south (Fornari, 1983).

KAHE POINT, OAHU

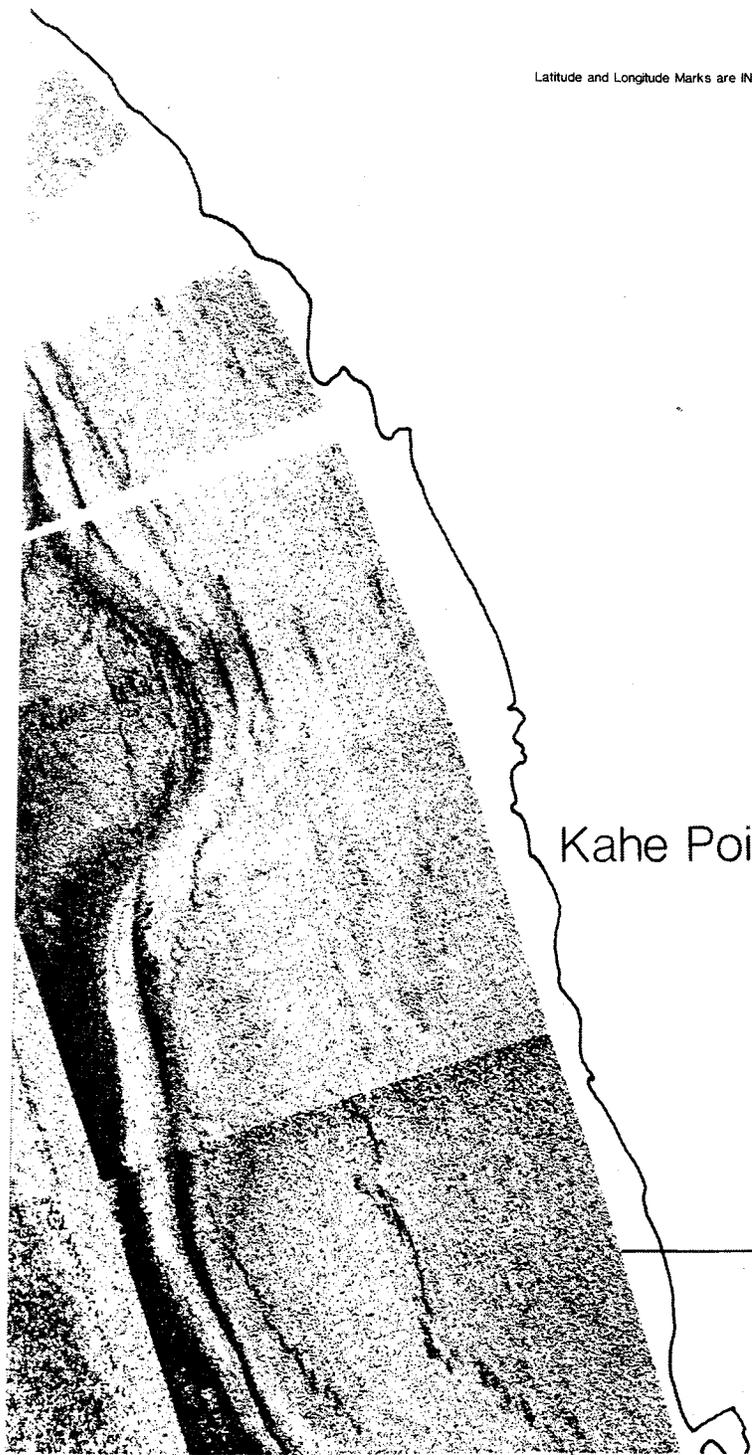
Sea MARC 2 Side-Scan

-21 24'



Right-Hand Sheet (1 of 2)
Join Along Edge, No Overlap

Latitude and Longitude Marks are INCORRECT see MAP-2



Kahe Point

21 20'

FIGURE 2 From: Fornari, 1984

Left-Hand Sheet (2 of 2)
Join Along Edge, No Overlap →



Latitude and Longitude Marks are INCORRECT
see MAP-2

MAP-2 From: Fornari, 1984

KAHE POINT, OAHU SEA MARC-2 PRELIMINARY INTERPRETATIONS
SCALE 1:7200

ACOUSTIC FACIES

R — possible rubble streams,
highly-reflective seafloor

C — cobbly, reflective seafloor

432-28 TURTLE Dive Track (from Fornari, 1983)

Lat. & Longs.
from 1983 TURTLE
dive compilation
(see Fornari, 1983)

21°22.0'N

Terrace step?

multiple

Shelf area

21°21.0'

Kahe Point

Coastline from
1/7200 SeaMARC-2
survey mosaic

gain change

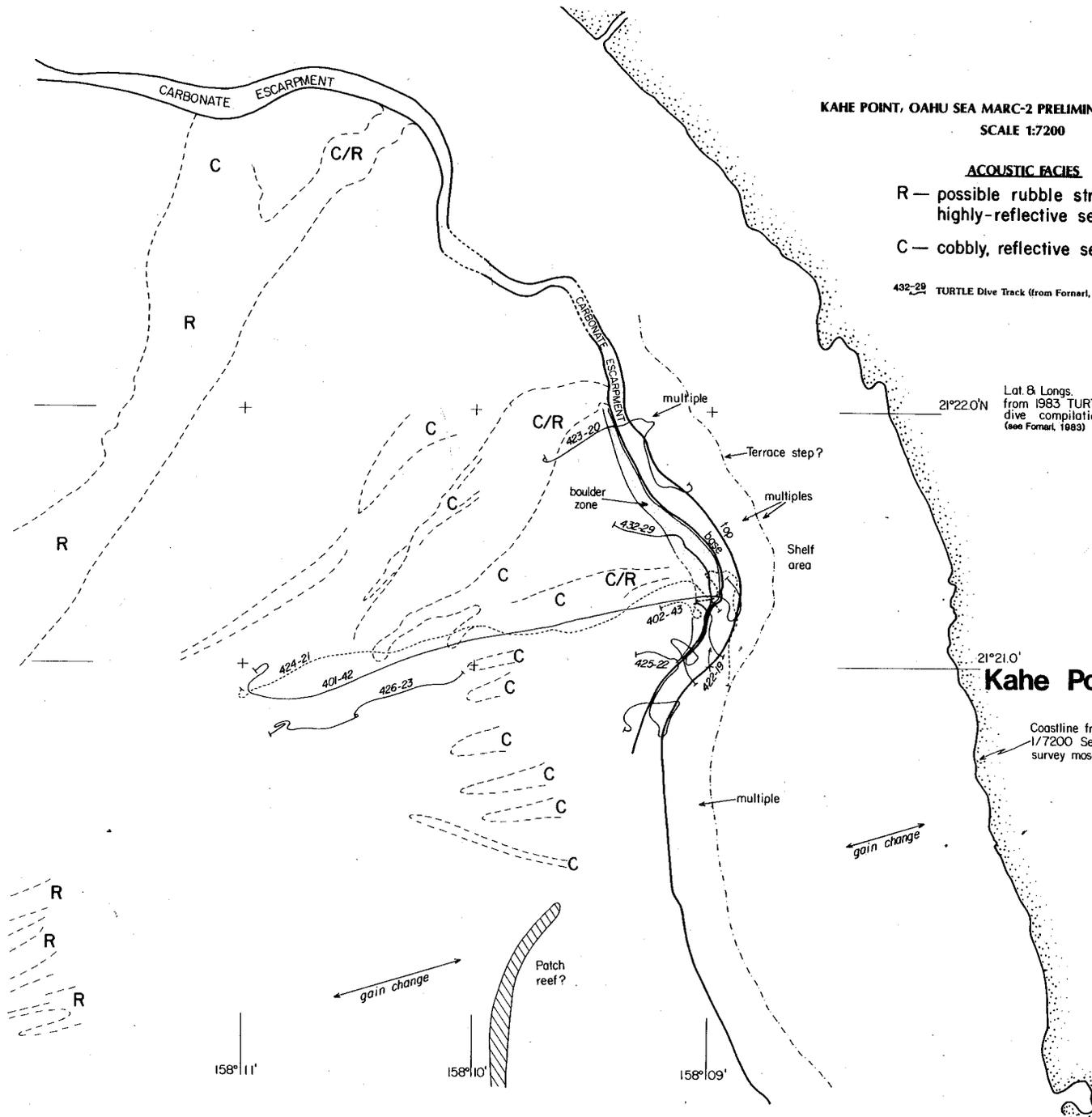
gain change

Patch reef?

158°11'

158°10'

158°09'



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REPORT DOCUMENTATION PAGE	1. REPORT NO. WHOI-84-31	2.	3. Recipient's Accession No.
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7. Author(s) Charles D. Hollister		8. Performing Organization Rept. No. WHOI-84-31	
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