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GEOLOGIC REPORT FOR THE O'OTEC SITE OFF KAHE POINT, OAHU, HAWAII

by

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The installation of an Ocean Thermal Energy Conversion (OTEC) plant requires knowledge of the morphology, structure, and sediment cover of the sea floor as input for the assessment of both engineering-design and environmental factors. Except for roving (grazing) plant ships, all types of proposed OTEC platforms have direct requirements for seafloor geologic data to safely design mooring, anchoring, cableway, and/or pipeline systems. In general, the necessary types of detailed bathymetric and geologic maps do not exist for most proposed OTEC sites.

The present study deals with the O'OTEC site off the western coast of Oahu (Fig. 1). The bathymetry and general marine geologic data of the southern Hawaiian Ridge was compiled by Wilde and others (1980) and provides a regional setting for the area. The site was selected because of accessibility to existing onshore power distribution systems at Kahe Point and because of generally favorable climatic and physical oceanographic conditions. The location and areal extent of this geologic study is similar to that of other site definition studies already in progress. The survey and data reduction were funded through Contract No. DE-AP-03-80-SF-11371 to the U.S. Geology Survey.

OPERATION

The field operations for the geologic survey of the submarine slope in the area off Kahe Point (Fig. 1) were completed during 26-30 January, 1981. The U.S. Geological Survey (U.S.G.S.) contracted with the University of Hawaii to use the R/V KANA KEOKI for the cruise. Seismic-reflection and bathymetric surveying utilized 12-kHz and 3.5-kHz profiling systems that are part of the KANA KEOKI's permanent geophysical gear as well as a mini-sparker profiling system provided by the U.S.G.S. In addition, the U.S.G.S. provided a Miniranger navigation system to obtain accurate positioning for the closely-spaced survey tracklines (Fig. 2). Ninety-three hours of underway profiling were completed between 0326/26 January and 0730/30 January. The operational details for the profiling and navigational systems are given in the next sections of this report. More details on the cruise schedule and participants were presented in a post-cruise report of 19 February, 1981.

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The high-resolution seismic-reflection records (Figs. 3 to 7) show that sediment covers the volcanic bedrock over much of the survey area. Near the end of the survey, therefore, we attempted 8 core stations (Fig. 2) using a 6 m barrel on a piston-core weightstand; the corer was used as a gravity corer. Four cores, at stations 1, 2, 6, and 8, are long enough to conduct geotechnical analyses. The results of the geotechnical work are presented in the companion open-file report (Winters and Lee, 1982).

Navigation

The Miniranger positioning system uses portable, radar-frequency transponders to provide range data to the ship from a set of land-based stations. For the O'OTEC survey, we put transponders at four sites to assure that ranges from at least two sites would geometrically be possible anywhere within the survey area. Ranges from two stations were monitored continuously, and a miniprocessor automatically determined ship's position for each set of ranges. The position information was relayed to an indicator on the bridge of the KANA KEOKI to aid in navigating the vessel along pre-selected tracklines. Fix data was recorded on magnetic tape once each minute long as two land stations provided range data.

The range data recorded on tape was reprocessed after the cruise to provide the trackline plot of Figure 2. Operational problems with the land-based transponders precluded one-minute fixes for the entire survey, but the position control for most of the tracklines is excellent with fixes every few minutes or more frequently. A smoothing routine has been applied to the raw position plot to remove the effects of spurious ranges. During the core stations, all possible pairings of the 4 transponders were interrogated to provide a check on position control.

Acoustic profiles

Throughout the survey at the O'OTEC site, the 12-kHz and 3.5-kHz acoustic profiling systems operated continuously. Both systems are part of the KANA KEOKI's permanent geophysical laboratory installations and include hull-mounted transducers. Records from both systems were displayed on EPC graphic recorders using a one-second sweep rate (i.e., the full width of the recording is approximately equivalent to 750 m assuming a sound velocity of 1500 m/sec). Neither acoustic system is a directional or narrow-beam unit; thus, the bathymetric profiles obtained are identical. The 3.5-kHz records are generally the clearest and most complete because of the stronger acoustic signal; therefore, these records were selected to construct the bathymetric map (Fig. 1), and the 12-kHz records were used only for periods when the 3.5-kHz unit was off for maintenance and changing paper.

The minisparker system provides a more powerful high-resolution reflection profiling capability that is designed to record subbottom structure in sediments that are coarser grained and/or thicker than can be adequately resolved with 3.5-kHz systems. The sound source is a 500 joule spark-discharge from a multipoint electrode towed behind the ship. The acoustic returns are detected with 10-m-long, 20-element hydrophone array also towed behind the ship. The signal was amplified using time-varied gain and filtered

(450 to 900 Hz bandpass) before being printed on an EPC recorder at a one-second sweep. The minisparker system was operated during all underway surveying but not during the coring stations.

The original rolls of seismic reflection records were copied on 35mm microfilm. The microfilm was then used to produce a transparent mylar-base print for making paper duplicates. These mylar prints have been spliced together to form Figures 3 to 7 of this report. The microfilm is available for direct copies as U.S. Geological Survey Open-File Report 82-468C (Normark and others, 1982). Figures 1, 2, and 3 present the 3.5-kHz reflection profiles, and Plates 4 and 5 present the minisparker profiles. The line number shown on each segment is in time sequence from the start of the cruise (see Fig. 2). The order of the profile segments is from north to south for the southwest-northeast trending lines and nearshore to offshore for the profiles trending subparallel to the coastline.

The reflection profiles are annotated on the hour and half hour with a solid time line ("event mark") crossing the record. In addition, each change of speed or direction of the vessel is noted with an event mark on the records; these event marks are annotated with time and nature of operational change. To locate specific features of interest on the reflection profiles, one determines the time by interpolation between time marks or event marks; this time (in hours, minutes, Julian day) can then be matched with times shown on the trackline chart (Fig. 2).

RESULTS

Bathymetry

The detailed bathymetric map in Figure 1 is based on the 3.5-kHz and 12-kHz acoustic profiles, which were obtained continuously throughout the entire 5-day survey. The time and depth, which was expressed in units of seconds of round-trip travel time, were recorded for each inflection point along the bathymetric profiles. The depth data, in seconds, were converted to corrected meters using sound velocity values given in Matthews Tables for area 42 (Matthews, 1939). The depth values were then merged with the corrected and smoothed position data, and a plot was generated by computer that presented all 20-m interval contour crossings encountered along each digitized bathymetric profile. We generated the final bathymetric map by hand extrapolation between the points on the contour-crossing plots. Discrepancies in depth at track crossovers were not common, and in most cases were minor, thus easily permitting a 20-m contour interval.

The greatest discrepancies occurred in deeper water (generally in depths greater than 1200 m) where the problems with hyperbolic (or "side") echoes is most severe because the bathymetric data was generated from standard wide-beam acoustic systems.

The bathymetric map (Fig. 1) of the O'OTEC site shows a narrow "shelf" separated by a relatively steep, narrow upper slope region from a 10-km-wide more gently sloping plateau between water depths of 400 and 1600 m. Deeper than 1600 m, the sea floor is steep and continuous to depths greater than 2700 m, which is the seaward limit of our survey. The area deeper than 1600 m is referred to as the lower slope. The steep relief that is common at both the upper and lower margins of the plateau is clearly illustrated in the slope gradient map (Fig. 8). The methods of construction and applications of this map are given in the next section.

Along the northern portion of the survey area, the plateau narrows and the overall slope becomes more uniform (Figs. 1 and 8). Several small submarine canyons (or, more properly, gullies) have incised the sea floor from the inner to the outer part of the plateau. The most striking morphologic feature in the area, however, is the apparent slump feature that is delimited by a roughly rectangular re-entrant in the upper slope and upper plateau contours in the area between Kahe and Maili Points. The slump scar is observed between the shelf and the 1100 m contour. The slight bulge in the contours below 1100 m suggests that some of the slumped material has come to rest on, or has formed, the outer part of the plateau. Submarine slumps similar to this feature have been documented offshore of several other Hawaiian Islands (Moore, 1964; Normark and others, 1979). This slump feature involves the volcanic bedrock of the island and is not a surficial sedimentary feature. The distribution of sediment on the plateau and adjacent slopes does not show a simple relation to either the location of the bedrock slump or to the general morphologic features.

Slope Map

The slope map (Fig. 8) depicts declivity of the sea floor, contoured in percent (change in elevation per 100 units horizontal distance). Contour interval is 10 percent; the 1 and 5 percent contours are also included. A conversion diagram that shows equivalent angular values of percent and degrees accompanies the map.

The slope map was derived from the bathymetric map (Fig. 1) with the aid of computer graphics techniques. The bathymetry was digitized along 10-meter incremental depth contours with a Tektronix Graphics Computer Terminal and Digitablet. The scattered bathymetric data were transformed into an ordered, rectilinear grid matrix using the Surface Gridding Library subroutine package (Dynamic Graphic's, Inc.), which employs global fitting techniques to generate the grid. The spacing of grid points was 0.1 inch on the map, or about 100 meters geographically.

The depths of each grid point and its 8 surrounding neighbors were used to calculate the gradient of depth in two geographic directions. The average of these two depth gradients was used to compute the sea-floor slope at that point. The Surface Display Library (Dynamic Graphics, Inc.) was then used to calculate and plot contours of sea-floor slope. The computer-generated contour map was hand-smoothed to eliminate biased and ambiguous contours.

Sediments

An extensive sedimentary cover was not expected in the O'OTEC site area although we did envision local patches of sediment in areas protected from strong bottom currents. The minisparker system was selected as a backup in the event that we encountered areas covered with sand or coarser sediment that would not be recognized from bedrock on 3.5-kHz acoustic reflection profiles. As it turned out, both the 3.5-kHz and minisparker systems show that much of the plateau and upper slope is covered by sediments. The subbottom-reflector character and maximum thicknesses observed on the two systems are quite similar. Thus, we are able to present a summary of the sediment distribution in the O'OTEC area using the acoustic characters from the profiling systems (Figs. 9 and 10).

A limited number (< 10) of sample stations was planned to characterize any sediment cover that might be found but not to attempt detailed mapping of sediment type by direct sampling. All of the successful core stations recovered biogenic sediment fairly uniform in character; in marine geologic terms, the sediment is termed calcareous ooze with only minor amounts of siliceous biogenic and terrigenous material (Shepard, 1973, p. 407). All samples are almost entirely biogenic material. Descriptions of the sediment samples, including index properties and the results of geotechnical testing, are presented in detail in Part B of this report (Winters and Lee, 1982).

Both the 3.5-kHz and minisparker profiles were classified on the basis of surface morphology and internal structure, which is assumed to be given by the acoustic subbottom reflectors. Figure 9 shows the raw results of this classification without smoothing. We recognize four general types of sediment cover: (1) generally smooth seafloor with distinct planar reflectors (see Figure 4, Line 43 around time line 0030; (2) hummocky or smoothly rolling seafloor with distinct subbottom reflectors that may be planar or locally mimic the wavey profile of the seafloor (see Figure 4, Line 37 between 1100 and 1130; (3) sharply hummocky or irregular seafloor with discontinuous and locally indistinct subbottom reflectors; in places, the character appears chaotic (see Figure 4, Line 10 around 0630; and, (4) generally smooth seafloor but with no distinct subbottom reflectors (see Figure 3, Line 21 around 0400; this type is structureless on the acoustic profiles and is commonly referred to as acoustically transparent in marine geologic literature. The acoustically structureless sediments are generally thin where seen on the upper slope and appear thick on the deeper (>1500 m) slopes where side echoes make it difficult to distinguish real subbottom reflectors from artifacts. Thus, we recognize that the structureless sediment may well be laterally equivalent to thicker, or better resolved, bedded sediments. Locally, two different sediment types are seen together in the profiles. We depict this in Figure 9 by using both patterns along the trackline; the pattern on the northerly (or righthhand) side of a trackline indicates the uppermost unit.

Figure 9 clearly shows discrepancies at some track crossovers. Such discrepancies serve to emphasize the limitations on the seismic profiling technique for mapping sediment type. The ability to resolve subbottom reflectors, especially the depth to which subbottom reflectors can be detected, is a function of transmit power, signal amplification level, pulse (or signal) length, speed of ship (i.e., shot spacing), sea conditions (i.e., noise levels at the hydrophone), and shape of the seafloor. Thus, slight changes in tuning may cause marked changes in record quality; during the O'OTEC survey the systems were still being tuned for optimum results during the first quarter of the survey. Therefore, subbottom character may appear different where later survey lines cross those early in the survey. In some cases, sediments that appear smooth and with planar subbottom reflectors may appear much less smooth or planar in a profile crossing perpendicularly. In addition, the total thickness of sediment has not been plotted because the deepest reflector observed over much of the area is smooth and flat, and thus, could be another sedimentary horizon.

The interpretation of the acoustic reflection data is difficult, and the lack of any marked differences in sediment type at the core sites (see Part B of this report, Winters and Lee, 1982) suggests caution is advisable. Nevertheless, based on interpretation of similar acoustic reflection characteristics in sediments along continental margins (see Damuth, 1980, for a full discussion), we make the following distinctions: (1) sediment with either planar or wavey reflectors is probably bedded sediment with the primary depositional features intact; the wavey-bedded sediments are probably formed as migrating sediment waves indicating stronger bottom currents locally; (2) sediment with discontinous reflectors and irregular sea floor may be indicative of material that has undergone mass movement, sliding or slumping, thus disrupting primary bedding; (3) acoustically structureless (or transparent) sediment gives no direct evidence of depositional processes. On continental margins, this transparent acoustic character is commonly attributed to hemi-plagic sedimentation processes, i.e. particle by particle fallout from suspension (Damuth, 1980).

The generalized sediment distribution map (Fig. 10) shows the distribution of the three basic sediment types described above. Acoustically transparent sediment is commonly found on the steeper slopes, but much of the steeper terrain is devoid of sediment on the acoustic-reflection records. Bedded sediments are generally restricted to the plateau area. Three main areas on the plateau are underlain by sediment redeposited by mass movement processes that roughly corresponds to the areas of "gullied" terrain. In general, areas of disturbed and bedded sediment are closely associated and no simple distribution pattern is evident. Most of the disturbed sediment was initially bedded material. The center of the major bedrock slump feature is appreciably free of sediment cover.

We have no age control on the sediment. If the irregular, discontinuous reflectors indicate past instability (sliding) of the sediment, we cannot estimate how long ago such movement occurred.

CONCLUSIONS

The O'OTEC geologic survey provides the following points of information concerning development of the OTEC facilities off Kahe Point: (1) The 1000 m isobath lies in the landward half of a gently sloping (10 to 20% grade; Fig. 8) plateau that is generally sediment covered. The plateau extends as much as 15 km from the coast to a water depth of 1600 m. Although the plateau sediment cover locally displays a morphology and internal structure indicative of submarine sliding, or other types of mass movement, we do not know the age of movement or extent of internal disruption. Thus, the geotechnical studies (part B of this report, Winters and Lee, 1982) on the sediments we recovered provide the only direct evaluation of the engineering properties of this sediment cover. (2) The more gently sloping plateau is separated from the "shelf" and coastal area by a steeper (30 to 90% grade; Fig 8) narrow slope that appears relatively free of sediment cover resolvable by acoustic profiling south of Maili Point. (3) The distribution of sediment type (Fig. 10) as mapped with the acoustic-reflection profiles does not show a simple relation to volcanic bedrock relief. The bathymetry basically reflects the volcanic surface because the resolvable sediment cover is generally less than 35 m.

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