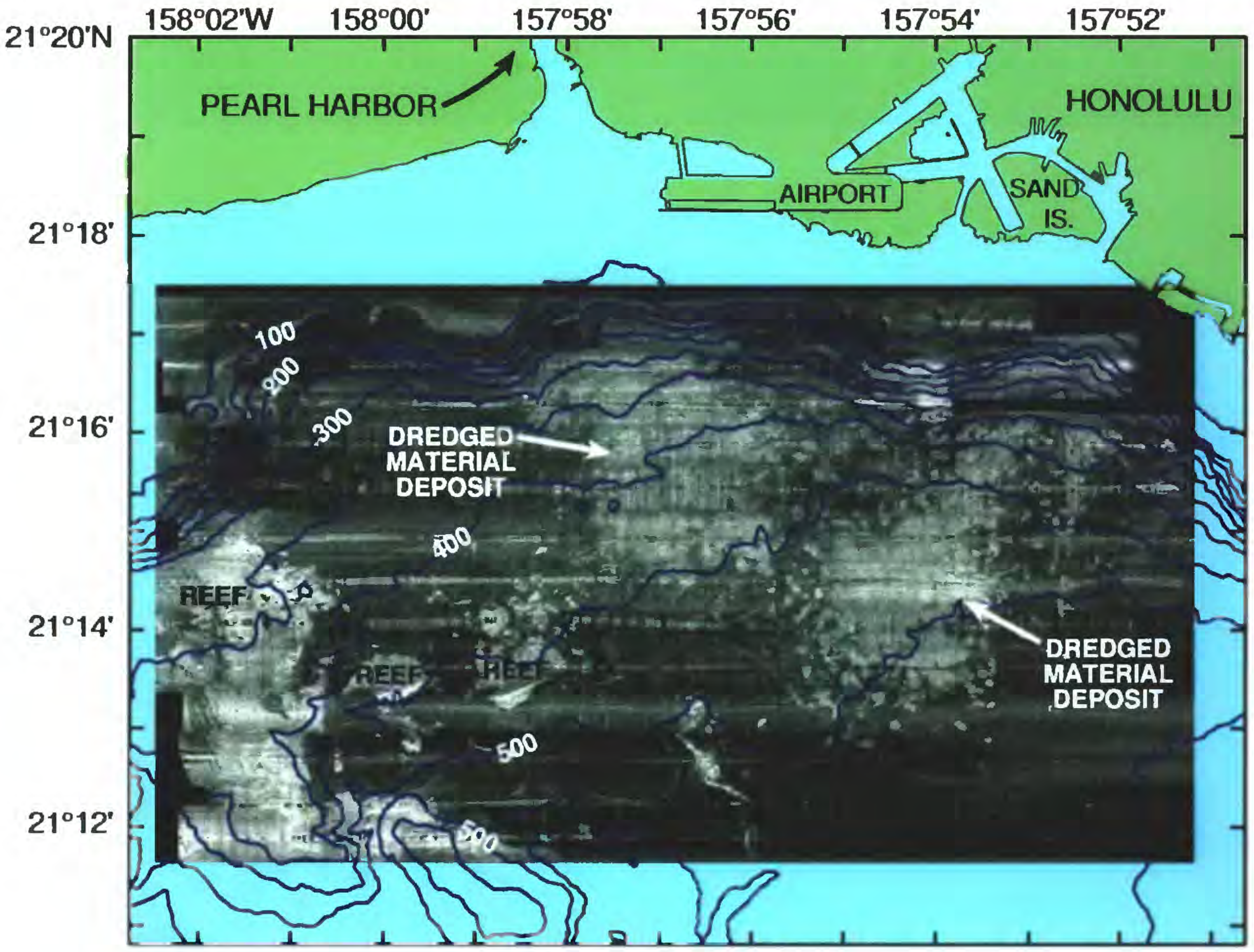
Department of the Interior
U.S. Geological Survey

FINAL REPORT: ACOUSTIC MAPPING OF DREDGED MATERIAL DISPOSAL SITES AND DEPOSITS IN MAMALA BAY, HONOLULU, HAWAII



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Open-File Report 95-17

[1] All at U.S. Geological Survey, MS 999, Menlo Park, CA 94025

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SUMMARY

Disposal sites for dredged material from Pearl and Honolulu Harbors are located in Mamala Bay off the south coast of Oahu, adjacent to the city of Honolulu, Hawaii. The disposal sites are situated the north–central reaches of a broad, gently sloping trough that slopes to the southeast. Water depths in and around the sites range from 300 to 600 m, with the South Oahu site (the active site) having a mean water depth of 450 m. The trough is bounded on the west by submerged reefs and banks, and on the east by a scarp that separates the trough from the narrow shelf that hugs the south Oahu coast from Diamond Head to Barbers Point. Studies that include bottom sampling and seafloor photography (Chave and Miller 1977a, 1977b, 1978a, 1978b; Neighbor Island Consultants, 1977; Tertra Tech, 1977; Goeggel, 1978; U. S. Environmental Protection Agency, 1980; Torresan and others, 1994b), show that the native seafloor sediment is primarily muddy carbonate sand, with areas of coraline and limestone rubble. Bedforms ranging from ripples to sand waves are common throughout the area (including the disposal sites), and imply active sediment transport.

The U.S. Geological Survey conducted an acoustical survey using 3.5 kHz and chirp sonar subbottom profilers and sidescan sonar to determine the character of the seafloor and near–surface substrate, and to delimit the extent and potential transport pathways of dredge materials and associated contaminants. These data were used to plan subsequent sampling strategies (carried out in May 1994), that were designed to assess both the geological and environmental impacts of dredge material disposal in Mamala Bay.

Sidescan sonar images show that the dredged material leaves a distinct imprint (acoustic signature) on the seafloor. Dredged material forms two major deposits that affect an area of about 100 km^2, and they are characterized by high–backscatter, circular to subcircular footprints 25–150 m across. The footprints are widely spaced at the extremities of the disposal sites but coalesce to form a high–backscatter blanket over the disposal sites. The high–backscatter blanket covers most of the natural, low–backscatter sediment that mantles the seafloor. Associated with some footprints are lower–backscatter aprons that are interpreted to be the finer–grained components of individual dredged material deposits. These aprons likely settled after the main body of a particular material dump settled. Close examination of plate 1 shows that bedforms are also visible on the dredged material deposits.

High–resolution subbottom profiles show that a subtle undulating seafloor topography characterizes most of the deposits. Pronounced mounding is visible in the southeast edge of the high–backscatter, former Honolulu Harbor disposal site, and the mounds extend east nearly 2 km from the dredged material deposit and into the low–backscatter seafloor that is unaffected by dredged material disposal. The mounds are up to 1 m high with apexes spaced up to 150 m along ship's track, and, owing to their presence primarily outside of the disposal site and in the low–

backscatter seafloor, the mounds are interpreted to result from natural rather than anthropogenic processes. Some mounds on the profiles correlate with the high–backscatter footprints seen on the sonar imagery, but most probably are natural rather than anthropogenic.

Surficial sediment thickness is indeterminable over most of the area affected by dredged material disposal. Subbottom profiles collected over the disposal sites are characterized by lateral discontinuities in seafloor reflectivity and hardness. Subbottom reflectors are not present below the seafloor reflector, and the dredged materials are opaque in subbottom profiles. Because the dredged material has an acoustic signature that differs from the native seafloor sediment (dredged materials are primarily mud and coarse carbonate rubble), the dredged materials likely scatter or absorb the 3.5–kHz signal resulting in the structureless subbottom profiles. In contrast, subbottom profiles collected from areas unaffected by dredged material disposal are characterized by a seafloor reflector that has no lateral discontinuities in reflectivity, and has a distinct subbottom reflector or hyperbolic diffractions. Closely–spaced diffractions seen on the 3.5–kHz profiles are common in the area west of the South Oahu disposal site and are associated with bedforms, and/or carbonate debris and rubble visible on seafloor photographs. Subbottom profiles collected south and east of the dredged material deposits are characterized by a smooth, continuous seafloor reflector having one or more subbottom reflectors.

In summary, dredged material disposal off of Honolulu Hawaii has created deposits that have a distinct acoustic signature on the sidescan sonar images and a more subtle signature on the seismic reflection profiles. The combination of subtle mounding, the coarse rubble contained in harbor dredged material, and the acoustic impedance difference between the dredged material and the underlying native sediment is likely responsible for the high–backscatter footprints seen in the sidescan sonar mosaic and the structureless 3.5 kHz subbottom profiles. Additional studies are required to define the biological and physical benthic processes, and the roles of the substrate and the ecosystem in the transfer and storage of dredged material–related contaminants in Mamala Bay.

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INTRODUCTION

Estuaries and continental shelves adjacent to metropolitan centers are a focus of increasing public concern owing to contamination from dredged material, pesticides, waste water, and other forms of pollution. Geological studies of a locally impacted marine environment can provide key information on the distribution, transport, and long–term fate of contaminants, because contaminants often accumulate with fine–grained sedimentary particles (Bothner, 1981; Anderson and others, 1988). Geological studies of the seafloor off major population centers allow investigators to understand the effects of anthropogenic stress on the environmental quality and biological health and productivity of these critical nearshore areas, thereby enabling marine policy makers to formulate sound decisions as to the use of the urban ocean (Bothner, 1981; Anderson and others, 1988; Butman and others, 1989; Karl, 1992; Karl and others, 1992; Schwab and Rodriguez, 1992; Hostettler and others, 1993; Hurst, 1993; Parmenter and Bothner, 1993; Shea and Kelley, 1993; Anderson, 1994; Bothner and others, 1994). Specifically, acoustic mapping of the seafloor is a proven geological technique for mapping and assessing the distribution of anthropogenic inputs, including dredged material and hazardous waste disposal in urban ocean settings (Carey and Fredette, 1993; Murray and others, 1993; Schwab and Rodriguez, 1993; Torresan and others, 1993a 1993b; Karl and others, 1994; Chavez and Karl, in press).

Mamala Bay is the embayment located between Diamond Head on the east and Barbers Point on the west, along the south coast of Oahu, and is adjacent to the city of Honolulu, Hawaii (figures 1–6). The geological characteristics of the seafloor and near–surface substrate play a fundamental role in determining the exposure of fauna in Mamala Bay to pollution and other forms of anthropogenic stress. Dredged material disposal, run off, and waste water outfalls can disperse contaminants in Mamala Bay, and many of these contaminants can adhere to fine sedimentary particles that concentrate in depositional sites (Bothner, 1981). The infaunal and epifaunal communities can then be exposed to the contaminants, and since the benthic communities are near the base of the food chain they can transfer a pathogenic load to indigenous aquatic species (Long and Morgan, 1990; Roesijadi and others, 1992).

The Hawaiian Islands have five offshore disposal sites that receive dredged material; Port Allen and Nawiliwili off of southern Kauai, South Oahu offshore of Honolulu, Kahului off of northeast Maui, and Hilo off the southeast coast of Hawaii (figure 1). All Hawaiian deep–draft harbors are dredged in 5– to 10–year maintenance cycles, or on an as-needed basis, and factors including high runoff may necessitate changes in dredging frequency. With respect to the Mamala Bay dredging disposal schedules, Pearl Harbor locations are dredged on an as-needed basis, while Honolulu Harbor is dredged at five-year intervals.

Figure 2 shows the location of three major disposal sites in Mamala Bay (the former Pearl Harbor site, the former Honolulu Harbor site, the active South Oahu site), two U.S. Army Corps of Engineers study sites used as part of the process for designating the South Oahu site in 1980 (U.S. Environmental Protection Agency, 1980) and the 1972 disposal site. The South Oahu disposal site, located offshore of Honolulu, Hawaii, in Mamala Bay (figure 2), receives the most dredged material and currently serves Pearl, Honolulu, and Barbers Point Harbors. From 1959 through 1978 disposal sites in Mamala Bay received about 5.3 million m^3 of dredged materials from both Pearl and Honolulu Harbors (U.S. Environmental Protection Agency, 1980, table 3–4). Of that total, Pearl Harbor accounts for about 87% (4.7 million m^3) while Honolulu Harbor generated the remaining 13% (0.6 million m^3) of the dredged material (Goeggel, 1978; EPA, 1980, table 3-14). In comparison to all Hawaiian Island disposal sites, the South Oahu site receives the overwhelming majority of dredged material, and may approach 90%. For example, in the 1977–1978 dredging cycle each Hawaiian harbor was dredged, and all five Hawaiian disposal sites were used. Of the total amount of dredged material disposed of in 1977–1978 (about 2.1 million m^3), 71% (1.47 million m^3) originated from Pearl Harbor, and 17% (0.35 million m^3) was dredged from Honolulu Harbor, totaling 88% (Tetra Tech, 1977; Goeggel, 1978; U.S. Environmental Protection Agency, 1980). The remaining 12% (0.26 million m^3) of dredged material was disposed of at the four other sites combined (Goeggel. 1978; U.S. Environmental Protection Agency, 1980, table 3–14 and figure 3–5).

In February 1993, the U.S. Geological Survey (USGS) conducted an acoustical survey in Mamala Bay for the U.S. Army Corps of Engineers (COE) and the U.S. Environmental Protection Agency (EPA), to determine the character of the seafloor and near–surface substrate, and to delimit the extent and potential transport pathways of dredged material and any associated contaminants (Torresan and others, 1994a). Trackline coverage for the survey is shown in figures 3 and 4. Tables located in Appendix 1 list the locations of each disposal site, the waste water outfalls, and the start and end coordinates for each trackline run for the 1993 survey. Data collected from the survey was used to plan strategies for a sediment sampling cruise (conducted May 9–23, 1994; Torresan and others, 1994b), with the goal of assessing both geological and environmental impacts to Mamala Bay resulting from dredged material disposal.

STUDY AREA

Mamala Bay is the embayment situated between Diamond Head on the east and Barbers Point on the west, along the south coast of the island of Oahu, Hawaii (figures 1–6 and plate 1). The disposal sites are located in the north portion of Mamala Bay, about 5 km south of Honolulu International Airport, in the north–central reaches of a broad, gently sloping trough that slopes to the southeast (figure 5 and plate 1). The trough is bounded on the west by submerged reefs and banks, and on the east by an escarpment that defines the seaward edge of the narrow and shallow (< 50 m) shelf that hugs the south Oahu coast (figures 5, 6 and plate 1). The bay is floored primarily by carbonate sand, and water depths at the sites range from 300 m to nearly 600 m, with the South Oahu disposal site having a mean water depth of about 450 m (figure 5 and plate 1).

PREVIOUS STUDIES

South Oahu disposal site designation studies were conducted during 1977 and 1978 for the COE and EPA. The primary purpose of the 1977–1978 studies was to collect field and laboratory data to define the baseline environmental conditions, with the aim of documenting the environmental impact of the ocean disposal of harbor dredged material in Mamala Bay (Chave and Miller 1977a, 1977b, 1978a, 1978b, Neighbor Island Consultants, 1977; Tetra Tech, 1977; Goeggel, 1978). The studies were conducted in three phases: (Phase 1) Pre–disposal studies, (Phase 2) Disposal studies, and (Phase 3) Post–disposal studies. The three topics examined were the biological effects to the benthic and demersal communities, the geological effects on the existing bottom sediment regimes, and the effect on water quality. The results are summarized in a 1980 Environmental Impact Statement (EIS) prepared by the EPA (U.S. Environmental Protection Agency, 1980). These site designations studies led the investigators and the EPA to conclude that there was no evidence to suggest that dredged material disposal would have adverse or deleterious effects on the environment of Mamala Bay, and that the South Oahu disposal site is a suitable harbor dredged material disposal site (U.S. Environmental Protection Agency, 1980).

OCEANOGRAPHY

Understanding oceanic circulation patterns in Mamala Bay is an important link to understanding the ultimate fate of any associated contaminants. There is a paucity of data and current measurements in Mamala Bay, but studies currently underway by the Mamala Bay Study Commission will correct this. Studies by Bathen (1974), Chave and Miller (1977a, 1977b, 1978a, 1978b), Neighbor Island Consultants (1977), and Tetra Tech (1977) during the 1977–1978 dredging cycle led investigators to conclude that the general ocean circulation in Mamala Bay is to the southwest, and in the vicinity of the South Oahu disposal site water movement is both tidally and seasonally controlled (Chave and Miller. 1977a, 1977b, 1978a, 1978b; Neighbor Island Consultants, 1977; Tetra Tech 1977; U.S. Environmental Protection Agency, 1980). Some investigators believe that subsurface currents at the Mamala Bay disposal sites may also be driven by tidally induced internal waves along the thermocline (Chave and Miller, 1977a, 1977b, 1978a).

Defining the ultimate fate of the silt and clay size particles contained in the dredged material will aid in determining the fate of associated contaminants. The dredging process loses an undetermined amount of silt– and clay–size material with excess water decanted from the dredge hopper prior to disposal, while another portion is dispersed in the water column at the time of disposal (Tetra Tech, 1977; U.S. Environmental Protection Agency, 1980). Shipboard observations indicate that while a large but unknown amount of silt and clay is lost during the dredging process, a major amount of fines are retained and disposed of at the site (Tetra Tech, 1977; U.S. Environmental Protection Agency, 1980). The 1977–1978 studies observed that an unknown amount of fines disperse from the disposal site in the form of a plume that moves to the southwest immediately following disposal. It is important to understand the local circulation patterns in order to quantify the amount of material contained in the dispersing plume, and to define its final resting site, because the finer components of the dredged material are most likely to contain the highest proportion of contaminants.

SEAFLOOR SEDIMENT AND DREDGED MATERIALS

Some of the seafloor of Mamala Bay has bedforms visible on the sonar mosaic (figure 4 and plate 1). Bedforms also appear on bottom photographs collected during the site designation studies (Chave and Miller 1977a, 1977b, 1978a; Neighbor Island Consultants, 1977; Tertra Tech, 1977; Goeggel; U.S. Environmental Protection Agency, 1980). The variety of bedforms common throughout the study area document active sediment movement, with the implied potential for the redistribution of dredged material beyond the original disposal site. Therefore, in addition to understanding local and regional ocean circulation patterns, it is critical that any study evaluate the nature and characteristics dredged materials at their source (the harbors) and at the disposal sites.

Environmental studies conducted to date show that the native seafloor sediment is primarily a muddy carbonate sand, with areas of outcrop, and carbonate rubble that includes shell, coral and limestone (Chave and Miller, 1977a, 1977b, 1978a, 1978b; Tetra Tech, 1977; and U.S. Environmental Protection Agency, 1980). Sediment sampling and bottom photography conducted during each phase of the 1977–1978 studies show that there is considerable variation in the composition of the seafloor in and around the disposal sites. Surficial sediment varies from primarily sand to sediment with substantial carbonate rubble (shell, coral and limestone), and the native seafloor sediment consists primarily of carbonate and basalt fragments that constitute about 90% and 10% of the sediment, respectively (Chave and Miller, 1977a, 1977b, 1978a; Neighbor Island Consultants, 1977; Tetra Tech, 1977; Goeggel, 1978; U.S. Environmental Protection Agency, 1980). The 1977–1978 site designation studies show that grain size distributions of sediment collected from the disposal sites during each phase of the study vary considerably from sample to sample, and range from sandy gravel to muddy sand. For example, Tetra Tech (1977) reports that pre–disposal sediment (Phase I) is poorly sorted, averaging 85% sand and 15% mud (silt and clay). Similarly, dredged material (Phase II) is also poorly sorted, but is substantially coarser, containing 49.3% pebbles, 13.8% granules and 36.9% sand (Tetra Tech, 1977). Tetra Tech (1977) reported that the grain size distributions of sediment collected after a disposal action varied considerably from sample to sample, and post–disposal (Phase III) studies samples lack mud, are poorly sorted, and vary from predominantly sand (about 80%) to predominantly gravel (about 75%).

Bottom photography conducted during the 1977–1978 dredging cycle also shows that anthropogenic debris litters the seafloor of Mamala Bay (Chave and Miller, 1977a, 1977b. 1978a, and 1978b; Tetra Tech 1977). Video and still photography collected during a USGS survey conducted in May 1994 (Torresan and others, 1994b) documents the debris to include military ordnance, barrels, a variety of canisters, tires, and lengths of wire rope.

THE K1-93-HW ACOUSTIC SURVEY

METHODS

Throughout the remainder of this report shipboard operations from the 1993 USGS survey are reported in Julian Day and Greenwich Mean Time (JD/GMT). In some cases local time and date are also shown. The geophysical and navigational instrumentation and methods are explained in greater detail in Appendix 2.

SCOPE OF WORK

The original scope of work presented by the USGS, Branch of Pacific Marine Geology (PMG) to the COE and EPA stated that the principal objective and primary products of the acoustic survey are maps of the seafloor, including a sidescan sonar mosaic and bathymetric map. These goals were achieved; primary products include a detailed bathymetric map (Chase and others, 1994), and a sidescan sonar mosaic of the Mamala Bay seafloor that delimits the general extent of the acoustically–resolvable dredged material deposits (figures 5, 6, and plate 1). There are no major acoustic data gaps, and there now exists a firm foundation and basis for further studies. Also included as a product is a characterization of the seafloor substrate in and adjacent to the disposal sites, interpreted from 3.5 kHz high–resolution subbottom profiles.

NAVIGATION

Navigation is a critical element of any acoustic marine survey because the location of specific seafloor features imaged or profiled must be accurately known so that identical features on adjacent sidescan swaths coincide, and other data sets can be registered to the sonographic mosaic. Also, it is often necessary to reoccupy specific sites for sampling purposes.

The Global Positioning System (GPS) was used to navigate the ship during the survey, and provided nearly 24 hours per day coverage. When GPS was not in service, LORAN–C or transit satellites were used for positioning. Steering of the ship was aided by a trackline–following display on monitors located on the bridge and at the navigation station in the geophysics lab (Gann, 1992; Appendix 2). Nominal accuracy of the GPS system used is 100 m, but may be as good as 20 m (Appendix 2). Most lines were run east–west/west–east (figures 3 and 4), as we were unable to run any north–south lines owing to the northeasterly trade winds and the resulting sea state.

SIDESCAN SONAR

An EG&G Model SMS 960 Seafloor Mapping System and 59–kHz SMS 990 sidescan sonar towfish were used to obtain the plan–view image of the seafloor shown in figure 5. Specific details of the sonar system, data collection, processing, and interpretation are discussed in Appendix 2. The system was set at a 1–km swath, and sidescan tracklines were spaced 800 m apart, providing 20% overlap between adjacent swaths (figures 3 and 4). The processed mosaic is shown in figures 5, 6, and plate 1. Plate 1 is a Mercator projection at 1:40000 scale, and has a resolution of 1.3 m per pixel, and the bathymetry is taken from Chase and others (1994).

BATHYMETRY

Bathymetric data was collected with a Raytheon DSF–6000, 12–kHz profiling system. Occasionally the 3.5–kHz system was used when the 12–kHz system was not operational. Data were automatically logged and merged with the sidescan sonar and navigation data. Following the survey, the bathymetric data were merged with depths from existing NOAA National Ocean Survey navigation charts numbers 19362 and 19364, USGS bathymetric data collected during previous survey; and data taken from the National Geophysical Data Center (NGDC, Boulder, CO) to produce the bathymetric map shown in figure 5, plate 1, and Chase and others (1994).

GEOPHYSICAL PROFILING SYSTEMS

High–resolution 3.5–kHz Seismic Reflection Profiling System

High–resolution 3.5–kHz subbottom profiles were collected concurrently with sidescan sonar imagery, to determine the acoustic signature and thickness of both the dredged material and natural sedimentary layers (figures 3 and 4). The profiling system comprises an Ocean Data Equipment Corporation Bathy 2000 signal correlator, and a Raytheon PTR transceiver, both driving a 3.5–kHz subbottom profiler housed in a towfish. Pulse repetition rates were 0.25, 0.5 and 1.0 sec. Real–time 3.5 kHz–return signals were displayed on a 16–bit format color monitor and on analog ink–jet color paper records. All data are digital, merged with navigation and archived on optical disc.

Chirp Sonar High–Resolution Profiling System

A Datasonics CAP–6000A chirp sonar subbottom profiling system was also used in an effort to map the thickness and extent of any surficial sedimentary layers associated with dredged material disposal. Operational and theoretical details of the chirp sonar are explained in Appendix 2 and references cited therein. The acoustical data were displayed real time on a super VGA graphics monitor and paper copies were produced on a color–jet printer. All data were archived on Sony digital audio tapes. The monitor and paper copies displayed color acoustic profiles and a variety of system settings. The chirp sonar proved unsuccessful owing to a combination of system noise and possibly the carbonate substrate. The poor quality of the chirp data precludes any detailed description of the profiles and subsequent interpretation. The chirp sonar data are not discussed in the remainder of the report.

RESULTS AND DISCUSSION

Results of the 1993 acoustic survey (presented herein) and the subsequent May 1994 sampling program (Torresan and others, 1994a and b) provide abundant evidence that the dredged material deposits are more extensive than the area defined by the official disposal site boundaries. Furthermore, preliminary interpretations of samples and photographic data collected in May 1994 indicate that the dredged material is more extensive than the area defined as dredged material deposits on the sidescan sonar mosaic and 3.5–kHz profiles (Torresan and others, 1994a and b).

BATHYMETRY

The bathymetry map presented in figure 5 and plate 1 shows that the disposal sites are located in the broad southeast sloping trough having a slope of about 20 m/km (1:50). Large pinnacles and canyons are absent, but several relatively small canyons and areas of irregular topography exist in the immediate vicinity of the disposal sites. There are no obvious features on the bathymetry that are clearly caused by disposal activities. As seen on the bathymetric map (figure 5, plate 1, and Chase and others, 1994), the seafloor is naturally irregular in texture and slope. It is impossible to identify anomalous features on the bathymetry map that result from dredged material disposal, although mounds are evident along portions of 3.5–kHz subbottom profiles (figures 7, 8, and 9) collected form near the eastern edge of the former Honolulu Harbor disposal site. The mounds extend well beyond both the disposal site boundaries and beyond the high–backscatter blanket interpreted as dredged material deposits, and probably result from natural rather than anthropogenic processes as stated in Torresan and others (1994a). The bathymetric data grid collected during the 1993 survey is too coarse in scale and the features created by disposal activities are apparently to small in relief to allow definition on the bathymetric map produced by Chase and others (1994) and shown in figure 5 and plate 1.

SIDESCAN SONAR AND 3.5–kHz HIGH RESOLUTION ACOUSTIC PROFILES

Sidescan sonar and subbottom profiling shows that the dredged material disposal leaves a distinct imprint on the seafloor and affects an area of about 100 km^2 (figures 4, 6, and plate 1). The sonar images show that dredged material deposits are characterized by high–backscatter, circular to subcircular footprints that are spaced up to 300 m apart at the extremities of the deposits, and coalesce to form a high–backscatter blanket over the center of disposal areas (figure 6 and plate 1). The high backscatter that characterizes the dredged material is probably due to the irregular seafloor at the sites, the number of coarse limestone, coral, and basalt clasts, and to the general hardness of the deposit. This blanket of high–backscatter dredged material covers the natural, low–backscatter sediment that mantles the Mamala Bay seafloor in the area. Examination of the sonar images (figures 5, 6, and plate 1) shows that within the high–backscatter blanket are subtle variations in backscatter that probably correspond to variations in the dredged material, especially in the abundance of coarse clasts. Associated with some of the primary dredged material footprints are lower–backscatter aprons that may represent the finer components of individual dredged material deposits (figures 5, 6, and plate 1). These aprons likely settled after the main body of a particular disposal action, forming a secondary deposit or apron. A number of other anthropogenic targets such as tires, wire cable, military ordnance, and various barrels or drums, litter the seafloor, and these are seen on bottom photographs collected in the 1977–1978 site–designation studies conducted in and around the disposal sites (Chave and Miller 1977a, 1977b, 1978a, 1978b, Neighbor Island Consultants, 1977; Tertra Tech, 1977, Goeggel, 1978). These targets are likely associated with ocean disposal activity in Mamala Bay, but most fall below the resolution of the sonar mosaic. Bedforms having wave lengths from 5 to 20 m are visible on the sidescan images (plate 1). They are primarily located in the western half of the survey area, but also occur within the disposal sites.

A number of enigmatic features appear on the sonar mosaic, characterized as sets of high–backscatter, short, parallel lines or "chatter marks", having distinct trends and spacing. The features, called trains in this report, are primarily located in the southern part of the study area, south of the South Oahu disposal site. One example is labeled "train" on figure 6. The features comprise sets of en echelon, high backscatter lines about 50–100 m long, having spacings of about 25–50 m, that combine to form linear or looping trains ranging from less than 0.5 km to over 1 km long. Most but not all of the lines within a train have the same trend. The trains are not resolved on any of the 3.5 kHz acoustic profiles and their origin is unknown, but they may result from disposal activity. For example, a disposal action may have released enough sediment to create a train in response to the local current regime, but without a continuing source of sediment, the train becomes starved, similar to the bedforms described by Cacchione and others (1987) and Cacchione and Drake (1990). The trains appear as bedforms responding to the local current activity, owing to the similar trend and spacing shown by the high–backscatter, short, parallel lines associated with the differently oriented trains. If disposal activity in fact formed these trains, then the strange and curved geometry of the trains may be a function of the disposal vessel turning or drifting during a discrete disposal action. At this time there is no evidence to suggest that these trains or their shapes are influenced by seafloor topography or channels.

The 3.5–kHz subbottom profiles complement the sonar imagery and show characteristic features relative to the location of the specific profile. Note that the seafloor reflector on all profiles shown in this report is typically characterized by a purple color. An overlying green signal observed on many records is an artifact of the display software (ODEC, oral communication).

There are two types of seafloor as seen on the 3.5–kHz profiles that occur within each site and adjacent to the eastern edge of the former Honolulu Harbor site, and these are distinguished by amount of relief shown on the 3.5–kHz profiles. Generally, the disposal sites are characterized by an undulatory seafloor as seen on figures 10, 11, 12, 13, and 14. The second type of seafloor seen on 3.5–kHz subbottom profiles is a mounded seafloor such as that observed along lines 4, 5 and 11 and seen in figures 4, 6, 7, 8 and 9. The mounds occur over the northern and eastern portions of the former Honolulu Harbor site and extend east about 2 km beyond the high–backscatter, plume–shape deposit and into the low-backscatter seafloor (figures 4, 6, 7, 8 ,9 and plate 1). The mounds are up to a meter high and have crests spaced up to 150 m apart along ship's track. Some mounds appear to correlate with the high–backscatter footprints visible on the sonar mosaic, such as those visible in figure 7 along line 4, and the mounds visible along line 11 as seen in figure 7. These mounds despite starting within the eastern edged of the plume–shape Honolulu Harbor deposit, extend beyond the high–

backscatter deposit and into the low backscatter native seafloor implying a natural rather than anthropogenic origin for the mounds. The location of the mounds east of the former Honolulu Harbor site and in a topographic low or trough that dips to the southeast (figure 5 and plate 1) suggests that native sediment may have formed bedforms in response to the local current regime. These mounds or bedforms may be migrating downslope to the southeast, although their shape and symmetry as seen in the 3.5–kHz profiles does not suggest or imply a specific trend or transport direction. At this time the origin of the mounds is unknown.

Most 3.5–kHz profiles collected over the disposal sites are characterized by a laterally discontinuous seafloor reflector, implying a change in acoustic impedance. This discontinuity is shown on profiles by color changes, e.g., changes in the seafloor reflector from dark purple to lighter purple or to green, or from greens to yellows. In places, the discontiniuties are quite subtle, but nonetheless are visible. These discontinuities typify most of the deposits that blanket both the former and the active disposal sites, and are shown in figures 7, and 10, 11, 12, 13 and 14. Typically, the substrate below the discontinuous seafloor reflector is featureless, lacking subbottom reflectors. An exception exists in the deeper area of the southeast portion of the former Honolulu Harbor site, which is characterized by pronounced mounding, and an undulating, continuous seafloor reflector that has one discontinuous subbottom reflector (figures 8 and 9). A possible explanation for the discontinuous seafloor reflector and the structureless substrate likely resides in the nature and composition of the dredged material. Since the dredged material is composed of a cohesive gray mud admixed by dredging with sand– to cobble–size carbonate and basaltic debris (Torresan and others, 1994b), the nature of the dredged material can attenuate and/or scatter the acoustic signal such that the resultant profile lacks resolution and appears structureless in most profiles.

Contrasting with the laterally discontinuous seafloor reflector and the featureless dredged material substrate, subbottom profiles collected along line 17 (figure 15), located between the former Pearl and Honolulu Harbor sites shows subbottom reflector(s). Also, the deeper areas of Mamala Bay south of the disposal sites are characterized by a smooth, continuous seafloor reflector that has one or more subbottom reflectors (figures 16, 17 and

18). This echo character may be characteristic of the seafloor prior to dredge material disposal. Finally, tightly–spaced diffractions are common on many profiles (especially west of the disposal sites) and are almost always associated with bedforms visible on the sidescan mosaic (figures 4, 6, 19, 20, and plate 1). Some diffractions are probably associated with coarse debris visible on seafloor photographs taken during 1977 (Chave and Miller, 1977a, 1977b), and some are likely related to buried reef deposits, in addition to bedforms and surficial debris.

CONCLUSIONS

Sidescan sonar shows that dredged material disposal leaves a remarkable imprint on the seafloor. Disposal has affected an area of about 100 km^2, forming two major deposits. These deposits are characterized by high–backscatter, circular to subcircular footprints that coalesce to form a high–backscatter blanket that mantles the seafloor near the center of each disposal site. The sonar images clearly document that the dredged material deposits extend well beyond the disposal site boundaries (figures 5, 6 and plate 1), and subsequent sampling shows that dredged material below the resolution limit of the sidescan sonar exists beyond the high backscatter area shown in the images (Torresan and others, 1994a and b). The high resolution acoustic profiles collected over the sites are characterized in places by gentle seafloor undulations, but are primarily characterized by lateral discontinuities in seafloor reflectivity and hardness. Typically, the substrate within the sites and below the discontinuous seafloor reflector is featureless, and devoid of internal structure and subbottom reflectors. Subbottom stratigraphy and structure may well exist but is not visible in the 3.5–kHz profiles, possibly owing to the acoustic signal being scattered and reflected by the coarse component in the dredged material. Alternatively, the acoustic signal may be absorbed by the dredged material. In contrast, profiles collected away from the sites, especially in deeper water to the south, do not show the strong discontinuities in seafloor reflectivity, and can have subbottom reflectors rather than the typically structureless substrate seen mantling each disposal site. Diffraction patterns on most 3.5–kHz profiles in the region west of the former Pearl Harbor and the active South Oahu sites are almost all associated with bedforms visible on the sonar mosaic and bottom photographs collected during the 1977–1978 site designation studies (Chave and Miller 1977a, 1977b, 1978a; Neighbor Island Consultants, 1977; Tertra Tech, 1977; Goeggel; EPA, 1980) and the USGS May 1994 survey (Torresan and others, 1994a and b).

With the completion of the acoustical surveys conducted by the USGS in 1993, a good acoustic data base now exists for Mamala Bay. More detailed studies are required to define the nature of the various substrates, the benthic processes, and the relative roles of the substrate and the benthic and neritic communities in the transfer and storage of contaminants associated with dredged material disposal. Analysis of sediment cores and photographs collected in May 1994 (Torresan and others, 1994b) will aid in "groundtruthing" the sonar mosaic and acoustic profiles, will evaluate contaminant concentrations in the sediment, and will help define the variety of anthropogenic stresses affecting Mamala Bay. Analyses employing sedimentological, geochemical, and biological techniques are required to better assess the impact to the seafloor, the benthic and neritic communities, the material flux, and the fate of contaminants associated with dredged material disposal. Specific studies should include evaluations of the harbor and the disposal site sediment and biological tissues for contaminants such as metals, pesticides, organics, organotins, PAHs, phenols, and phthalates, and the evaluation of the effect of bottom currents and bioturbation in dredged material redistribution and contaminant transfer. Future studies will benefit from additional field programs specifically designed to collect benthic fauna.

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT)

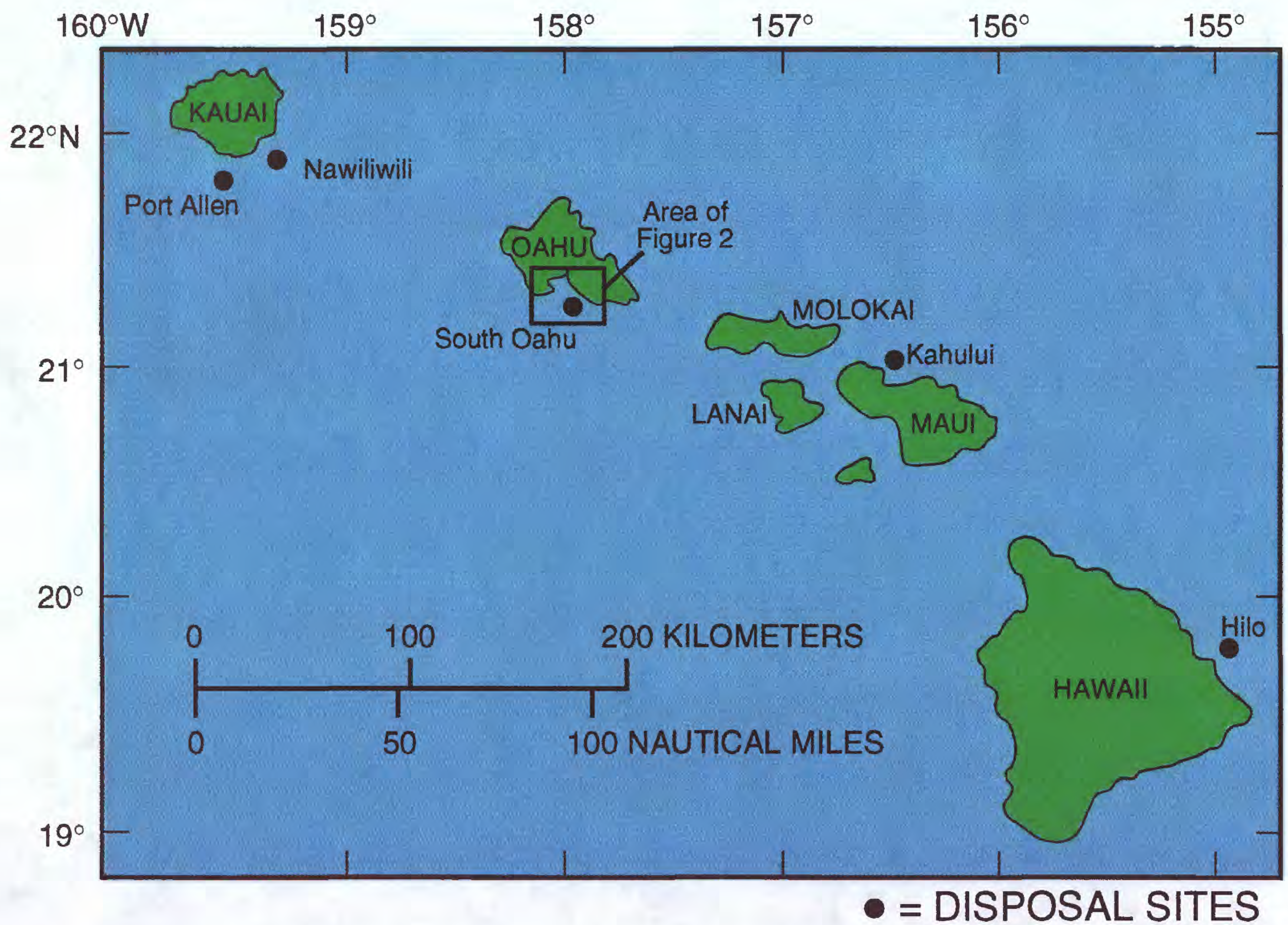

160°W
159°
158°
157°
156°
155°
22°N
21°
20°
19°
KAUAI
Nawiliwili
Port Allen
OAHU
Area of
Figure 2
South Oahu
MOLOKAI
Kahului
LANAI
MAUI
HAWAII
Hilo
0
100
200 KILOMETERS
0
50
100 NAUTICAL MILES
● = DISPOSAL SITES

FIGURE 1

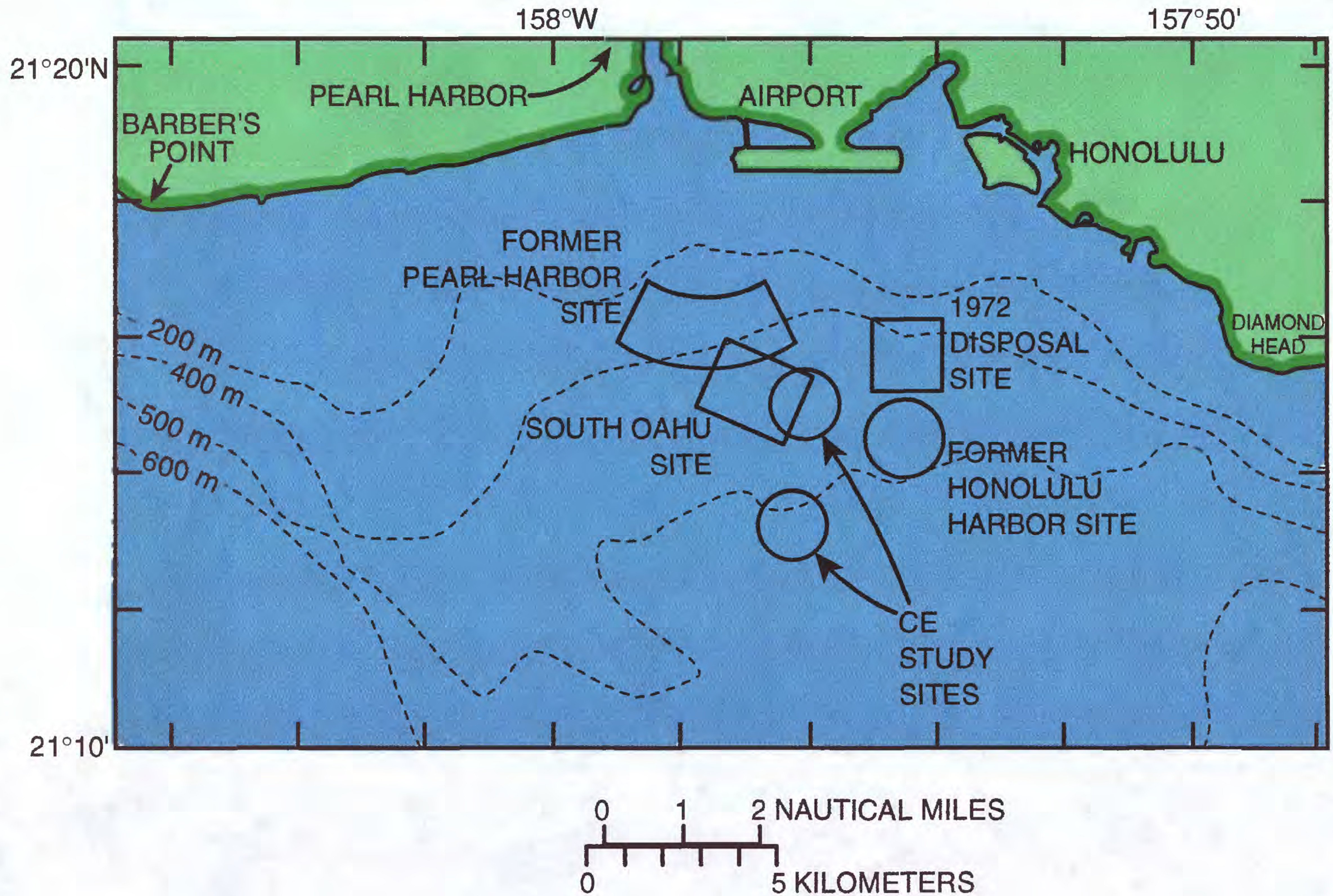

158°W
157°50'
21°20'N
21°10'
PEARL HARBOR
BARBER'S POINT
AIRPORT
HONOLULU
DIAMOND HEAD
FORMER PEARL HARBOR SITE
1972 DISPOSAL SITE
SOUTH OAHU SITE
FORMER HONOLULU HARBOR SITE
CE STUDY SITES
200 m
400 m
500 m
600 m
0 1 2 NAUTICAL MILES
0 5 KILOMETERS

FIGURE 2

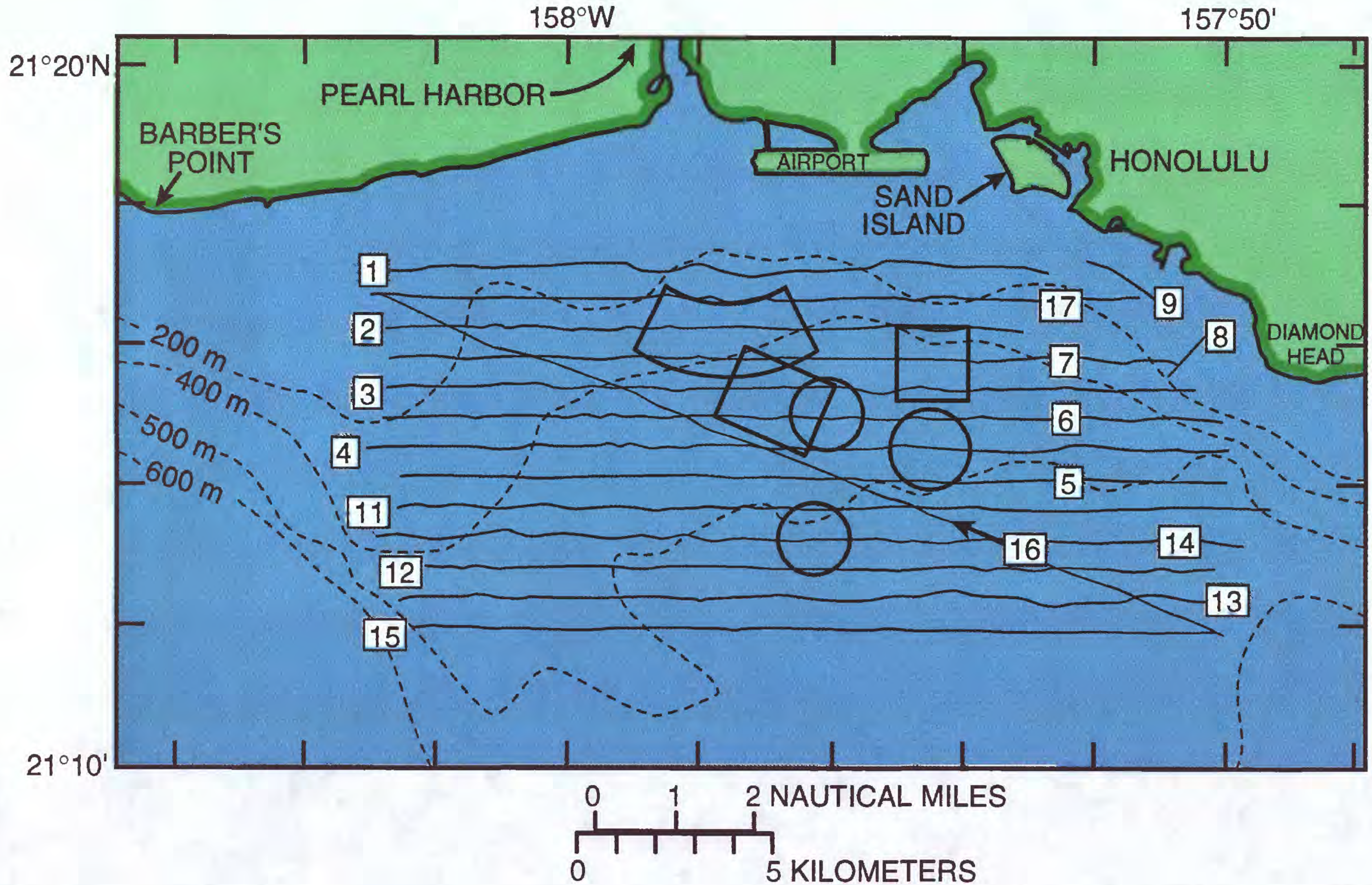

158°W
157°50'
21°20'N
21°10'
PEARL HARBOR
BARBER'S POINT
AIRPORT
SAND ISLAND
HONOLULU
DIAMOND HEAD
200 m
400 m
500 m
600 m
1
2
3
4
5
6
7
8
9
11
12
13
14
15
16
17
0 1 2 NAUTICAL MILES
0 5 KILOMETERS

FIGURE 3

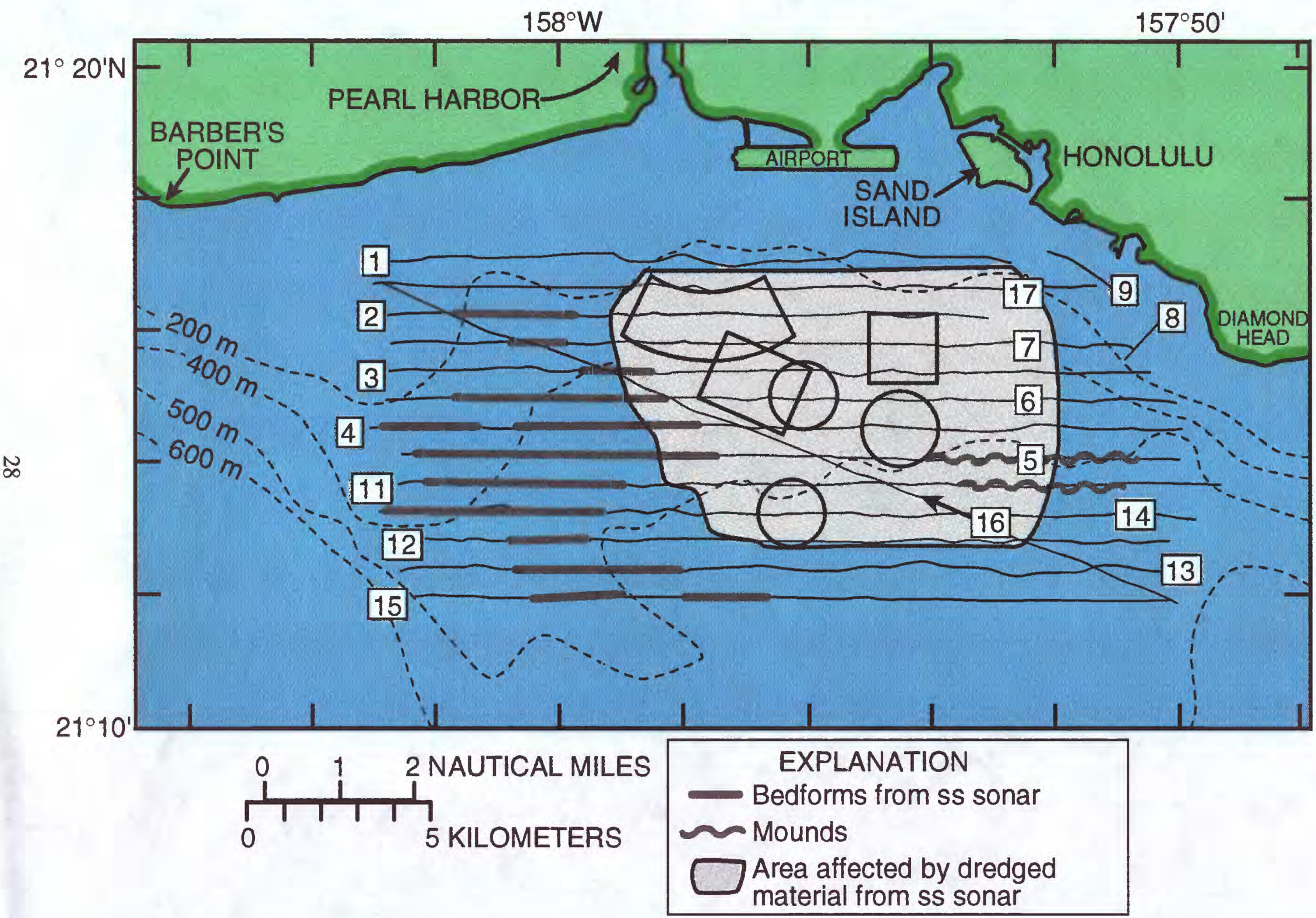
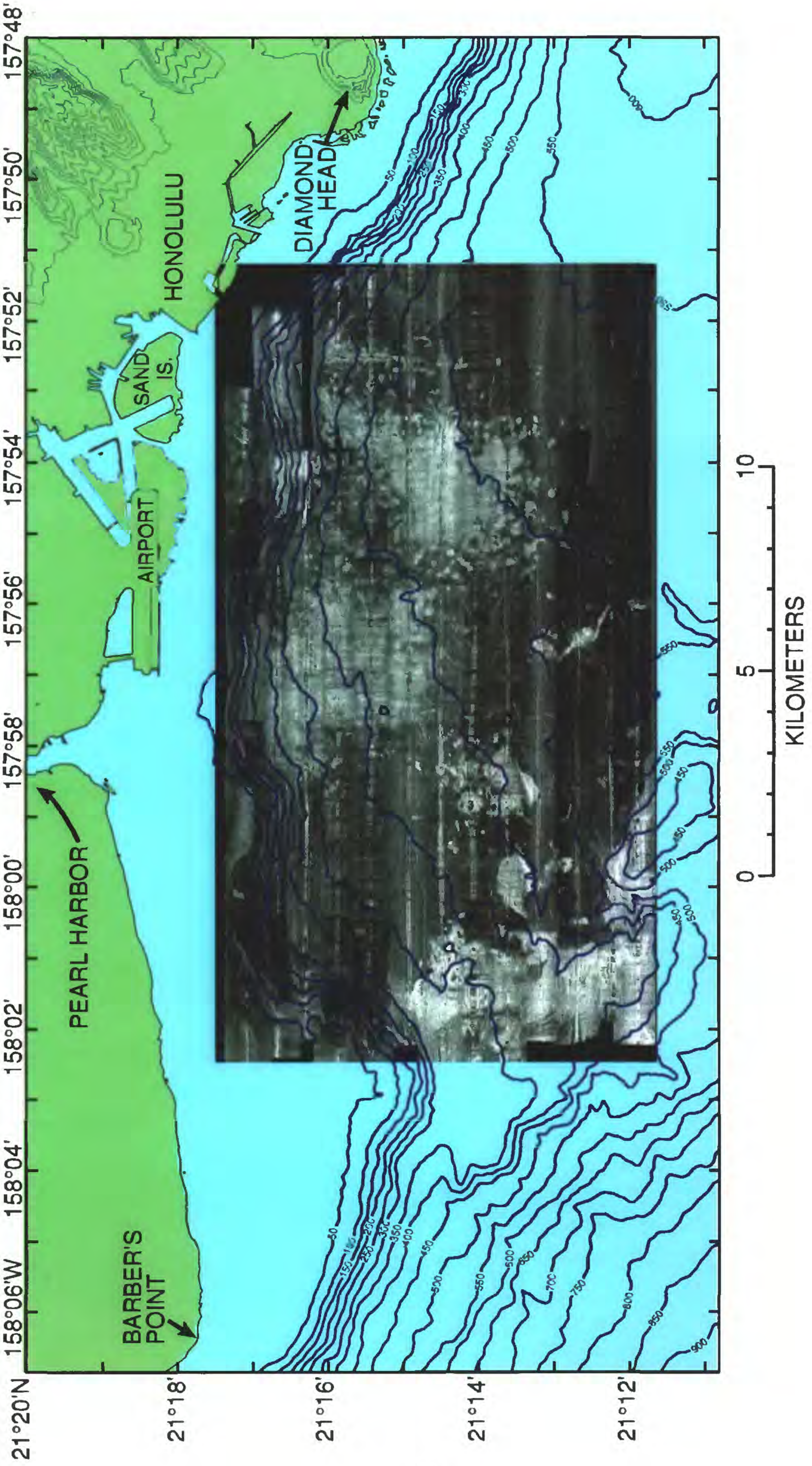
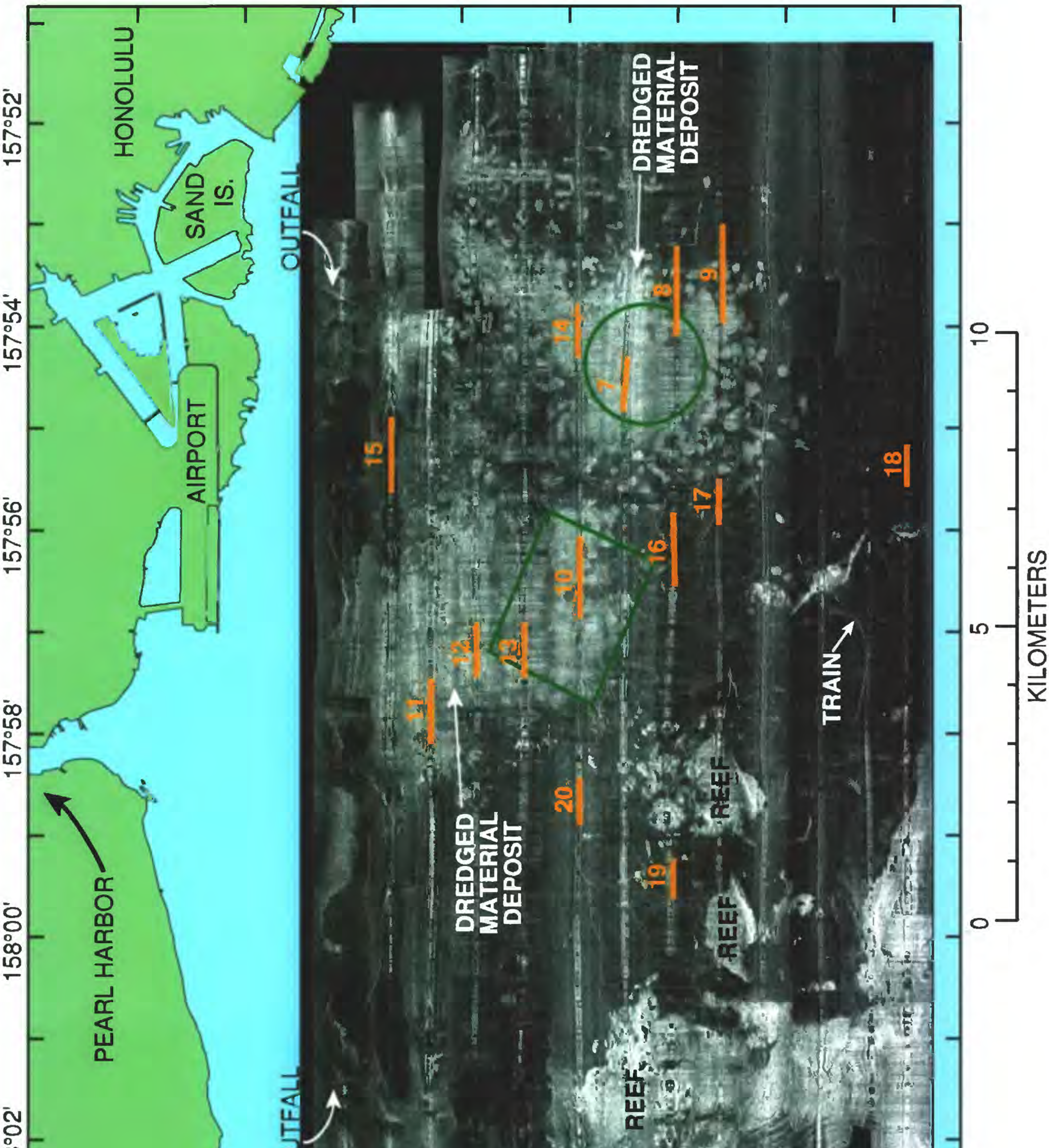

158°W
157°50'
21° 20'N
21°10'
PEARL HARBOR
BARBER'S POINT
AIRPORT
SAND ISLAND
HONOLULU
DIAMOND HEAD
200 m
400 m
500 m
600 m
1
2
3
4
5
6
7
8
9
11
12
13
14
15
16
17
0
1
2 NAUTICAL MILES
0
5 KILOMETERS
EXPLANATION
Bedforms from ss sonar
Mounds
Area affected by dredged material from ss sonar

FIGURE 4



157°48'
157°50'
157°52'
157°54'
157°56'
157°58'
158°00'
158°02'
158°04'
158°06'W
21°20'N
21°18'
21°16'
21°14'
21°12'
BARBER'S POINT
PEARL HARBOR
AIRPORT
SAND IS.
HONOLULU
DIAMOND HEAD
0
5
10
KILOMETERS

FIGURE 5



21°20'N
21°18'
21°16'
21°14'
21°12'
158°02'
158°00'
157°58'
157°56'
157°54'
157°52'
PEARL HARBOR
HONOLULU
SAND IS.
AIRPORT
OUTFALL
OUTFALL
DREDGED MATERIAL DEPOSIT
DREDGED MATERIAL DEPOSIT
REEF
REEF
REEF
TRAIN
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
5
10
KILOMETERS

FIGURE 6

LINE 4
OLD HONOLULU HARBOR SITE

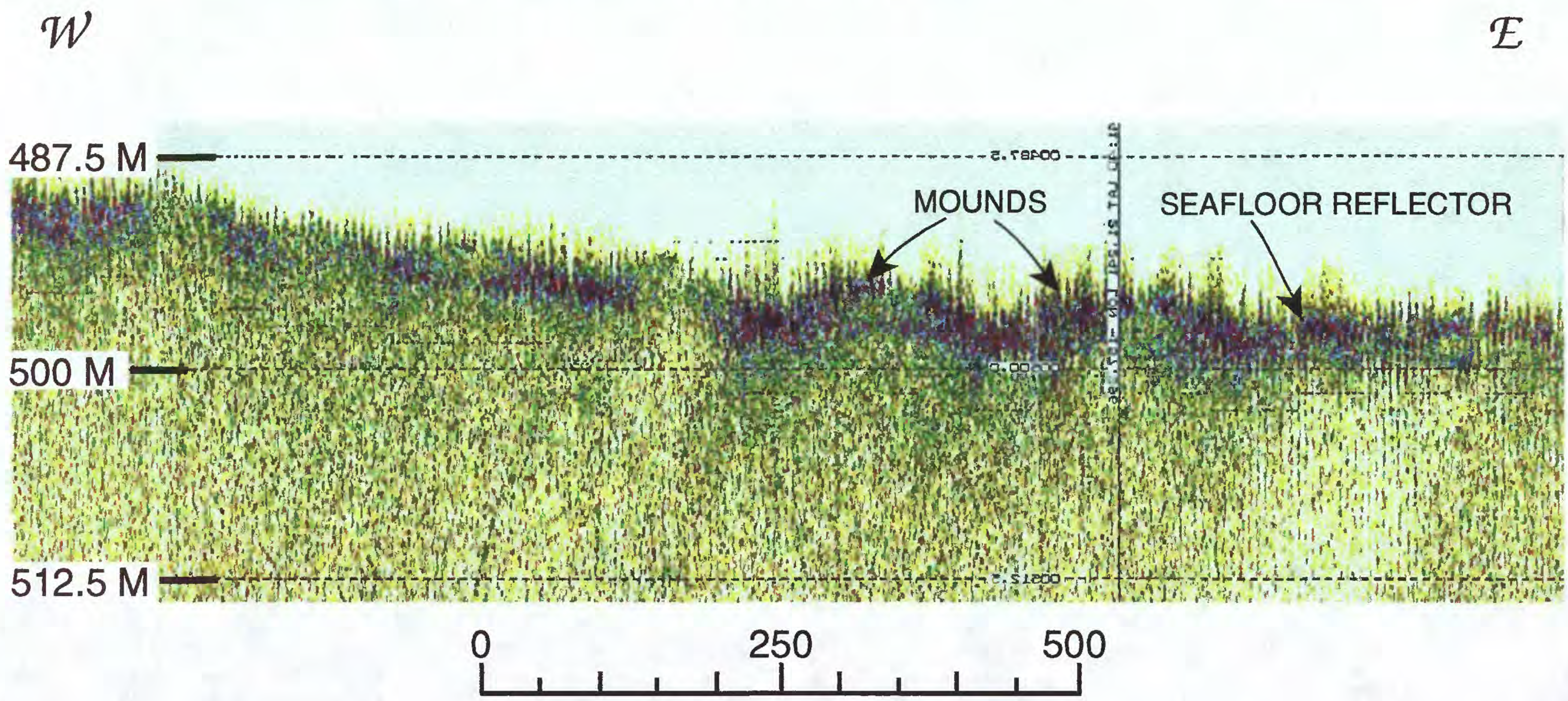


FIGURE 7

LINE 5
SE PORTION OF OLD HONOLULU HARBOR SITE

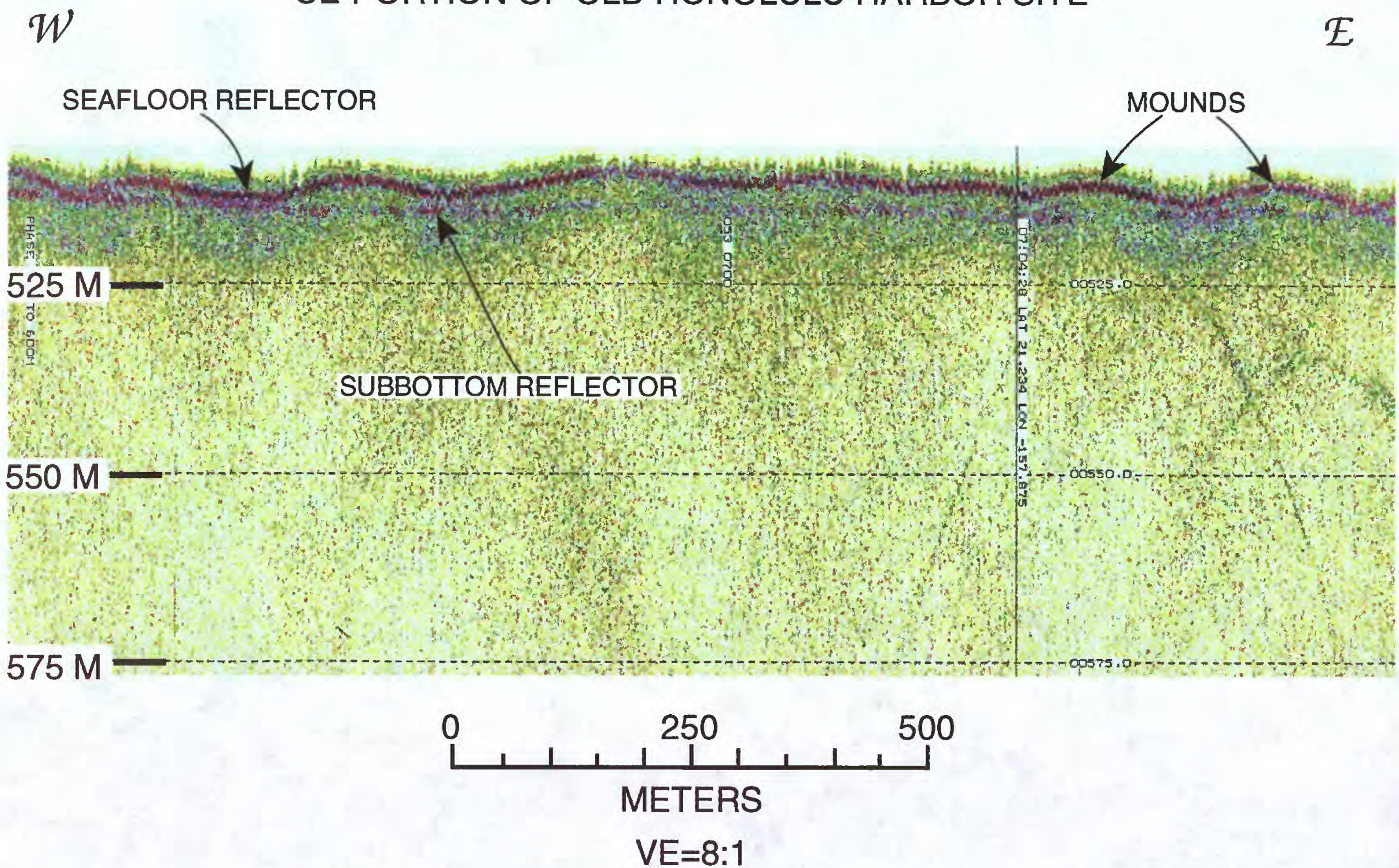


FIGURE 8

LINE 11
OLD HONOLULU HARBOR SITE

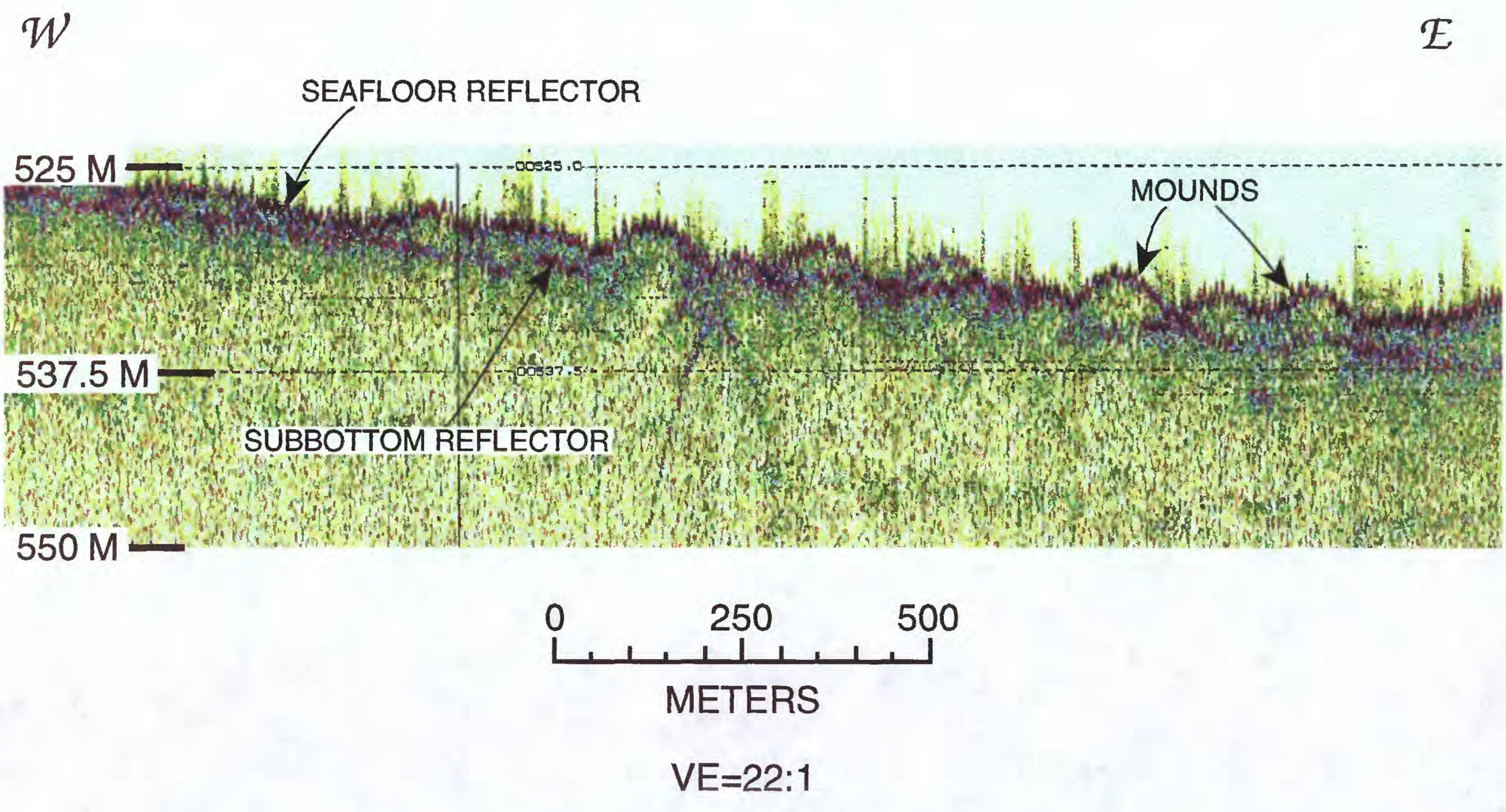


FIGURE 9

LINE 6
SOUTH OAHU SITE

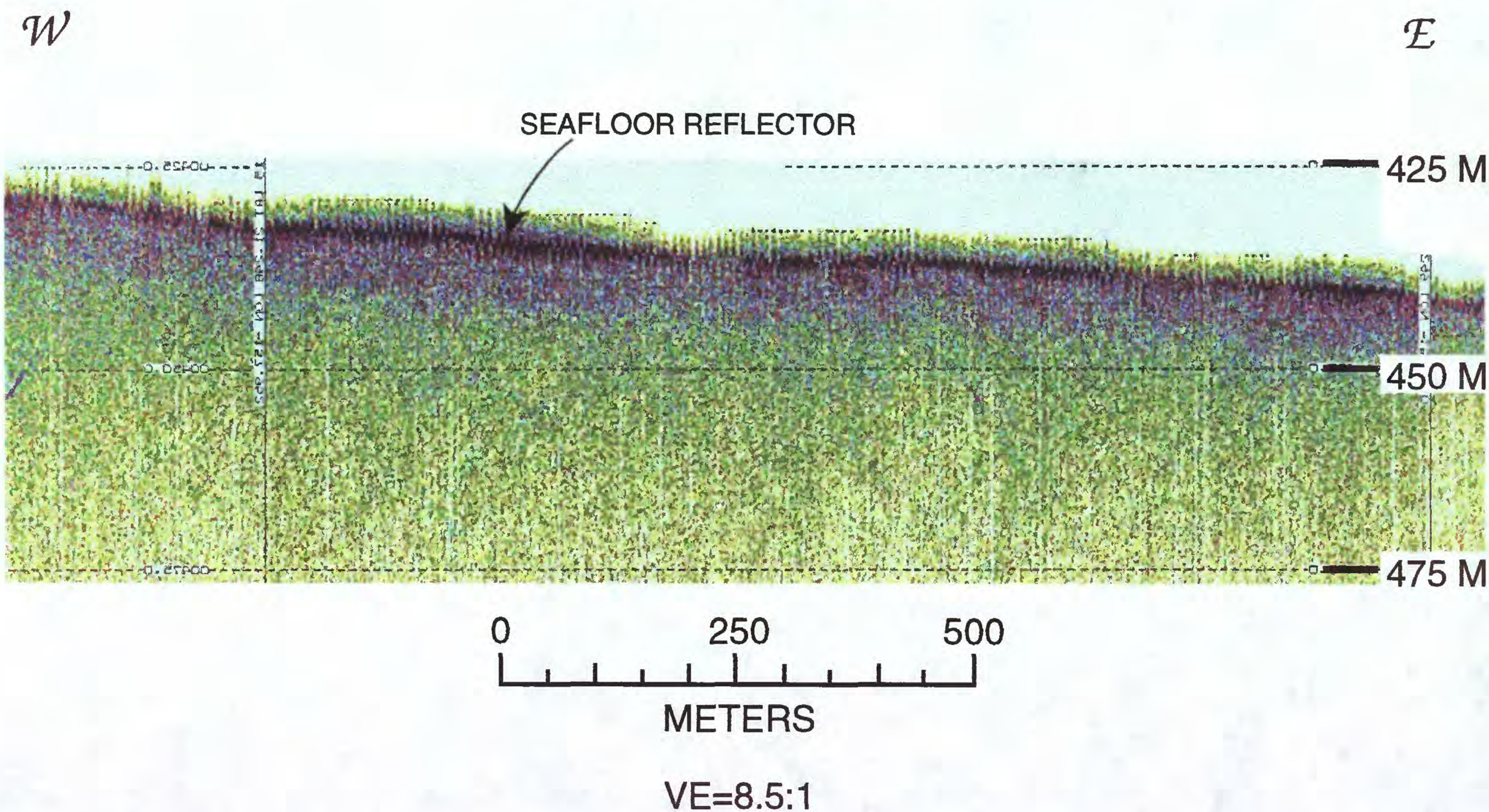


FIGURE 10

LINE 2
OLD PEARL HARBOR SITE

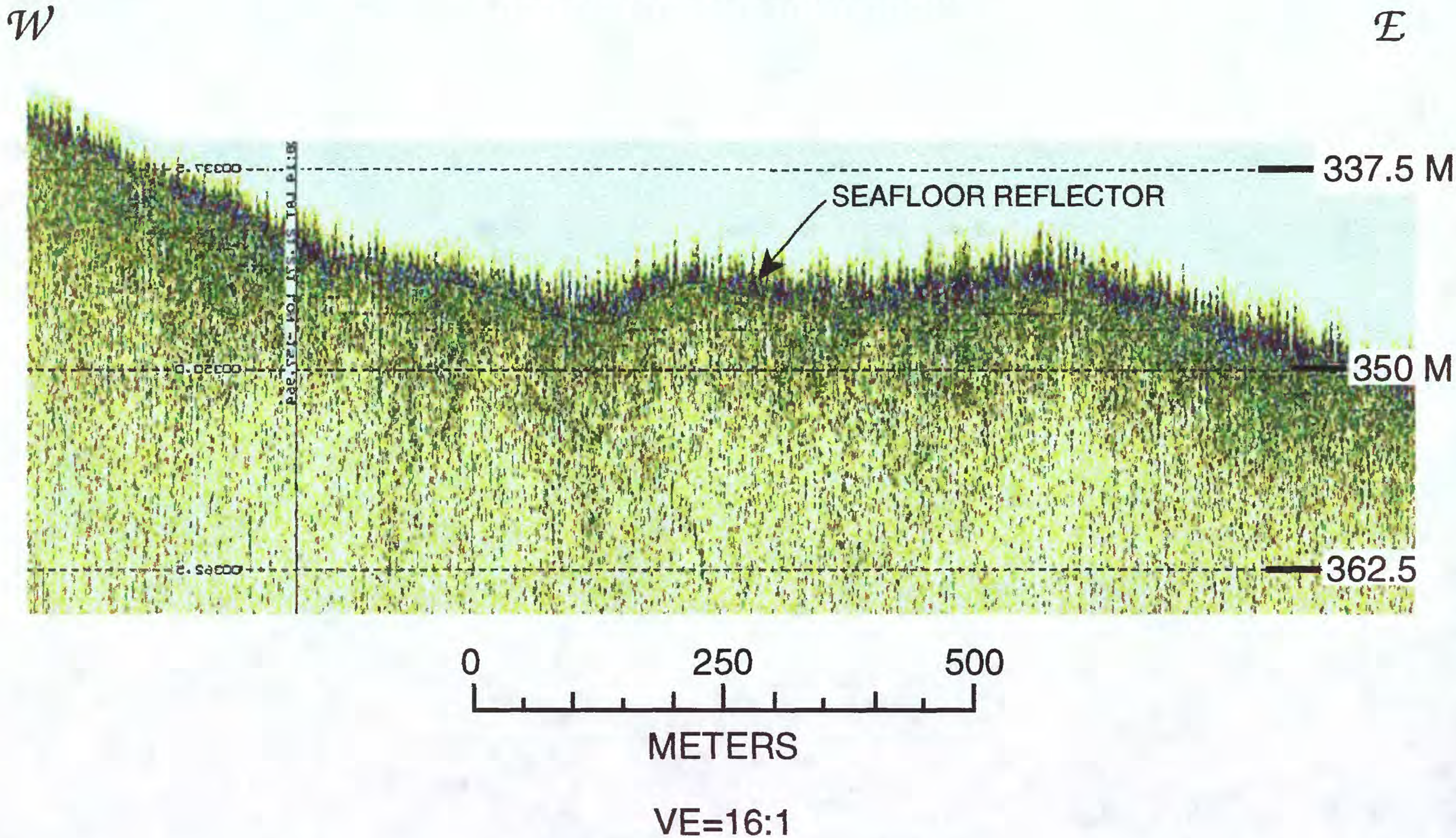


FIGURE 11

LINE 7
OLD PEARL HARBOR SITE

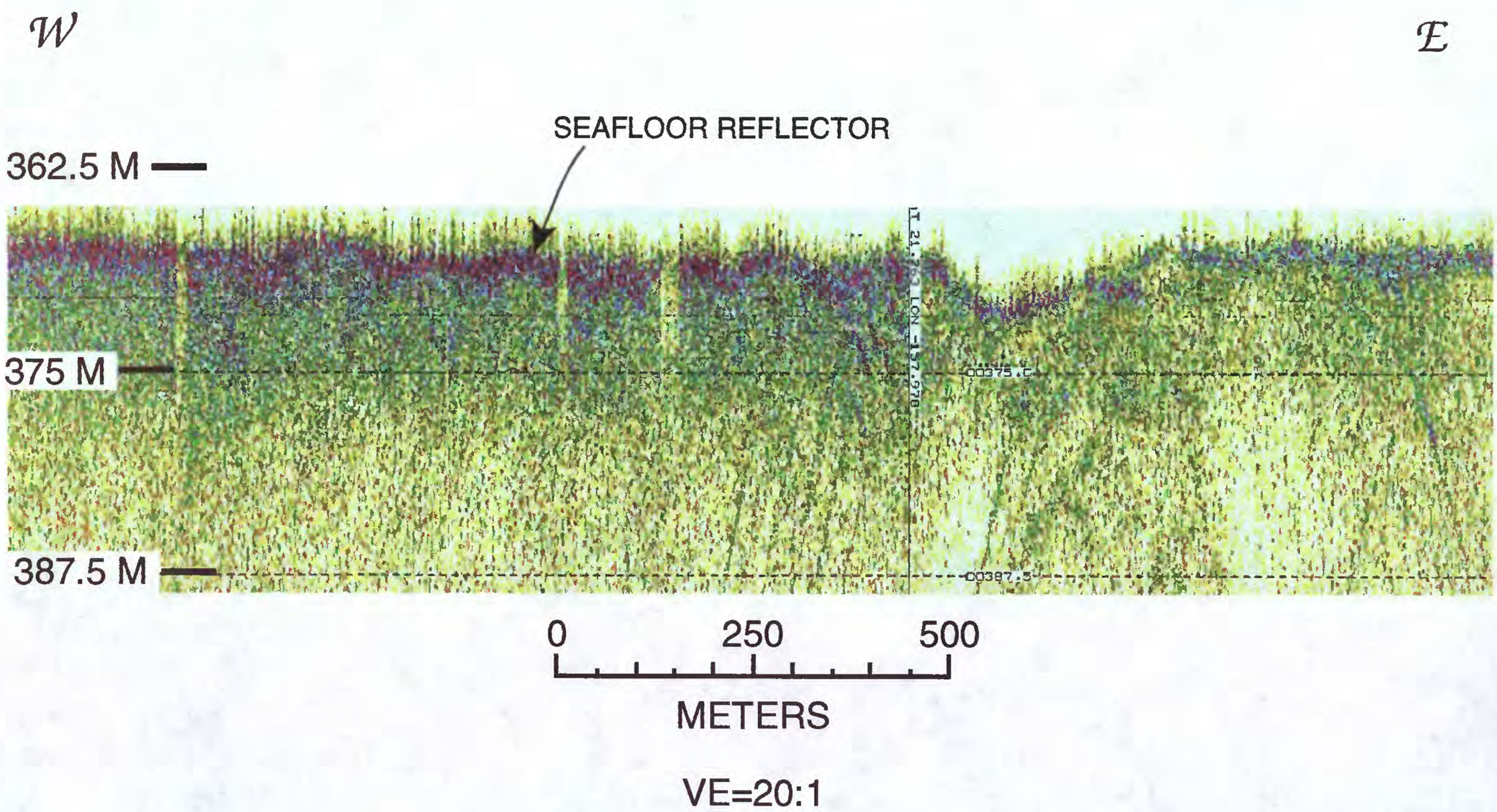


FIGURE 12

LINE 3
SOUTH OAHU SITE

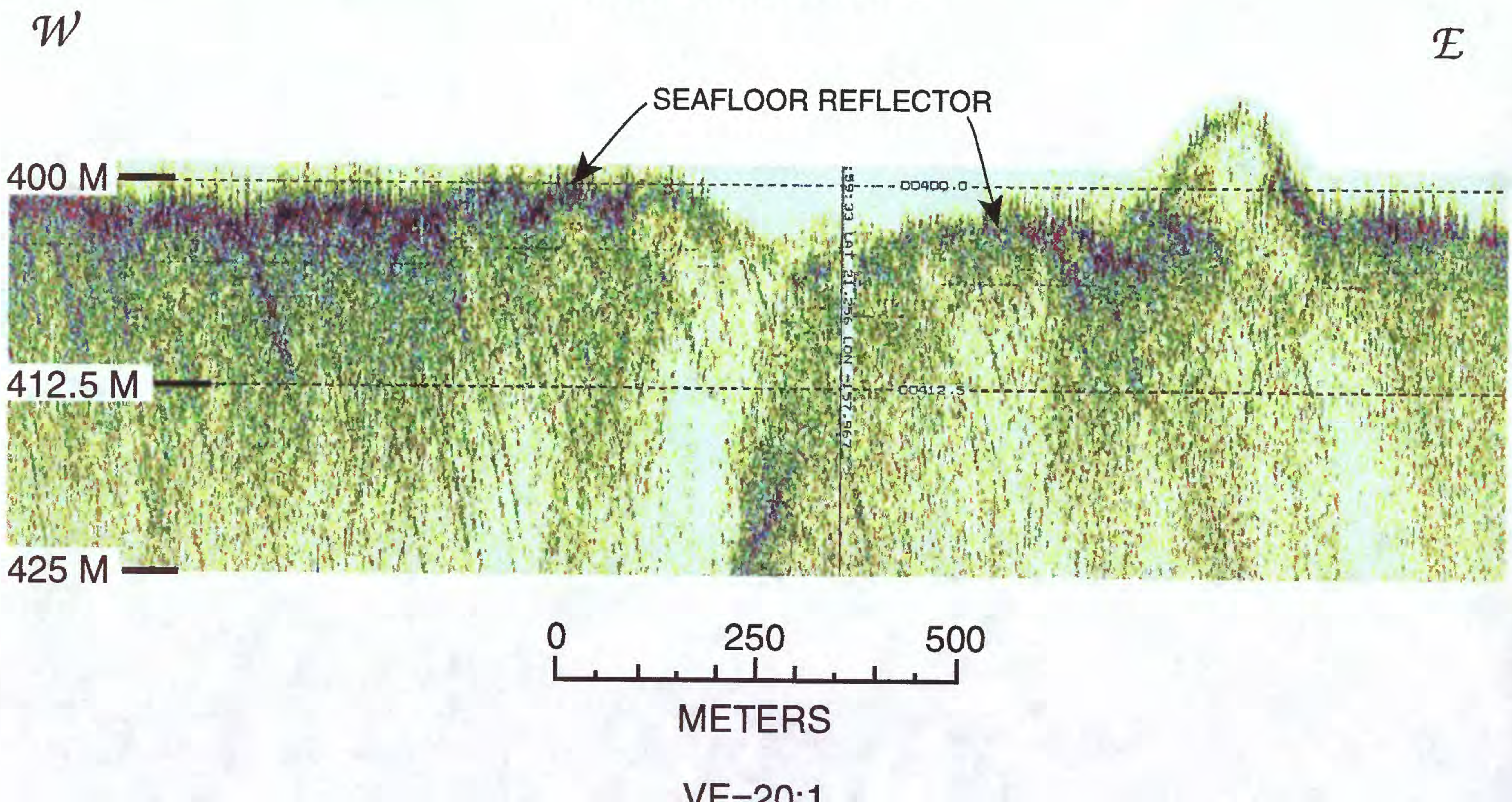


FIGURE 13

LINE 6
OLD HONOLULU HARBOR SITE

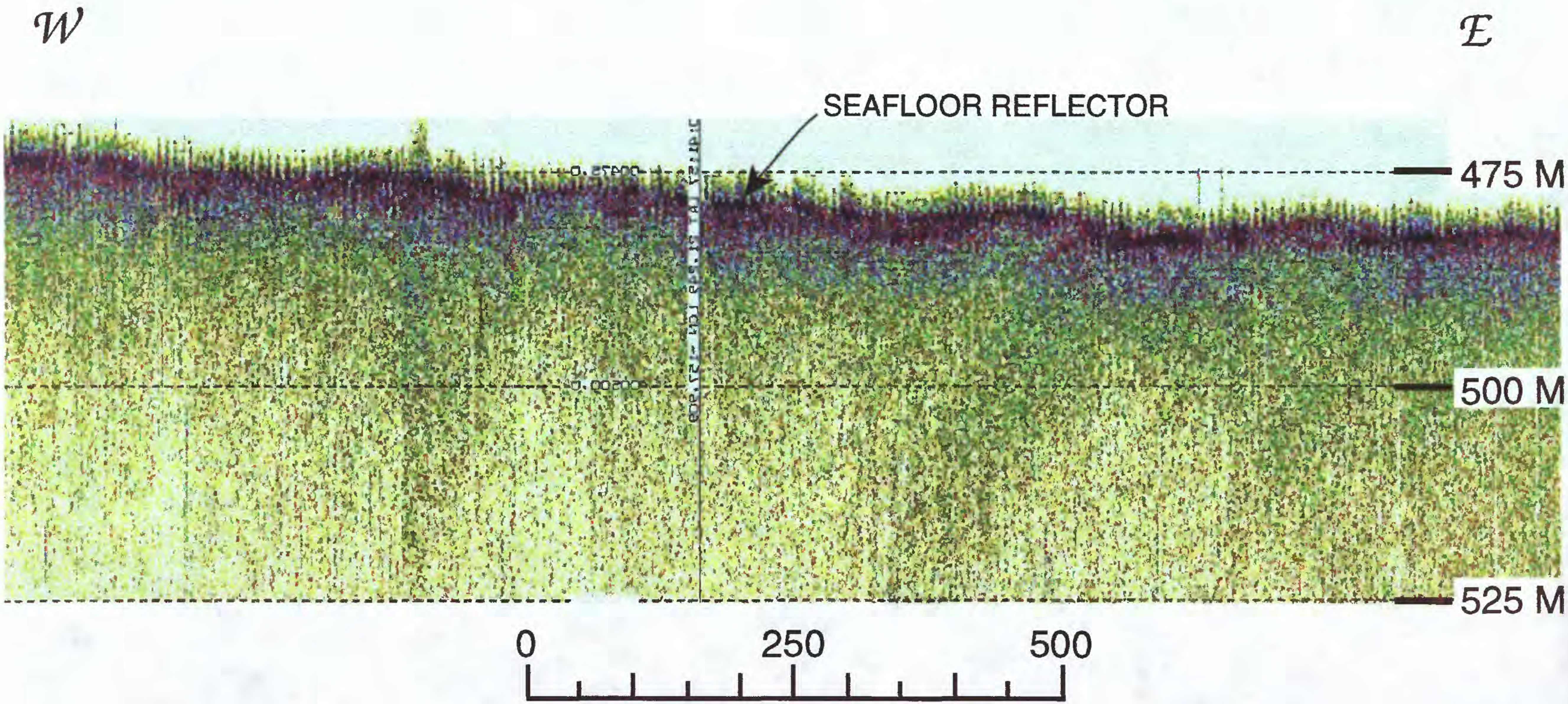


FIGURE 14

LINE 17
EAST OF OLD PEARL HARBOR SITE

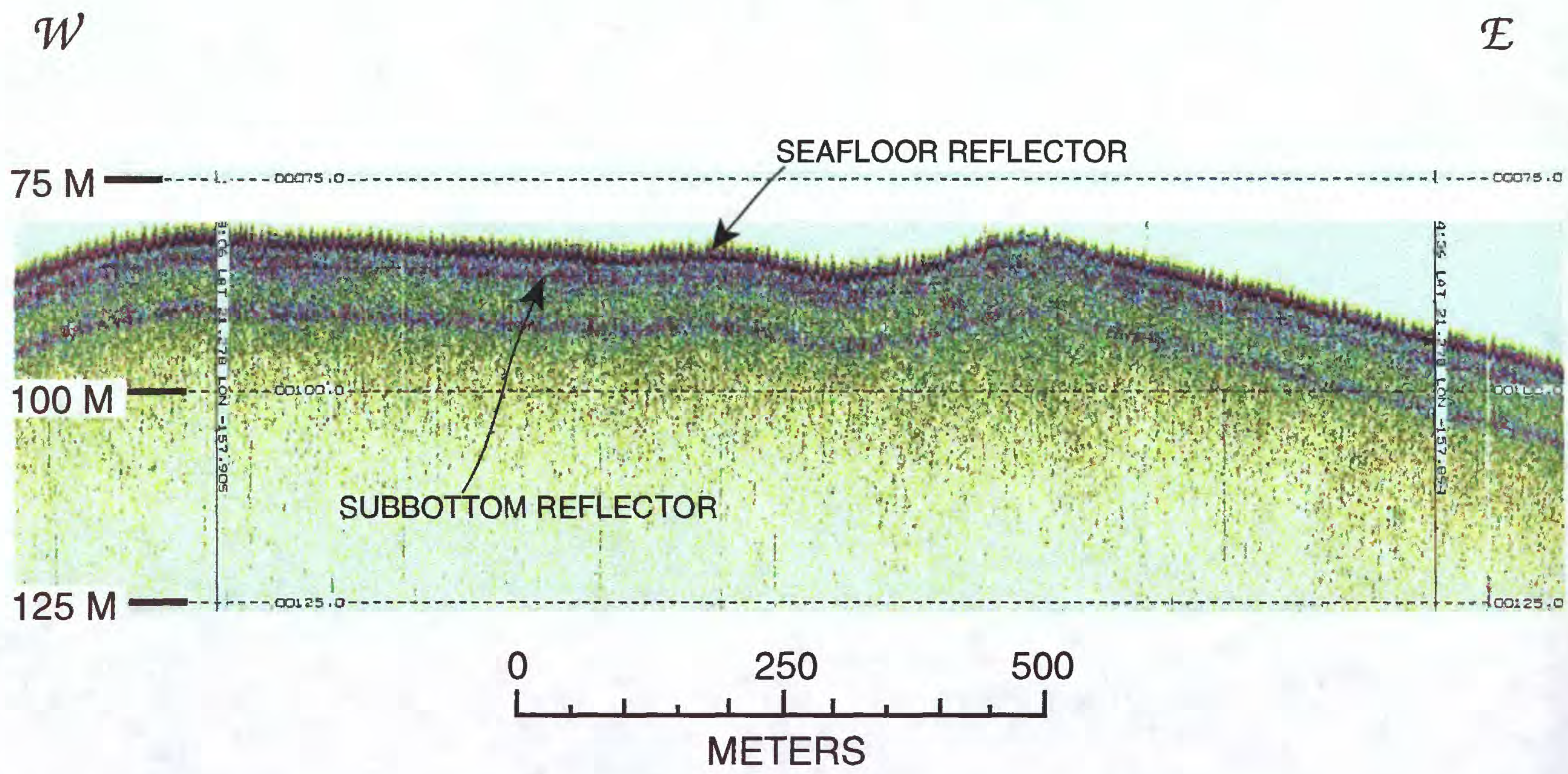


FIGURE 15

LINE 5
SOUTH OF SOUTH OAHU SITE

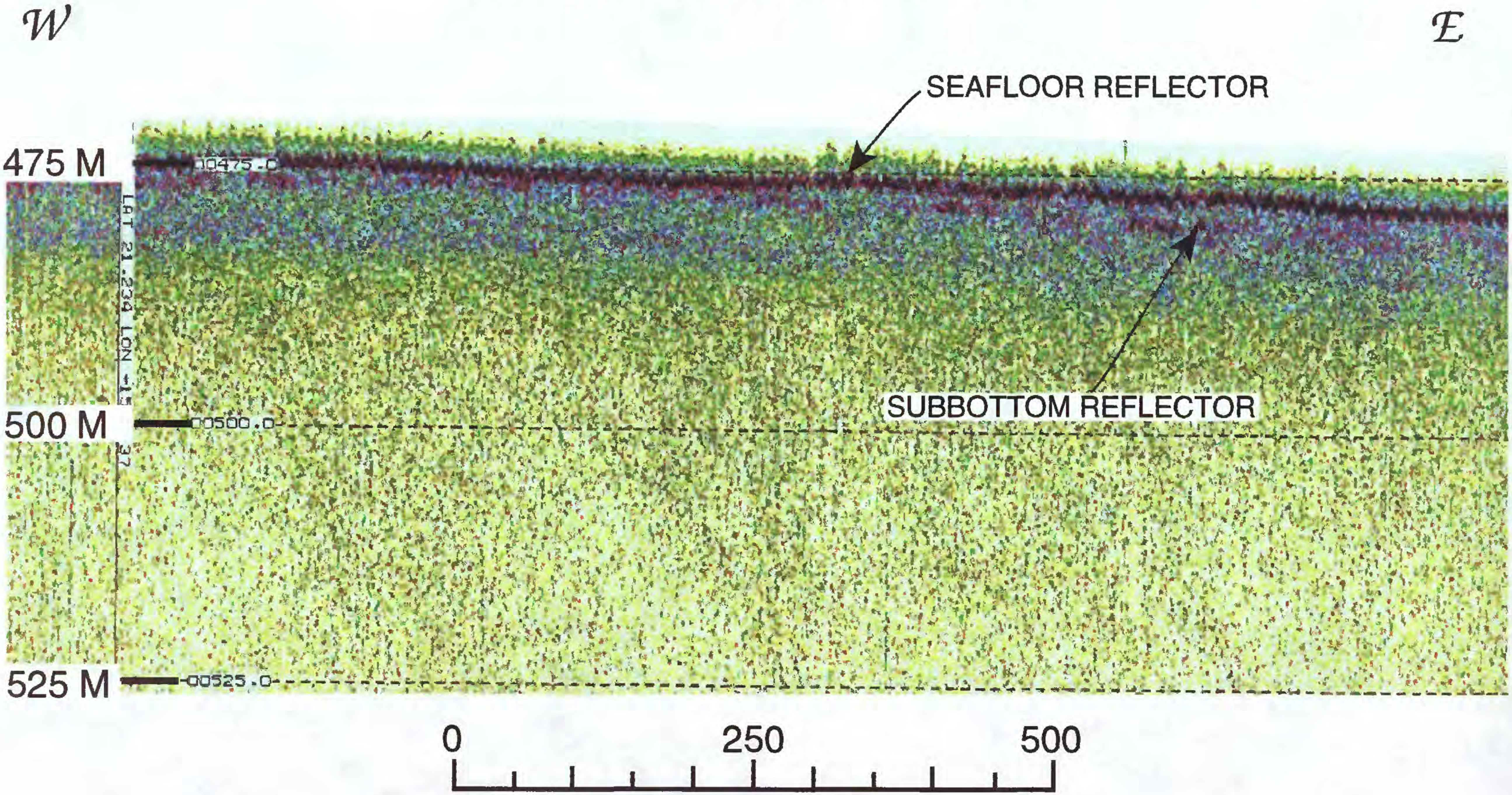


FIGURE 16

LINE 11
WEST OF OLD HONOLULU HARBOR SITE

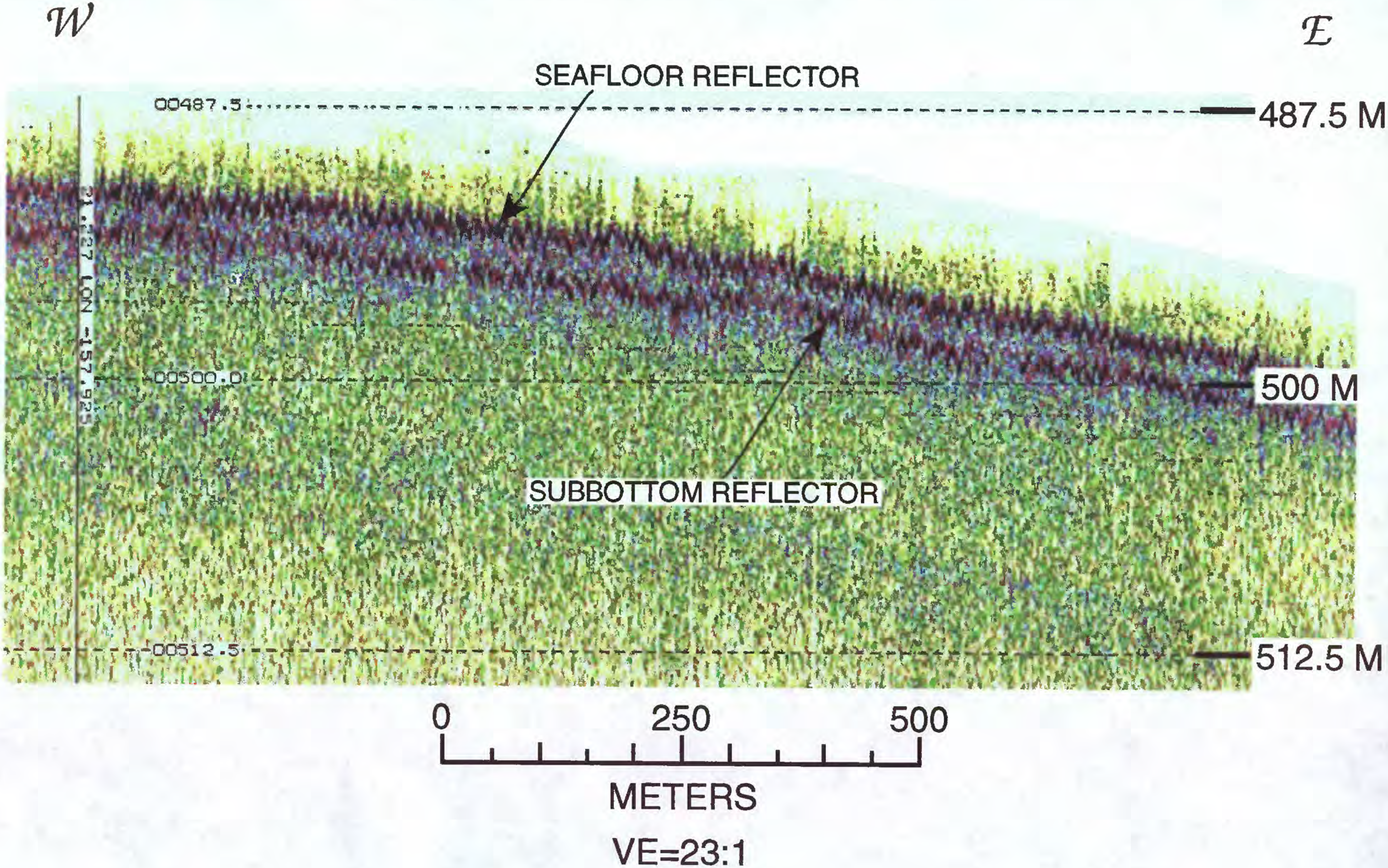


FIGURE 17

LINE 15
SOUTH OF DISPOSAL SITES

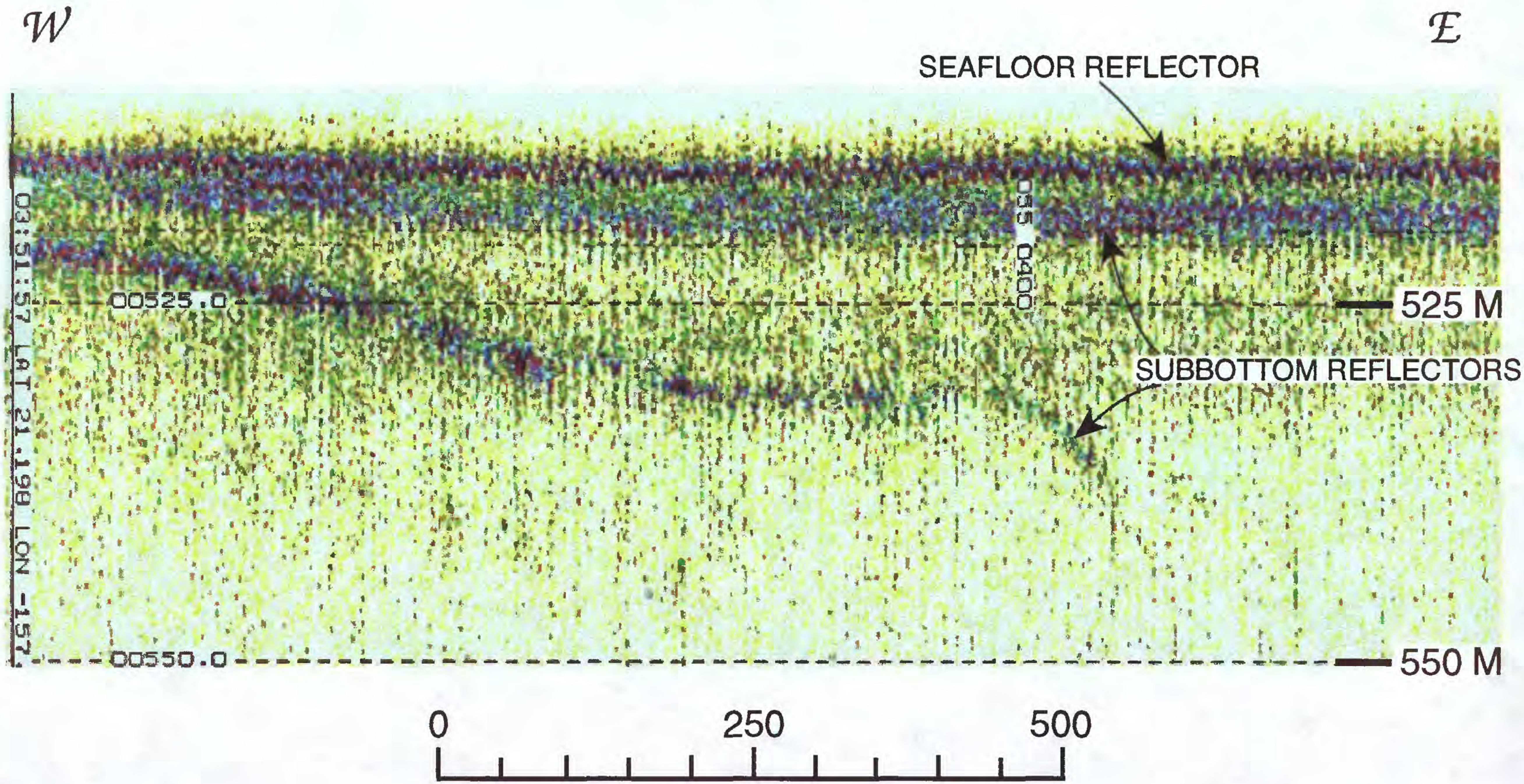


FIGURE 18

LINE 5
WEST OF DISPOSAL SITES

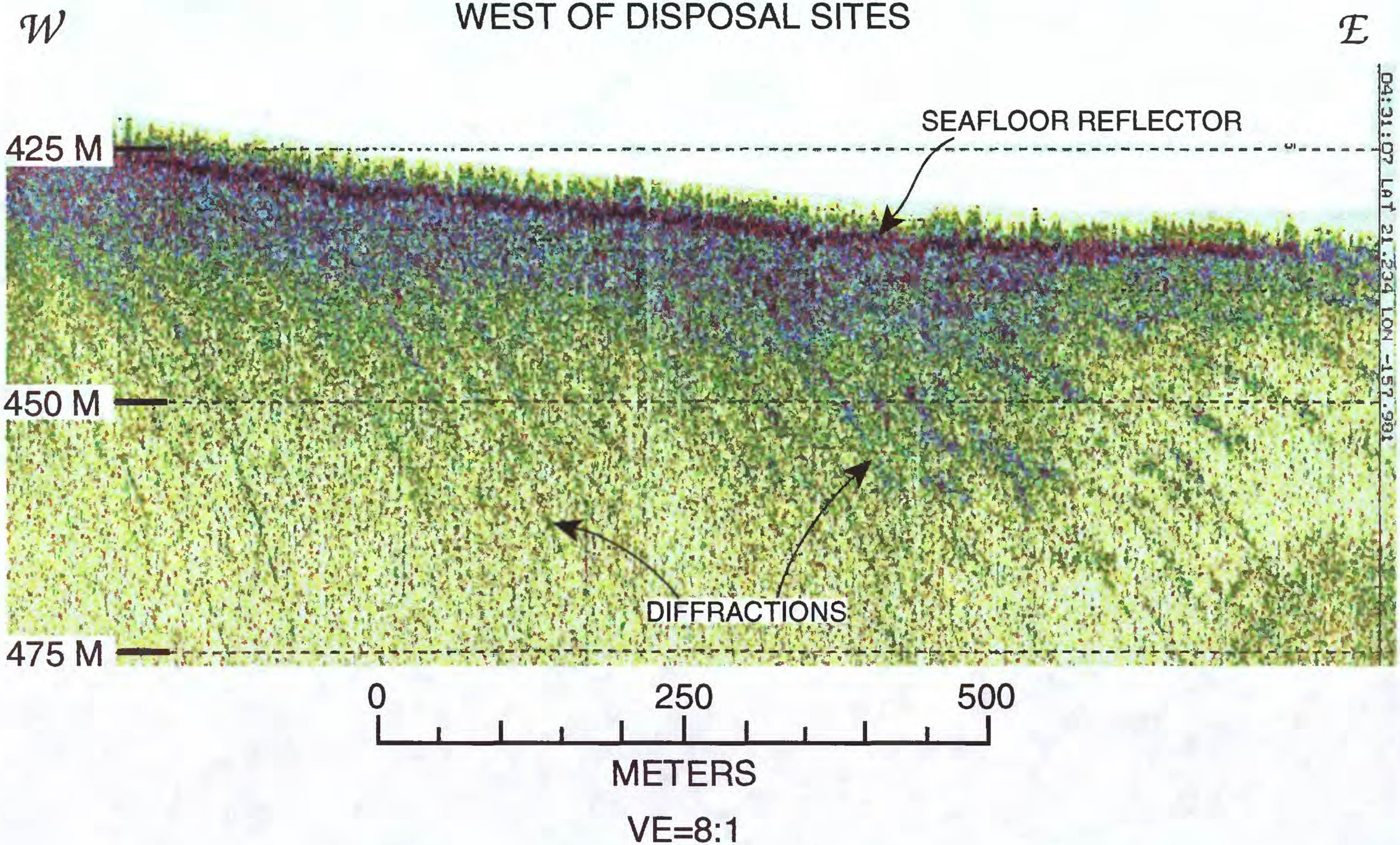
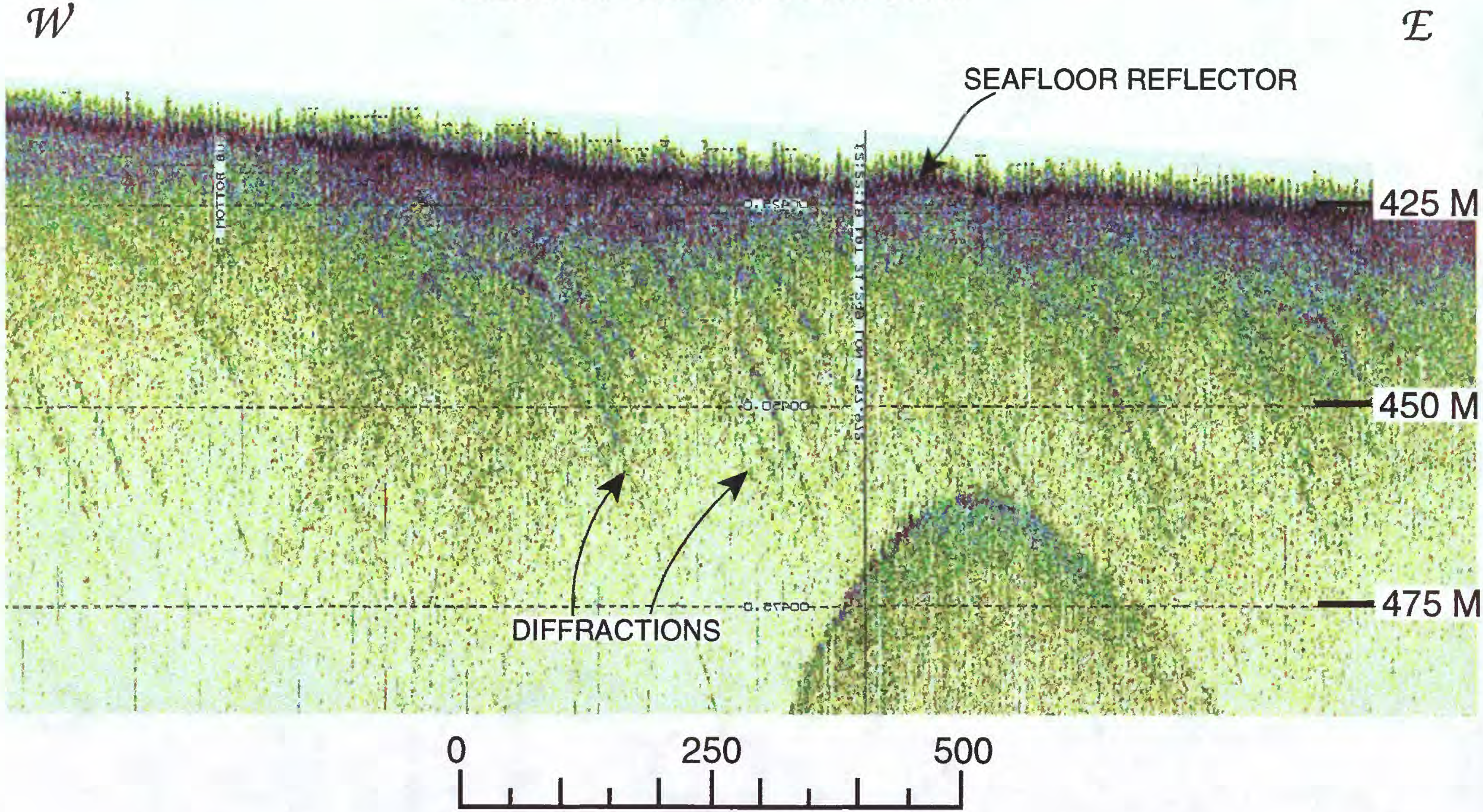


FIGURE 19

LINE 6
WEST OF SOUTH OAHU SITE



VE=8:1

FIGURE 20

APPENDIX 1

Cruise K1-93-HW Statistics

US Geological Survey Scientific Crew

Michael E. Torresan (co-chief scientist)
Monty A. Hampton (co-chief scientist)
John H. Barber Jr. (geologist)
Peter Dartnell (geologist)
John T. Gann (navigator/software design)
Lawrence D. Kooker (electrical engineer)
Michael E. Boyle (electrical engineer)
Walter Olson (marine technician)

Summary of Field Operations

Cruise Dates: 20 February–26 February, 1993 (051/2200–057/1937 GMT).

The U.S. Geological Survey, Branch of Pacific Marine Geology conducted a geophysical survey off of Honolulu Hawaii, Hawaii, for the U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency (figures 3 and 4). The survey was a follow–up to reconnaissance surveys conducted during the summer of 1991 in the vicinity of offshore dredged material disposal sites used for the disposal of dredge material from both Pearl and Honolulu Harbors. The geographic coordinates of the survey (table A1) define an area of about 254 km^2. The survey employed sidescan–sonar and high–resolution geophysical profiling to characterize the seafloor and surficial sediment both in, and adjacent to the disposal sites and two sewer outfalls located in Mamala Bay (figures 2–6). The purpose of the survey was to determine the character and topography of the seafloor in and around the disposal sites and outfalls, and determine the extent, thickness and nature of any associated deposits.

The survey was conducted aboard the University of Hawaii R/V Kila. The R/V Kila departed from the University of Hawaii Marine Center at Snug Harbor, Pier 45, Honolulu, Hawaii, at 051/2200 (1000 hrs Saturday, 20 February, 1993). We devoted the first few hours of survey time to streaming all gear and verifying that all systems were in proper working order. Once operational we collected chirp sonar and 3.5–kHz data along a predetermined reference line to "calibrate" and fine tune each profiling system. The survey commenced on 052/0500, along a series of nearly east-west lines, starting in shallow water and progressing seaward (figures 3 and 4). Lines ranged in length from 10 to 13 nm. Trackline spacing averaged 800 m, and survey speed was about 3 to 5 knots. Water depths ranged from a minimum of 20 m to a maximum of about 600 m (figure 5 and plate 1).

The survey was conducted in two phases. Phase one collected both sidescan sonar imagery and 3.5-kHz subbottom profiles, taking three days (February 20–February 23, 1993). Phase 2 also required 3 days (February 23–26, 1993), during which chirp sonar high-resolution subbottom profiles were acquired. Bathymetric data was collected during both Phase 1 and 2. The survey concluded Friday, 26 February, 1993 (057/1937). Over 300 line km of sidescan sonar, 3.5 kHz, and chirp sonar data were collected, and over 600 line km of bathymetric data were also collected.

Survey Area, and Location of Dredged Material Disposal Sites and and Waste Water Outfalls

Table A1: K1-93-HW Survey Coordinates

Latitude	Longitude
21° 17.4'N	158° 03.0'W
21° 17.2'N	157° 51.8'W
21° 15.5'N	157° 50.0'W
21° 11.7'N	157° 50.0'W
21° 11.7'N	158° 03.0'W

Table A2: South Oahu Dredged Material Disposal Site Coordinates

Latitude	Longitude
21° 15.96'N	157° 57.33'W
21° 15.40'N	157° 55.96'W
21° 14.96'N	157° 57.80'W
21° 14.40'N	157° 56.36'W

The center of the South Oahu Disposal Site investigated in this survey is 6.1 km offshore:

21° 15.17'N 157° 56.83'W

The Old Honolulu Harbor Disposal Site, is a circle with a 0.5 nautical mile radius originating from the point:

21° 14.50'N 157° 54.52'W

Two waste–water outfalls were also imaged during this survey; coordinates are listed below:

Sand Island Outfall: 21° 17.02'N 157° 54.40'W
Honouliuli Outfall: 21° 17.00'N 158° 01.83'W

Table A3: Sidescan Sonar, 3.5 kHz and Bathymetric Lines

Line No.	START LINE Time (JD/GMT)	Location (Lat/Lon)	END LINE Time (JD/GMT)	Location (Lat/Lon)
1	052/0500	21°17.05'N 157°58.56'W	052/0844	21°17.05'N 157° 52.59'W
2	052/0913	21°16.20'N 157°53.08'W	052/1258	21°16.20'N 158°03.00'W
3	052/1328	21°15.36'N 158°02.78'W	052/1730	21°15.36'N 157°50.42'W
4	052/1750	21°14.50'N 157°49.94'W	053/0005	21°14.48'N 157°02.96'W
5	053/0300	21°14.08'N 158°02.30'W	053/0805	21°14.08'N 157°49.93'W
6	053/0840	21°14.90'N 157°49.97'W	053/1438	21°14.92'N 157°02.70'W
7	053/1500	21°15.79'N 158°02.68'W	053/1917	21°15.79'N 157°50.66'W
8	053/1934	21°15.61'N 157°50.86'W	053/1952	21°16.17'N 157°50.31'W
9	053/2015	21°16.63'N 157°51.00'W	053/2037	21°17.22'N 157°52.01'W
10	053/2040	21°17.19'N 157°52.28'W	053/2115	21°15.78'N 157°56.09'W
11	053/2300	21°13.65"N 158°02.70'W	054/0255	21°13.63'N 157°49.29'W
12	054/0445	21°12.78'N 157°50.13'W	054/1205	21°12.77'N 158°01.94'W
13A	054/1230	21°12.32'N 158°02.90'W	054/1255	21°12.37'N 158°01.31'W
13B	054/1500	21°12.32'N 158°01.05'W	054/1700	21°12.35'N 157°55.30'W
13C	054/1710	21°12.35'N 157°54.88'W	054/1906	21°12.35'N 157°49.99'W
14	054/1940	21°13.19'N 157°49.74'W	055/0100	21°13.22'N 158°02.86'W
15	055/0135	21°11.91'N 158°02.55'W	055/0542	21°11.89'N 157°51.95'W
16	055/0635	21°11.87'N 157°49.97'W	055/0915	21°16.59'N 158°03.01'W
17	055/0930	21°16.69'N 158°02.64'W	055/1412	21°16.70'N ^157°51.25'W

Table A4: Chirp Sonar and Bathymetric Lines

Line No.	START LINE Time (JD/GMT)	Location (Lat/Lon)	END LINE Time (JD/GMT)	Location (Lat/Lon)
18A	055/2033	21°17.13'N 157°51.73'W	055/2136	21°17.09'N 157°57.59'W
18B	055/2338	21°17.12'N 157°54.97'W	056/0215	21°16.99'N 158°02.81'W
19A	056/0255	21°16.23'N 158°01.52'W	056/0609	21°16.24'N 157°54.41'W
19B	056/0845	21°16.21'N 157°57.13'W	056/0950	21°16.26'N 157°54.16'W
19C	056/1204	21°16.21'N 157°57.15'W	056/1215	21°16.25'N 157°56.49'W
19D	056/1245	21°16.22'N 157°55.60'W	056/1350	21°16.24'N 157°51.49'W
20	056/1412	21°15.37'N 157°51.76'W	056/1740	21°15.36'N 158°02.73'W
21	056/1800	21°14.46'N 158°02.58'W	056/2103	21°14.53'N 157°51.37'W
22	056/2122	21°13.67'N 157°51.31'W	056/2338	21°13.64'N 158°02.75'W
23	057/0003	21°12.75'N 158°02.66'W	057/0216	21°12.77'N 157°51.14'W
24	057/0234	21°11.88'N 157°51.33'W	057/0451	21°11.92'N 158°03.07'W
25	057/0511	21°13.19'N 158°02.65'W	057/0744	21°13.23'N 157°51.34'W
26	057/0805	21°12.37'N 157°51.48'W	057/1013	21°12.32'N 158°02.67'W
27	057/1055	21°14.02'N 158°02.57'W	057/1246	21°14.10'N 157°51.50'W
28	057/1302	21°14.93'N 157°51.44'W	057/1501	21°14.93'N 158°02.61'W
29	057/1515	21°15.81'N 158°02.71'W	057/1702	21°15.83'N 157°51.86'W
Cal 1	057/1714	21°15.57'N 157°50.89'W	057/1733	21°16.18'N 157°50.27'W
30	057/1751	21°16.67'N 157°51.64'W	057/1937	21°16.66'N 158°00.12'W

NOTE: All times are in Julian Day and Greenwich Mean Time (JD/GMT)

APPENDIX 2: SCIENTIFIC EQUIPMENT METHODS AND SUMMARY

Geophysical and Navigation Systems

EG&G SMS 990 59-kHz Digital Sidescan Sonar and SMS 960 Modem:

An EG&G SMS 990 high-resolution, digital sidescan sonar towfish and EG&G SMS 960 digital modem and recorder were used for the sidescan sonar survey. The system operates at 59 kHz, with a DC to 600–Hz bandwidth, and was set at a 1 km swath. The towfish was maintained at a nominal altitude of 50–100 m above the seafloor. Trackline spacing was 800 m providing a 20% overlap of imagery between adjacent lines. Advertised spatial resolution of the system is up to 1/800 of the selected swath width, equating to about 1.3 m for the 1–km swath employed. The system generates orthorectified images onboard ship in real time, that were used for quality control during the survey. The corrected real-time imagery was displayed on a graphic recorder having 16 gray tone levels, and uncorrected images were displayed on a Raytheon 800 TDU recorder. Unprocessed digital sonar data is acquired through USGS-developed MudScan software (Gann and others, 1993), merged with concurrently collected bathymetric data, and the digitally acquired data are archived on magneto-optical disc for post-cruise, full-scale digital processing and digital mosaicking.

The sidescan sonar system was deployed on 052/0411 and retrieved on 055/1412, following the survey. The system performed well, with only two periods of down time owing to one failed circuit board and one corroded connector.

Following the survey, the uncorrected sonar data were processed and digitally mosaicked using the USGS Mini Image Processing System (MIPS), to remove geometric distortions and noise inherent to the collection of sonar data. Post-cruise processing began with removal of the water column, followed by radiometric (shading, destriping and debanding, speckle removal, and nadir tonal improvements) and geometric (slant–to–ground range projection, aspect ratio, and delta velocity) corrections. Details of the processing routines employed in producing the digital mosaic are described by Chavez and Soderblom (1974), Chavez (1986), and Gardner and Chavez, (1987).

Interpretation of the Sidescan Sonar Mosaic:

Sidescan sonar mosaics are images of the seafloor that are analogous to an aerial photograph. Acoustic energy transmitted from the sidescan sonar vehicle is backscattered from the seafloor and the backscatter strength is recorded on a shipboard recorder and archived on optical disc. These digital acoustic data are then computer processed following the survey, so that the final mosaic represents a corrected, plan view of the seafloor. Seafloor features viewed on the processed mosaic are in their correct spatial position and true geometric shape.

The mosaic is presented as a black and white image, with various shades of gray used to define the variety of seafloor features. These shades of gray represent the varying energy levels of acoustic backscatter, and, for the mosaic presented in this report, the lighter shades represent higher acoustic backscatter. Typically, hard substrate, steep slopes, and rough bottoms produce higher backscatter (lighter features), but, many complex variables combine to determine how sound is backscattered and reflected from the seafloor. One assumption made by researchers is that the sidescan sonar is only imaging the seafloor. This is likely true for the system employed in this study, however, some sound energy may penetrate below the seafloor up to a few tens of centimeters. The amount of subsurface penetration is linked to the frequency of the sonar (the higher the frequency, the shallower the penetration), and nature of the seafloor substrate. Consequently, mosaic interpretation is not as straightforward as aerial photo interpretation, and, other data sets (i.e., high-resolution seismic reflection profiles, bottom photographs, and seafloor samples) are required to supplement the imagery so that accurate interpretations can be made.

The mosaic presented in this report (plate 1) is presented in Mercator projection at about 1:40000 scale, has a resolution of 1.3 m per pixel, and shows two principal types of high–backscatter features: dredged spoil deposits and submerged reefs. The dredged spoils form two major high backscatter deposits in the central portion of the mosaic (figure 6 and plate 1), that comprise circular to subcircular mounds or footprints that coalesce to form the larger deposits. The second set of high–backscatter features represent submerged (drowned) reefs. These reefs are primarily coralline debris and limestone. A large reef is visible as a broad area of high backscatter on the western side of the mosaic (figure 6). Native seafloor sediment has a typical low backscatter and is visible as the darker background on which the higher backscatter dredged material is resting.

Raytheon DSF–6000 Echosounder:

A hull-mounted Raytheon DSF–6000, 12–kHz echosounder was employed for bathymetric profiling. The transducers were fired at a 1 second interval, and the resulting analog records show a sharp seafloor return with essentially no subbottom penetration. The system has a theoretical resolution of about 5 cm and a horizontal resolution of 5 to 15 meters over the surveyed depth range (i.e., about 20 to 600 m). Water depths are recorded assuming an acoustic velocity of sea water equal to 1500 m/sec, and a correction was made for offset of the transducers from the sea surface. The digital bathymetric data is merged with the concurrently collected sidescan sonar data and stored on both optical and floppy disc for post–cruise processing. The system performed flawlessly for the duration of the survey.

3.5-kHz High–Resolution Subbottom Profiling System:

High-resolution 3.5–kHz subbottom profiles were collected concurrently with sidescan sonar imagery. The system comprises an Ocean Data Equipment Corporation (ODEC) Bathy 2000, chirp signal correlator and Raytheon PTR transceiver, driving a 3.5–kHz subbottom profiler having four Raytheon TR109 transducers (mounted in a towfish). Pulse repetition rates were 0.25, 0.5 and 1.0 sec. The 3.5–kHz return signals were displayed on a 16–bit format color monitor and on analog HP ink–jet color paper records. The monitor displays the acoustic profile, date, time (JD/GMT), location, ship speed, pulse repetition rate and duration, water depth, and gain. All data are digital, merged with navigation and archived on optical disc. The theoretical resolution of the system is 11 cm in the vertical and 5 to 30 meters in 30 to 1000 meters water depth. Owing to printer and monitor resolution, the practical resolution is on the order of 0.5 meters. A correction was made for offset of the tow fish/transducers from the sea surface, and the acoustic velocity of sea water was assumed to be 1500 m/sec.

The 3.5–kHz tow fish was deployed on 051/2335 (March 20, 1993). The system was tested, found operational, and official logging commenced at 052/0000. The system performed well with no maintenance required throughout the course of the survey. The 3.5–kHz profiling terminated on 057/1937 (March 23, 1993).

Datasonics Chirp Sonar High–Resolution Subbottom Profiler:

A Datasonics CAP–6000A chirp sonar subbottom profiling system was used for this study, and is described in detail by Mayer and LeBlanc (1983), Schock and others (1989), and Schock and LeBlanc (1990a, 1990b). The chirp system produces very high resolution subbottom profiles from a precise, computer generated, swept frequency output whose reflected returns are match filtered to compress the pulse and suppress noise. The acoustic profiles are displayed real time on a super VGA graphics monitor and on ink–jet color paper copies. The raw-data is archived as a full wave form return signal on 4-mm DAT tape; this allows the received signals to be replayed through the CAP–6000A system at scales and gain settings that allow optimum observation of subbottom reflections.

The chirp sonar system was deployed for testing on 051/2252 and tested as operational. Chirp sonar profiling commenced on 055/1955, and concluded on 057/1936. The system performed poorly throughout the survey, owing to noise inherent to our specific chirp sonar and to noise generated by the winch. When the system did operate properly, we were unable to resolve any subbottom layers that approached the advertised resolution (20 cm). The poor quality of the chirp data may also result from the nature of the seafloor sediment in Mamala Bay. Communications with colleagues who have employed chirp sonar in Mamala Bay indicate similar results with other chirp systems (James Barry, MMTC, Look Laboratory, University of Hawaii; and Mark Erickson, Sea Engineering Inc., Waimanalo, Hawaii; oral communication).

YoNav Navigation System:

The primary shipboard navigation system employed was autonomous or single-receiver GPS (the Global Positioning System), and shipboard navigation was provided by a Trimble 4000AX GPS receiver. GPS is a 3–dimensional location system, the foundation of which is the Department of Defense's (DOD) NAVSTAR satellite constellation. The system is based on observations of signals emitted from the satellite constellation. Satellite range observations are then processed by GPS receivers that determine geodedic latitude, longitude, and height relative to a reference ellipsoid (Georgiadou and Doucet, 1990; Wells and Kleusberg, 1990). The single-receiver GPS has an accuracy of 100 meters, 2D RMS, which occurs when the U.S. Government DOD program "Selective Availability" (SA) is implemented. SA denies GPS users the full position accuracy of GPS. However, when SA is not implemented, observed accuracy is about 50 m, 2D RMS.

LORAN–C and transit satellites were the primary backup positioning systems. Navigational data was collected with the USGS-designed YoNav Navigation system, capable of collecting a variety of navigation signals including GPS, LORAN–C (either hyperbolic or rho–rho), transit satellites, and micro-wave frequency shore–based transponder systems. The YoNav system is a PC–based data acquisition and display program written in Microsoft C/C++ designed by the USGS to provide navigation services on almost any DOS platform. The YoNav system incorporates a real-time trackline display and line generating software for both the ships' bridge and scientific personnel and is described in detail in Gann (1992). The display shows the ships' position relative to the desired survey line, allowing bridge personnel to more easily stay on line. The GPS system worked well, providing 24 hours per day navigation.

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