

HAWAII DEEP WATER CABLE PROGRAM

PHASE II-D

TASK 1

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**SIDE-SCAN SONAR AND SWATH BATHYMETRY
MAPPING SURVEY OF THE PREFERRED
CABLE ROUTE FROM MAUI TO OAHU, HAWAII**

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Department of Business and Economic Development

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**SIDE-SCAN SONAR AND SWATH BATHYMETRY
MAPPING SURVEY OF THE PREFERRED
CABLE ROUTE FROM MAUI TO OAHU, HAWAII**

Prepared by

Seafloor Surveys International, Inc.

for

Parsons Hawaii

Hawaiian Electric Company, Inc.

and the

State of Hawaii

Department of Business and Economic Development

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PURPOSE AND BACKGROUND INFORMATION

The overall goal of this portion of the Hawaii Deep Water Cable (HDWC) project is to demonstrate that at least one feasible route for a submarine electric transmission cable exists between the islands of Maui and Oahu.

Various studies of the shallow water marine topography surrounding the principal Hawaiian Islands, including those previously conducted for the HDWC program, provide background information applicable to this proposed survey. These studies suggest that most of the "preferred route" from Ahihi Bay, Maui, to Waimanalo, Oahu, will run along submerged terraces that were formed by reefs that grew during the low stands of sea level accompanying periods of Pleistocene glaciation. In other areas of the state where these terraces have been studied, they have been found to have relatively smooth surfaces that are generally covered with sand-sized sediments. The areas where the fossil reef material is still exposed are typically found to contain gaps and passes in the reef, or portions of the reef surface which are sufficiently smooth that they would not constitute a barrier to the cable. The major portion of the proposed route from Ahihi Bay to the western end of Molokai was expected to have these fairly favorable characteristics.

The most serious potential obstacles along this route were thought to be the edges of the reefs where the cable must drop off into the deeper water portions of the Kaiwi (Molokai) Channel. This problem is the same as has been identified by surveys on the sides of the Alenuihaha Channel between the islands of Maui and Hawaii, although at least on the Kohala (Hawaii) side of that channel the reefs are partly covered by sand. If the terraces and their associated reefs are not buried, they have the potential of dropping nearly vertically for 300 to 400 meters. Where these features have been surveyed in detail off Kahi Point, Oahu, slopes as great as 30 to 40 degrees are found. Similar conditions were anticipated in the Kaiwi Channel.

EQUIPMENT USED

SeaMARC/S

SSI has designed and is operating a high-resolution, 150 KHz side-scan sonar system that produces geometrically correct acoustic images of the seafloor (analogous to aerial photographs) while simultaneously producing co-registered hydrographic quality swath bathymetry maps. This unique new survey system, called the SSI SeaMARC/S, is the most technologically advanced seafloor mapping system available. It is the only system in the world that can provide these high-resolution, co-registered, acoustic images and swath bathymetry data in shallow water; the only comparable system is the lower-resolution SeaMARC II operated by the Hawaii Institute of Geophysics, which is designed for use in deep water (generally depths greater than 1000 meters). The SSI SeaMARC/S system is ideally suited for the HDWC survey.

The full specifications of the SSI SeaMARC/S are provided in Appendix A. Critical to the HDWC survey is the capability of the SSI SeaMARC/S to readily adjust resolution and swath widths to meet survey needs as they develop. The system can operate at up to a 1000 meter swath width, so rapid bottom coverage is obtained and objects with dimensions on the order of several tens of meters can be identified. When more resolution is needed, the SSI SeaMARC/S can be operated closer to the seafloor so swath widths as little as 50 meters, with proportionally greater image resolution, can be surveyed. At the same time, SeaMARC/S measures the swath bathymetry, providing 100% coverage of the bottom throughout an area as wide as approximately 3 times towfish altitude. The bathymetry data has an accuracy that is better than 2% of the towfish altitude.

In critical areas of the HDWC survey all significant bottom features were imaged to provide information on texture and bottom character, and bathymetry to about +/- one to five meters (depending on water depths) was obtained. Although other systems can provide bathymetric profiles with greater accuracy, such profiles are less precisely located and the bathymetry of the seafloor between these profiles has to be interpolated. The bathymetry derived from the SSI SeaMARC/S is comprised of dense, independently measured soundings over 100% of the swath. Although the SSI SeaMARC/S bathymetry may be somewhat lower

resolution than some deep tow bathymetry profiles, it is far more useful for determining regional bottom character (and thus the HDWC route) than any profile data.

Data display, logging and playback systems

The system used for at-sea data logging and display is based on a Masscomp 5600 computer configured with a single 68020 processor, 4 MBytes of RAM, a 1 GigaByte optical disk for data storage, a data acquisition and control front-end processor, an HP plotter for real-time navigation plots and Tektronix color plotters for real-time display of bathymetry, fish attitude and various instrument parameters.

The logging program treats each ping emitted by SeaMARC/S as a discrete event and writes a 3072 byte record to the optical disk for each such event. This record contains the side-scan sonar and bathymetric information associated with the ping as well as time, navigation data and the fish attitude and instrument parameters. Concurrently, but lagging a minute behind, a playback program reads the records from the optical disk and displays them on the paper recorders. This provides a monitor record of all the various data streams as well as demonstrating that the data have successfully been recorded on the optical disk.

The land-based processing system used to render the data into final form is also based on a Masscomp 5600 computer, similar to that used for data logging. A Houston Instruments plotter for large navigation plots, a Raytheon Thermal Display Unit for displaying the side-scan data and a large-screen high-resolution color graphics system for data processing are additions to the system.

Ship navigation system

The surface ship navigation system used for this survey was a Del Norte Technology, Inc "Trisponder" using the Model 542 Digital Distance Measuring Unit (DDMU). The DDMU is a microprocessor-based system designed for use with X-band frequency microwave transponders. These transponders use very short electromagnetic waves with a frequency of 8.0 to 12.4 GHz. The Trisponder is a line-of-sight system that works to a maximum range to 80 km, and claims an accuracy of +/- 1 meter. The Model 542 DDMU has a guidance software package that provides steering information for the survey ship's helmsman, including direction to steer to get to a preprogrammed line, rate of closure on to the line, and distance to go to the end of the line. It also provides position and ground speed information and is capable of multi-baseline operation.

During all of our surveys, while in microwave transmission range of the island stations (generally about 80 kilometers) we calculated a position for the ship once every five seconds using the Trisponder system.

The multi-baseline program allows the DDMU to choose which of the several transponders from which it is receiving data has the best geometry to provide a fix for a given ship location. This program will also take this fix information and calculate distances to the other transponders that it is receiving, and compares this distance to the measured distance from these transponders. This information is displayed on the monitor and gives an indication of the quality of the fixes provided by the Trisponder system.

The Model 542 DDMU also provides a digital output of the data displayed on the monitor. This output was digitally recorded on the same computer system used to log the SeaMARC/S data.

Good angles between stations could not always be maintained due to the physical constraints of the geography of the islands. In the Kaiwi Channel, for example, the only possible locations for the land stations are on Molokai and Oahu, and the cable route runs between those islands. When the survey ship is located almost on the base line between land stations the calculated position is not well-controlled, even when the individual range measurements are excellent. Under these conditions the Trisponder will still provide fixes, but the considerable deviation between individual fixes (one every five seconds) has to be smoothed out with resultant loss of navigational resolution and accuracy. (See the section on navigation data for a further discussion of this problem.)

Several short sections of the survey route were in microwave transmission shadows caused by local obstructions (trees, small hills, Molokini etc). These included a portion of panels 12, 13 and 33. In the early morning of 5 March, Trisponder-controlled navigation was lost due to weak batteries at the remote sites. Surveying continued, controlled by radar fixes on prominent features on shore. The areas surveyed during this time include portions of panels 28, 30, 31 and 33.

Land-based navigational control

The microwave transponders used with this navigation system were located at landmarks on the islands of Oahu, Molokai and Maui. These sites were chosen to give optimum angles between the vessel and the land stations, and whenever possible were set on well-located triangulation stations. The location of stations that were not on known triangulation stations were picked using the highest resolution maps available.

After the Phase 1 cruises, when it was determined that some of the island-based navigation control sites were mislocated (in at least one case because the supposed accurate position provided to SSI was wrong), the suspect station locations were systematically checked by SSI using a satellite translocation positioning system. This positioning system, which was leased by SSI from NCS International (a marine navigation company located in Ventura, California), was composed of three portable Transet orbiting satellite positioning receivers and a master satellite receiver/computer. The system works by placing the master station on a known geodetic landmark while simultaneously placing the slave stations on the sites to be repositioned. The systems then run for enough time to precisely record the overhead passage of a series of navigation satellites (usually at least a day of recording time). The position determined by each satellite pass is then compared to the positions determined for that same pass over the known station, so that random errors caused by radio transmission irregularities or incorrect orbit calculations can be compensated for in determining the position of the slave station. After a series of passes, the poorly known position of the slave station can be located to an accuracy of +/- 3 meters, which is a degree of accuracy adequate to properly utilize the Trisponder net. This position relocation effort took several man-weeks of effort, in addition to the expense of leasing the necessary satellite positioning equipment. The end result, however, was that SSI established a navigation network between East Maui and Oahu that is more accurate than would have been previously available.

The inter-island navigation control stations established by SSI will be important for any future navigation, and are described in detail in Appendix B.

Towfish positioning

During most of the survey, water depths were less than about 250 meters and the towfish was deployed at depths of only about twenty meters, so it was positioned close behind the survey ship. During these times, the towfish position was calculated on the basis of a measured offset behind the ship, and it is assumed that the towfish travels along the same track as the ship at this fixed offset. This towfish position is well within the other navigational accuracies of the survey. However, in the Kaiwi Channel, the towfish was deployed to greater depths and was thus offset far behind the survey ship. During these times, the position of the towfish had to be accurately located relative to the survey ship so that the position of the towfish would be accurately located relative to the survey's geographical coordinate system. This towfish location was determined by using a Trackpoint II ultra-short base line positioning system, which

was leased from another branch of NCS International (based in Houston, Texas).

The Trackpoint II is a small array of three transducers which send an acoustic signal from the survey ship to a transponder located on the towfish. When this transponder detects the outgoing signal, it replies with a sound pulse. The surface array measures the range and direction of the towfish-mounted transponder, thus providing the position of the SeaMARC/S towfish. SSI also leased a navigation integration system (and a technician to operate the system) from NCS to perform the complete towfish navigation task.

Ships and deck gear

The ship used for the first phase of the survey was the fishing vessel HAWAII MAKAI. She has an overall length of 76 feet, a diesel drive and single screw. The HAWAII MAKAI is equipped with an auto pilot and Furuno color, dual-frequency echo sounder. This equipment was extremely useful in conducting the survey.

The SeaMARC/S was towed from an hydraulic winch and wire hauling system belonging to SSI. This equipment was positioned on the upper "01" deck of the HAWAII MAKAI and the tow cable fair-lead through a block hanging from a moveable davit installed by SSI on the stern of the vessel. The SeaMARC/S fish was deployed using an articulated crane belonging to the HAWAII MAKAI.

During the second phase of the survey, the Research Vessel KILA, operated by the University of Hawaii Marine Center, was used. The KILA is 104 feet overall length with a 13 foot draft. She has a dual diesel drive and is manned by a crew of five. She is equipped with an autopilot, 12 kHz echo sounder, articulated crane and stern A-frame. The SeaMARC/S winch and wire hauling system was set on the upper "01" deck similar to the set-up on the HAWAII MAKAI, and a small over-the-side crane was also used on the KILA to get the towfish in and out of the water. Being considerably larger than the HAWAII MAKAI, the KILA was a much more comfortable operating platform.

PRELIMINARY CRUISE PLAN

The initial plan was to conduct this survey in two phases. Phase 1 was to be a reconnaissance survey of the entire preferred route that was designed to identify all problem areas for the electric cable installation. After analysis of the Phase 1 data, the Phase 2 surveys would be designed to provide more detailed data in potentially troublesome areas, or to survey alternate routes to bypass unfavorable portions of the planned route. This preliminary report covers work completed during both the Phase 1 and Phase 2 efforts.

The original schedule for Phase 1 was to complete the field work during the period 10 to 25 November 1986. This schedule could not be followed for two reasons. First, this schedule was predicated on the condition in the Parsons RFP, Section C, page 5, that indicated that SSI would receive a Notice to Proceed on 1 November 1986. The Notice to Proceed was not received until late December. Secondly, problems with data transmission through the long tow cable needed to survey the deep portion of Kaiwi Channel were discovered during a check-out cruise scheduled prior to starting the survey. Final resolution of this problem did not come until just prior to the start of the work in the Kaiwi channel on 16 December. A further constraint on the schedule was that the HAWAII MAKAI charter could only be extended until 19 December 1986.

Due to the delays in getting the first survey started and the HAWAII MAKAI schedule constraint, the work plan was modified so that instead of all the Phase 1 objectives being completed in one cruise, the shallow portions of the route from Molokai to Maui were to be surveyed first, then the deeper Kaiwi Channel portion would be completed in a separate cruise. This schedule was subsequently even more tightly constrained because of bad weather that occurred in late November and early December. During this period, there were several days when gale warnings were posted for all channels in the Hawaiian Islands, conditions that made it impossible to operate.

The final plan for Phase 1 scheduled the Maui to Molokai reconnaissance portion of the survey during the period 12 to 16 December, and the broad scale Kaiwi Channel portion of the survey from 16 to 19 December 1986. Phase 2 was to be scheduled as soon

as preliminary data analysis for unacceptable spans was completed by Makai Ocean Engineering.

The second phase of the survey was initially scheduled for the period from 9 to 20 February. The start was first delayed until the 12th of February because the SeaMARC/S had to be sent to Seattle for factory modifications to improve the telemetry electronics which caused problems during the first cruise. The cruise was delayed again when the Captain of the HAWAII MAKAI skipped town and the owner decided to take the ship back to the west coast. Arrangements were made to charter the KILA and the cruise was rescheduled for 2 to 6 March and 10 to 11 March, 1987.

CRUISE NARRATIVE

Phase 1

The HAWAII MAKAI left the Snug Harbor pier in Honolulu Harbor at 1910Z (Z is Zulu time, HST + 10 hours) on 12 December 1986, and headed for Laau Point, Molokai. During the transit across Kaiwi Channel, the navigation system was checked by activating the station at Puu Amikopala, Molokai. (These remote navigation transponder stations are set in a stand-by mode to conserve batteries until remotely interrogated, after which they will continuously respond to the master station [DDMU] on the survey vessel.) The Puu Amikopala transponder came up at 2140Z when the boat was 156,300 feet distant from the station. At 2330Z the trisponder at Kewela came on-line. Initial attempts to get the DDMU to navigate using these two stations were unsuccessful because of baseline resolution problems. The navigation system was finally up and running by 0015Z 13 Dec and the HAWAII MAKAI returned to turning point 2 (see the first location map, Figure 1, in the accompanying Atlas 1: Ship Track Plots) to begin the survey.

The SeaMARC/S towfish was deployed at 0100Z and commenced surveying line 1 - 1 at 0115Z. The water depth at the start of this line was about 60 meters, so surveying was initiated with a 200 meter swath width to provide optimum resolution and swath coverage for these relatively shallow depths. Problems with the data logging system, which caused several program crashes, meant that much of the data from this first line did not get recorded and would later have to be repeated.

Line 1 - 1 crossed the head of the Southwest Molokai Submarine Canyon at about 0500Z. At this point, the canyon drops from a terrace at about 60 m depth to a depth of 125 m. At 0508Z we switched to a 500 m swath width because of the deeper water. During the process of surveying this line, it became apparent that the Trisponder was not operating properly in the multi-baseline mode, although the operator control display indicated that this feature was turned on. While maneuvering to get onto line 2 after finishing line 1 - 1, this multi-baseline problem was corrected.

Prior to the start of line 2 the SeaMARC/S towfish was lowered deeper into the water in order to further isolate it from strong surface motion caused by the continuing poor weather conditions. The system was back on-line at 0704Z and line 2 - 3 started at 0743Z. Although the towfish motion was still more than desired, some improvement was noted.

During the course of surveying line 2, the SeaMARC/S data became increasingly noisy and attempts to solve the problem proved fruitless. At 1228Z, after turning onto line 3, we decided to temporarily abandon the survey to repair the system. SeaMARC/S was pulled aboard for repairs and the HAWAII MAKAI proceeded to an anchorage off Lahaina, approximately 3 miles from turning point 3. The problem turned out to be a short at the shipboard end of the tow cable. The HAWAII MAKAI was underway from the Lahaina anchorage at 0915Z. SeaMARC/S was redeployed at 1940Z and by 1955Z we were surveying to the SE on line 3 - 1.

While in the calm waters in the lee of West Maui, where we had good ranges to all four trisponder stations, the apparent offset we were getting in the lines due to poor positioning of the Puu Amikopala station was corrected. The position of this station was adjusted 50 feet west and 150 feet south. This change resulted in the reduction of the difference between measured and calculated ranges from Puu Amikopala from values of over 10 meters to values that were always under 10 meters.

At 0014Z 14 December 1986 line 3 - 1 was completed and line 4 commenced. The next 3 hours, until 0315Z, were spent surveying 4 parallel lines from turning point 4 towards the shore at Ahihi Bay. During parts of these tracks, the trisponders at Puu Laina and Kewela were blocked by the island of Molokini, causing loss of navigation control. However, these time periods were short and no course adjustments were made during the time navigation was not available, allowing for straight line interpolation across the navigation gaps.

At 0315Z, line 3 - 2 was started. At 0357Z a U-turn was steered while the SeaMARC/S towfish was lowered to a depth of 45 meters to get it closer to the bottom in the deeper waters at the south end of line 3. Surveying on various segments of line 3 continued until 1436Z, when a power surge caused the data logger to crash and loss of all signals from the SeaMARC/S towfish. The towfish was brought aboard at 1500Z. Since we were not far from Lahaina, we again proceeded to that anchorage to effect repairs. A transistor in the power supply had been damaged by the power surge; this was replaced with one borrowed from a spare power supply we had aboard the ship. While anchored off Lahaina, a partially filled optical disk containing all the data collected to that time was transferred to shore for transport to Honolulu. This would allow on-land data processing to start prior to the return of the HAWAII MAKAI.

By 1920Z, we were underway again. Because of apparent problems with the trisponder navigation system, we were not able to start surveying until 2245Z. We started surveying south on line 3 - 3, and finished the last of the line 3 segments at 0200Z 15 December 1986.

After stopping the logging system to put a new chart into the on-line navigation plotter, we proceeded northwest on line 2 - 1 at 0218Z. At 0637Z we changed course onto line 1 - 2 and continued to survey various parts of line 1 until 1309Z when we turned back onto line 2. Navigation control for this segment of line 2 was poor because the station at Kewela was not operational. The batteries powering the transponder had died, and attempts to buy replacements the previous evening (Sunday evening Molokai time) had failed. We continued surveying various segments of line 2 until 2241Z 16 December. During the short period from 2244Z to 2253Z on this line 2 survey we circled to change optical disks. This was the end of the first disk that we had filled completely (one Gigabyte of data) without having the system shut down.

At 0241Z we resumed surveying on line 1 and completed the work on this line at 0600Z. Between 0600Z and 0622Z we surveyed a box on the flat portion of the southeast corner of Penguin Bank to get data to develop a better flat bottom table. At 0622Z the SeaMARC/S towfish was retrieved and the HAWAII MAKAI headed for Honolulu. We tied up at Snug Harbor at 1040Z 16 December 1986 (0040 HST).

Later in the morning of 16 December the HAWAII MAKAI proceeded to the Makapuu Pier and remained there while the transponders were moved from their Maui and Molokai positions to sites on Oahu. During the day changes were made to the SeaMARC/S telemetry system to allow the use of a longer tow cable. This would allow us to deep-tow the system in the deeper portions of the Kaiwi Channel where the bottom is more than 500 meters deep.

The HAWAII MAKAI departed Makapuu just before dark and proceeded to turning point 5 offshore of Waimanalo. During the launch of the SeaMARC/S fish in rough seas the fish hit the side of the boat and all signals from the fish were lost. Since it would be unsafe to try to recover the fish in the rough conditions prevailing (state 4 seas), we proceeded to calmer waters in the lee of Koko Head, retrieved the fish, and proceeded to Snug Harbor to effect repairs. The HAWAII MAKAI tied up at Snug Harbor at 0030 HST. Upon opening the fish an oscillator that controls all the timing in the SeaMARC/S system was found out of its socket. When this was replaced everything worked properly.

On the afternoon of 16 December the DDMU was taken to Molokai to position the trisponder station at Puu Amikopala,

using the transponders set up at known points at Makapuu Light House and Koko Head as controls. This showed that the location was a further 15 feet west and 31 feet south of where we had calculated it should be on 13 December.

The next attempt to survey the Kaiwi Channel portion of the route started at 1400HST 18 December when the HAWAII MAKAI left Snug Harbor. Small craft advisories were up, so the SeaMARC/S fish was launched in the lee of Koko Head to take advantage of the calm. The fish was safely launched at 1730Z and towed to a point midway along line B. Surveying of the actual proposed route started when we turned onto Line B and headed to the northwest at 1945Z. When the on-line navigation plotter showed that we were steering a course that was not on the line, a check of the parameters entered in the DDMU was made. This showed that a wrong position was entered for turning point 1. This was corrected, and we resumed surveying the correct line B - 1 at 2040Z. We continued to survey various portions of line B until 0020Z 19 December.

After raising the fish in anticipation of the shallow water at the landward end of line A, we commenced surveying this line at 0050Z. Because we were now steering a course that went directly with the large waves, we immediately had problems with the auto pilot. The ship's bow would swing off course going down a wave and the auto pilot would over-compensate to bring the ship back on course. This continued until the swings became excessive and twice the boat actually swung through a full 360 degree circle. This lack of control was an unacceptable risk. Finally, the large waves forced us to abandon attempts to survey parallel to the preferred cable route, so a survey pattern orthogonal to the suggested route was run. An extra pass was made along this line to assure complete coverage. The survey of Line A was completed at 0311Z 19 December.

After lowering the fish deeper into the water, we recommenced surveying on line B. Several passes were made along the portion between turning point 5 and the deep portion of the Kaiwi Channel. This segment of the route survey was completed at 0555Z, and a fast transit run was made across the deep portion of the channel. The portion of the line across Penguin Bank to turning point 1 was surveyed between 0700Z and 1635Z. From 1645Z to 1945Z, a slow-speed, deep tow crossing was made of the deeper part of the channel. After this the fish was retrieved and the HAWAII MAKAI headed for Honolulu having successfully completed Phase 1 of the survey.

Phase 2

The KILA departed Snug Harbor at 1800Z (0800 HST), Tuesday, 3 March 1987, and arrived off Laau Point, Molokai, at 2200Z. Initial problems with the navigation system were solved by

changing the angle that the antenna was mounted on the mast. All the transponders that were within line-of-sight came on except for Kewela, which finally came up after new batteries were installed.

When SeaMARC/S was launched a series of interrelated electronics problems were discovered. These were due to modifications made while the system was in Seattle and the installation of a new Digiquartz depth sensor and its related electronics. As the problems usually were not apparent until the system was in the water, there were several rounds of making repairs, launching and testing the system, retrieving the fish, and starting again with more repairs. The system was finally in the water and operational at 0915Z 5 March 1987. During part of the time that repairs were being made to SeaMARC/S a 12kHz echo sounding survey was made of the submarine canyon north of Lanai, one of the rough areas found during the first survey.

The SeaMARC/S survey started west of Kaunakakai, Molokai at a point on line 1. At about 0945Z we changed course onto line 2 and surveyed to the southeast until we crossed the canyon north of Lanai. Several parallel lines were surveyed offset toward Lanai until the landward end of the canyon was imaged. After ascertaining that there was a route around the head of the canyon, we proceeded back to the original line and at 1610Z changed course back onto line 2.

At 1834Z we changed course onto line 5, a new line that was laid out as a result of the Phase 1 survey, to try to find a shallow water route (less than 100 meters water depth) that would bypass the boulder-strewn deep lagoon that we had surveyed west of Maui. Because a transponder had to be moved from Puu Laina to McGregor Point, and back, we wanted to finish this part of the survey during daylight hours. At 2140Z we changed course onto line 6, a north-south line that would intercept line 4 offshore of Ahihi Bay. We turned onto line 4 at about 2240Z, and surveyed to its seaward end and back again before turning onto a line parallel to line 6 at 2355Z. At 0225Z 6 March, while surveying to the northwest on line 5, we lost navigation control while the transponder at McGregor Point was moved back to Puu Laina.

Surveying recommenced on line 5 when the navigation grid was re-established at 0625Z. At 1105Z we changed course onto line 3. At 1340Z (0340 HST) we lost navigation control with the Trisponder system due to weak batteries at the remote sites. We continued the line using radar navigation and attempted to keep on a straight line by not changing course. On reaching line 4 at 1455Z we changed course to go back on a new line located between lines 3 and the 5/6 combination. This was an attempt to ascertain if the large boulders found at the base of the 100 meter reef, which caused unacceptable spans in the original survey, were common to the entire area west of Maui where the large

submerged deep lagoon was located. The new data, although not well located because of the navigation problems, did show boulders at the base of the reef throughout the area. As these ubiquitous boulders are considered a hazard to the cable, it appears that the newly established shallow route following lines 5/6 will be the preferred route.

At 1700Z the transponder batteries had been replaced by the land parties and we had good navigation again. We proceeded to turning point 2 and changed course onto a line parallel to line 2. At 2150Z we adjusted course to get a continuous track around the canyon north of Lanai. At 2205Z, however, we again lost our transponder navigation control so proceeded toward Molokai using Loran electronic navigation. The transponders were up again at 2312Z and we completed the track around the canyon and started back across to the Molokai side of the channel. Because in the center of the channel we were working near the baseline of the two available transponders (one on Molokai, one on Maui), the DDMU lost track of the baselines and placed the survey ship on the wrong side of the base line as we approached Molokai. At this point we were dangerously near the reef off the south coast of Molokai so we broke off the survey until we could properly reconstruct our track and position. At 0125Z on 7 March, we were back on track toward TP 2. At 0230Z we changed course onto line 1. Line 1 was successfully completed at 1525Z. The SeaMARC/S towfish was retrieved and the KILA started for Oahu.

During the subsequent port stop the Trackpoint II towfish location system was to arrive from the mainland and be installed on the KILA. Although the technician arrived from Texas to operate the equipment, some of the equipment was delayed in shipment. All portions of the system finally arrived, and after fabricating and installing modifications to an over-the-side boom on the KILA, the Trackpoint II was installed, tested, and calibrated in port.

The second part of the Phase 2 cruise started at 2330Z 10 March 1987 (1330 HST), when the KILA departed Snug Harbor for the Kaiwi Channel. SeaMARC/S was launched at 0225Z 11 March with a transponder for a Trackpoint II fish location system mounted on the umbilical 134 feet forward of the SeaMARC/S transducers. By 0440Z all systems were operational and at 0535Z we were on the line at the Oahu end of the deep portion of the channel. As we traversed down the slope the tow cable was continuously let out to keep the fish within range of the bottom. At 0615Z all the wire that could safely be deployed was out and we continued down the rest of the slope. At 0715Z the deep part of the channel was reached and SeaMARC/S continued to produce good survey data. The deep part of the channel was crossed and the fish slowly raised as we approached the slope on the Molokai side of the deep channel. By 0900Z the fish was back near the surface at normal

towing depths and we continued across Penguin Bank to the end of the line.

At 1130Z we turned back to survey a parallel line and by 1320Z were back to the edge of the deep portion of the Kaiwi Channel. The fish was again lowered and a traverse made across to the Oahu side of the deep channel. Another traverse back across the deep part of the channel was completed at 2308Z and the fish brought aboard to check a ground fault that was causing a deterioration of the data. The system was back in the water and logging resumed at 0130Z 12 March 1987. About 0240Z we were back on line and at 0820Z the deep water survey was completed and the fish back in its shallow tow configuration.

At 0910Z we began the survey of the final major obstruction delineated during the Phase 1 cruise, a canyon head northeast of Makapuu. After seven passes through the area, an apparently acceptable route was found around the head of the canyon. The survey then continued on to the end of the line and a parallel route was surveyed back to the deep portion of the Kaiwi channel. At 1310Z the fish was aboard and the KILA started for Snug Harbor. KILA tied up at the University of Hawaii Marine Facility at 1530Z (0530 HST) 12 March 1987 after completing the data gathering portion of the project.

DATA

Navigation

Transponder stations were located at 8 different locations; 3 on Maui, 2 on Molokai, and 3 on Oahu. (See Appendix B for a description of the individual stations.) The coordinates of the stations were determined in the Hawaii state grid system, zone 2. Because the island of Oahu is not in zone 2, which only includes Maui County, the positions of the stations on Oahu had to be converted to zone 2 coordinates. Since the stations on Oahu are all within 60 miles of the zone 2 central meridian, this does not introduce a significant error, as positions within 79 miles of the central meridian are considered acceptable. These station positions and the positions of turning points at the ends of the lines to be surveyed were entered in the Transponder microwave navigation system master control unit (DDMU) and used to control the surveys. A digital output from the DDMU containing position and time data was sent to the data logging system and recorded with the sonar mapping data on optical disk.

Once ashore the navigation data were read off the optical disk and processed to produce a ship's speed and heading file. As a first step in editing this file, any data that produced point-to-point speeds that were 1.5 knots different from the previous calculated speed were considered erroneous and these were deleted. The navigation files were then plotted at a scale of 1:10,000. These plots were examined for track offsets due to the DDMU switching between transponder control stations. In the majority of cases where switches were known to have occurred there were no indications of track offsets, indicating that the transponder positions were located with an accuracy that exceeded the navigational resolution at this survey scale. Where offsets did occur the suspect track was noted and the navigation was adjusted using overlapping data control points observed while constructing the side-scan sonar and bathymetry mosaics. Since we knew the navigation for the first lines surveyed on lines 1 and 2 was suspect (due to the initial mislocation of the Puu Amikopala station), the navigation data from these tracks were adjusted to match the properly navigated adjacent survey lines during construction of the mosaics.

As expected, the one area where we had significant problems with navigation was in the middle of Kaiwi Channel. This is an area where none of the station combinations were able to meet the criterion for giving good positions. The DDMU is programed to accept angles between the stations of from 30° to 150° . When the angles between the transponder stations exceed these limits there

is the possibility that significant across track errors can exist. In the Kaiwi Channel it is only possible to work with stations on Oahu and Molokai. When the survey vessel is in the middle of the channel there is no combination of land stations that fall within the acceptable geometry for full navigational accuracy.

The figures labeled Box 1 to Box 33 in the accompanying Atlas 1 show the final navigation plots at a scale of 1:30,000 for each of the 33 data panels. Figure 1 (at a scale of 1:550,000) shows the location of the 33 individual panels that comprise the data display portion of the atlas. This figure is also included in Atlas 1.

Side-scan sonar and bathymetry

The side-scan sonar and bathymetry data from the SeaMARC/S system have been assembled into geographically correct mosaics that are presented as Panels 1 through 33 in the accompanying Atlas 2: Survey Data.

The bathymetry data in the Atlas are contoured at a 5 meter contour interval (assuming a sound speed in water of 1500 meters per second). Each bathymetric chart was produced by assembling a mosaic of color-coded bathymetric data to check navigation and overlap accuracy, and then gridding all the bathymetry data in the area of each Atlas 2 panel. Each cell in the grid represents a 20 meter by 20 meter area of the seafloor. Where multiple data points exist for a single grid cell the data were averaged, using the "goodness" of each point as a weighing factor for the average. The "goodness" value of a bathymetry point is a measure of the number of phase samples (each phase sample can be translated into a raw bathymetry value) associated with the determination of the depth at a certain geographical spot.

The side-scan sonar data were replayed onto a paper record as strips along individual tracks and assembled to construct a mosaic by cutting the strips and laying them down on the navigation. The preparation of a side-scan mosaic requires interpretation and human intervention, so is not easily done entirely by computer, as is possible with the bathymetry data. Unlike a photograph that has a primary light source that illuminates the total area of the image from one direction, the ensonification of the ocean floor in a SeaMARC/S image is from the center of the survey track. Thus for a given track, objects on opposite sides of the center of the image will be ensonified from opposite directions. In the case where the same object is ensonified in overlapping data sets, the two images can show it ensonified from opposite sides. Depending on the shape and orientation of an object or geologic feature on the seafloor, it will likely look quite different when viewed from different directions. For example, a steep change in topography, such as a reef face, will

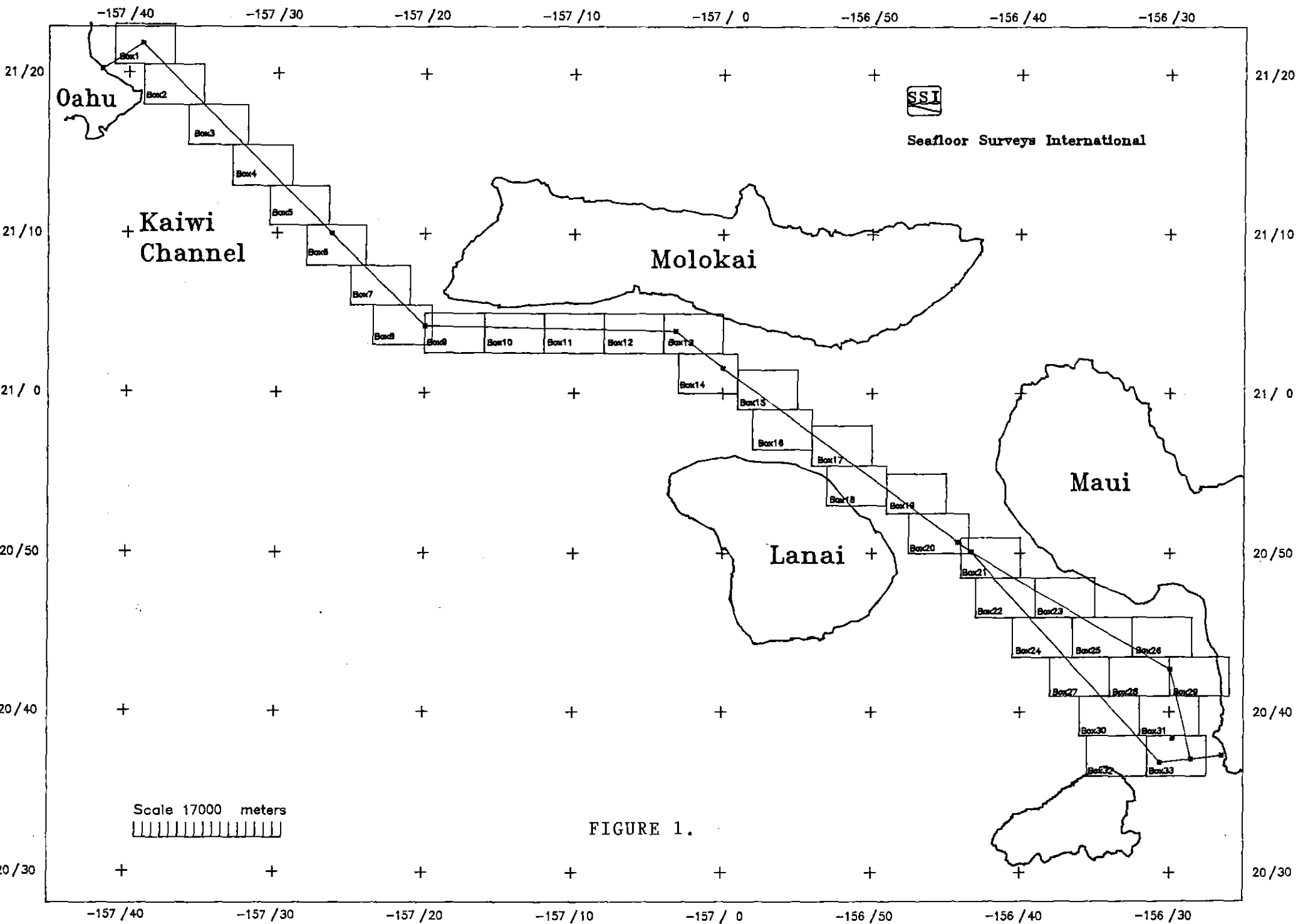


FIGURE 1.

produce an acoustic shadow (no data) when ensonified from the uphill side and it will appear as a strong reflective surface when viewed from further down-slope. When the mosaic is assembled, care is taken that overlaps in the side-scan data are edited in such a way that the resultant image best exemplifies the character of the bottom and features on the bottom.

Data Presentation

The side-scan and co-registered SeaMARC/S bathymetry data are presented in Atlas 2 as a series of 33 survey panels, each corresponding to a portion of the survey as located in Figure 1. Each side-scan survey sheet is a photographic reproduction of the acoustic character of the seafloor at a scale of 1:12,500, with a transparent overlay of the bathymetry at the same scale and the same Universal Transverse Mercator projection. At this reduced scale, much of the resolution of the side-scan data is lost. In order to have the full resolution available, a set of 12 books, Atlas 3, of full-scale side-scan data has been prepared to accompany Atlas 2. These books are arranged by time, so that the user need only refer to the appropriate track plot in Atlas 1 to determine the survey time at a certain location, then find the full-scale data in the corresponding full-scale book.

A brief summary of our interpretation of the survey data, keyed to each of the side-scan and bathymetry data panels, follows:

Panel 1:

The bottom is mostly smooth except for the edge of the Makapuu Submarine Canyon that appears at the southeast corner of the image. The preferred route follows the track along the southwestern edge of the image, thus avoiding the head of the Makapuu Submarine Canyon.

Panel 2:

This image shows a bottom character similar to that seen on panel 1 and is mostly smooth except for the Makapuu Submarine Canyon. Again the recommended route follows the southwesternmost track, avoiding the submarine canyon.

Panel 3:

The seafloor in the northern portion of this panel is a continuation of the smooth topography seen in the previous two panels. At approximately $21^{\circ}17'N$ the bottom slopes off rapidly into the deeper portions of the Kaiwi Channel. This steep slope is in part mantled by sediment deposits forming large sediment waves. These waves, or giant ripples, appear to be migrating along the slope parallel to the channel axis. This may be due to

strong currents caused by the restrictive nature of this narrow deep channel.

Panel 4:

Most of this image covers the relatively flat, deep portion of the Kaiwi Channel. A large sand deposit at the northwest edge of the image again displays large ripples, or waves, aligned perpendicular to the axis of the deep portion of the channel.

Panel 5:

The northwestern portion of this image is a continuation of the deep part of the Kaiwi Channel. South of $21^{\circ}12'N$ the bottom rises rapidly towards Penguin Bank. This slope has a mixture of outcropping rocks and sediment deposits that again appear to be moving parallel to the axis of the deep channel. The southeast edge of the image shows a smooth, gently rising bottom.

Panel 6:

The ocean bottom continues its gentle rise toward the top of Penguin Bank. Striations on the side-scan sonar image that are at an angle to the slope represent sediment movement due to bottom currents.

Panel 7:

This portion of the seafloor continues to rise to the southeast until approximately $21^{\circ}07'N$ where the flat, smooth upper surface of Penguin Bank appears.

Panel 8:

This image is a continuation across the smooth surface of Penguin Bank.

Panel 9:

The bottom along this portion of the southwest coast of Molokai continues at a depth equivalent to the top of Penguin Bank. The bottom is covered with rippled sand and possibly some larger sand waves.

Panel 10:

The bottom at the western edge of this panel is smooth and covered with sediment. The dark spots on the image between $157^{\circ}12.5'W$ and $157^{\circ}14'W$, where the bottom drops off into the Southwest Molokai Submarine Canyon, probably represent outcropping rock. These outcrops have no discernable relief, so are not likely to be a hazard to the cable.

Panel 11:

The bottom is mostly smooth, especially on the most landward track which is north of the head of the Southwest Molokai Submarine Canyon.

Panel 12:

The smooth bottom continues to 157°07.5'W, where the preferred track crosses the reef edge at a depth of 125 meters. The reef edge appears to be covered by sediments. At 157°05.5'W the track crosses this buried reef again and gets back into 100 meter deep water. In the center portion of the image, south of the preferred track, the reef outcrops through the sediment cover.

Panel 13:

The bottom continues to be smooth until a large embayment in the reef edge is encountered between 157°01.5'W and 157°02.5'W. Reef rock outcrops along the edges of the embayment. A track landward of the embayment was started but navigation control was lost when we crossed the baseline between the two microwave transponders we were using at the time. While we still had navigation control, about two thirds of the way across the head of the embayment, a smooth route that appeared to bypass the embayment was surveyed.

Panel 14:

This image shows another large embayment in the 100 meter reef front. This time there is a pinnacle reef of about 250 meters diameter and 30 meters of elevation off the edge of the reef. Certainly the cable route will have to avoid the pinnacle reef. East of this embayment the route again crosses a smooth area with depths of 100 meters.

Panel 15:

The preferred cable route through the western part of this image is smooth and probably covered with sediment. Toward the east, approaching the shallow reef edge near the south edge of the image, the bottom sediment produces a streaky pattern on the side-scan image, implying bottom scouring by a higher water current regime. The reef edge is steep with large blocks of reef material that have detached from the face littering its base. The cross track going to the northeast was an attempt to find a shallow route past this reef edge and the embayments in the deeper reef to the west. Loss of navigation control when we crossed the transponder baseline prevented successful completion of this track.

Panel 16:

This image shows a submarine canyon cut into the 100 meter reef north of Lanai. Initial analysis by Makai Ocean Engineering showed unacceptable cable spans at the steep edges of the canyon. During Phase 2, an acceptable route around the head of the canyon was mapped. This is seen at the southwestern edge of the image. Southeast of the canyon the bottom is smooth and probably mostly covered by sediment. Dark patches indicate buried patch reefs.

Panel 17:

To the west of $156^{\circ}52'W$, the bottom is mostly smooth and covered with sediment. Again, the occasional dark patches may indicate buried patch reefs. If necessary, a route around these apparent sediment-draped patch reefs can be identified for the purpose of laying the cable.

Panel 18:

The bottom in this image is similar to that seen on panel 17. The major difference is that the outcropping ridge at $157^{\circ}49.8'W$ extends across the entire image. Because the preliminary analysis by Makai Ocean Engineering showed that this would not be a problem if the cable were laid at low tensions, a route around this feature was not pursued.

Panel 19:

The bottom in the western two-thirds of this image is covered with sediment. Ripple marks indicate that this area has a higher bottom current regime than the area surveyed to the west. The southeastern edge of the panel is dominated by a pair of outcropping ridges.

Panel 20:

Most of the seafloor in this panel is covered by ripple-marked sediment. A few outcrops are seen in the side-scan image, but they can be bypassed by the cable if necessary.

Panel 21:

The western half of this image shows more ripple-marked sediment. Between $156^{\circ}42'W$ and $156^{\circ}43'W$, a roughly horseshoe-shaped outcropping ridge was surveyed. East of the ridge the bottom is again smooth. The side-scan sonar image shows that this portion of the bottom has a higher level of acoustic reflectivity than that found further west. Patches of lower reflectivity material are also occasionally observed on this portion of the bottom. The change in bottom reflectivity

probably reflects a change in the composition of the bottom material.

Panel 22:

The original route surveyed through this area has a bottom primarily covered by sediment. The most southwestern track shows the edge of the 100 meter reef where it drops off into a deeper lagoon. The preferred route, the most northeastern track, has the same high reflectivity bottom observed on Panel 21.

Panel 23:

The preferred route, the most northern track, continues to be similar to that observed on Panels 21 and 22. The bottom drops to depths of 95 meters in a 25 meter deep channel between $156^{\circ}36'W$ and $156^{\circ}37'W$. A route around this embayment is visible at the north edge of the northern-most line surveyed.

Panel 24:

The terrace surface near Maui that is the revised most-favorable cable route is shown in the northwestern corner of this image. At approximately $156^{\circ}38'W$, the bottom drops from the terrace off into the deep lagoon. This steep drop-off and the scattered blocks of reef rock at the base of the drop-off produced unacceptable spans in the original Makai Ocean Engineering analysis. As this drop-off extends across the whole image, an alternate route which stays on the landward terrace was surveyed for this area during the Phase 2 data acquisition cruises.

Panel 25:

The revised preferred route continues to be on the terrace, as shown in Panels 23 and 24. Between $156^{\circ}34'W$ and $156^{\circ}35'W$ the route passes north of an embayment that has a steep drop-off, from 80 meters to 125 meters water depth. This steep drop causes shadows (white areas) on the side-scan sonar image. The track in the southwestern corner of this image was an attempt to cross the deep lagoon along another alternate route to the original preferred route surveyed in Phase 1. This alternate track also appears to be unsuitable due to steep slopes, outcropping rock, and huge boulders at the base of the drop-off that stand high enough off the bottom to cause shadows on the image. Based on the unfavorable side-scan sonar and bathymetry data, this track was not even turned over to Makai Ocean Engineering for analysis. The bathymetry for this track is not shown on the overlay, because navigation for this portion of the survey was controlled only by radar, so was not up to the standards set for the rest of the survey.

Panel 26:

The most landward track on this panel is mostly smooth, sediment-covered bottom with occasional outcrops. Some of the outcrops along the seaward track have sufficient relief to cause acoustic shadows, but do not show up in the SeaMARC/S bathymetry data. This would suggest relief on the order of a meter or two.

Panel 27:

This portion of the bottom of the deep lagoon is fairly smooth, although there are ridges and several large pinnacles. A path can be delineated through this area that would avoid the pinnacles, if a safe route into the deep lagoon can be found.

Panel 28:

The revised preferred route continues on the shallow terrace near Maui across the northeastern portion of this image. The track at the northwestern corner of the sheet shows a very rough bottom with scattered limestone blocks typical of the edge of the reef at the deep lagoon. Again, the bathymetry is not shown, as this track was navigated by radar only.

Panel 29:

Along this segment of the revised preferred route the bottom is smooth and covered by sediment, although there are some outcrops in the northwestern corner of the image. Near the dogleg in the track the bottom is almost totally sediment-covered, but just at the turn the 65 meter reef outcrops. This reef can be avoided by staying on the terrace at its base.

Panel 30:

Most of the area in this image is in the deep lagoon and has a smooth bottom. Toward the southeastern edge of the image the bottom rises smoothly out of the deep lagoon.

Panel 31:

This portion of the preferred route is smooth and sediment-covered. The tracks in the western portion of the image were navigated by radar.

Panel 32:

The ocean bottom in this survey sheet is smooth and covered by sediment. Large sand waves appear in the southwestern portion of the panel. They indicate a higher current regime in the channel between Molokini and Kahoolawe.

Panel 33:

The most favorable route is along the smooth, shallow tracks along the eastern edge of this image. The western part of the image shows the original preferred route, which crosses a sandy area that has large ripple marks and then drops into deeper water west of Molokini.

Analysis

To satisfy the objectives of the Hawaii Deep Water Cable Program, a quantitative analysis of the SeaMARC/S data relative to cable-laying parameters was deemed appropriate. Because of their past experience with the analysis of high resolution bathymetric data for the cable program, this job was contracted to Makai Ocean Engineering. Profiles of SeaMARC/S digital bathymetry data were provided by SSI at locations specified by Makai Ocean Engineering. These profiles were oriented directly under the tow fish, or at some given distance away from the track. A complete report on the Makai Ocean Engineering analysis will be submitted separately. However, for completeness a brief summary of their findings is included in this report.

The Makai Ocean Engineering analysis of the Phase 1 data set found that there were areas where critical cable spans occurred off Central Maui, west of Lahaina, north of Lanai, south of West Molokai, and across a submarine canyon off Makapuu, Oahu. They also determined that the data in the deeper water portion of the Kaiwi channel was not suitable for their analysis. Some of the critical spans, for example those off Lahaina, were only present at higher cable tensions and thus would not constitute a barrier to cable installation in these relatively shallow waters.

During the Phase 2 cruise, special efforts were made to find routes around the steep areas that were problem areas in the Phase 1 data. The potential cable spans off Central Maui, Panels 24 and 27 in Atlas 2, were due to the very large blocks located at the base of the 100 meter reef. Several crossings of the base of this reef were made, and the blocks were found to be a common feature on all the crossings. With considerable searching, a route through the blocks could probably be found, but it seemed more logical to find an alternate route in shallower water where we expected the bottom to be smoother. This alternate route proved quite favorable, and became our revised preferred route. The calculated cable spans north of Lanai and off Makapuu are located in areas where the route crossed steep-sided submarine canyons. Acceptable routes around the heads of these canyons were found and surveyed.



Seafloor Surveys International, Inc.

May 1986

SSI SeaMARC/S SPECIFICATIONS

The Seafloor Surveys International (SSI) SeaMARC/S is a combination side-scan sonar and bathymetric mapping system. It produces simultaneous, real-time, co-registered side-scan images and bathymetric maps of the bottom of fresh and salt water bodies from 3 to 2000 meters deep.

General specifications

Operating frequency.....150 kHz
Ping rate.....20 per second to 1 per second
Tow depth.....1 to 1500 meters
Water depth.....3 to 2000 meters
Tow altitude (= water depth
minus towed array depth)...5% to 50% of swath width
(2 to 500 meters)
Data logging format.....laser disk

Side-scan system

Image format.....slant-range and speed corrected
Swath width.....50, 100, 200, 500, or 1000 meters
Pixel size.....2.5 cm to 50 cm
Beam width (along track).....1.0 degrees
Minimum identifiable object..0.5 to 50 meters
Minimum detectable object....1 cm (one wave length)

Bathymetric system

Display format.....color encoded depth plots
Swath width.....3.4 times altitude
Accuracy.....better than 2% of altitude
Resolution.....better than 0.5% of altitude

Support requirements

Minimum ship size.....15 meters
Exterior deck area.....10 square meters
Interior deck area.....4 square meters
Power.....110 VAC, 50-60 Hz, 3 kW
Survey crew.....3 people
Shipping.....in standard air cargo containers

Deliverable products

Geometrically correct, integrated
bottom image mosaics (standard)
Contoured bathymetry charts (standard)
Computer enhanced acoustic images (optional)
Seafloor reflectivity and texture maps (optional)

TABLE 1.



Seafloor Surveys International, Inc.

SSI SeaMARC/S DATA ACQUISITION OPTIONS

<u>Image Swath Width</u>	<u>/</u>	<u>Altitude Range</u>	<u>/</u>	<u>Ping Rep Rate</u>	<u>/</u>	<u>Pixel Size</u>
50 meters	/	2.5 - 25.0 m	/	20 per sec	/	2.5 cm
100 meters	/	5.0 - 50.0 m	/	10 per sec	/	5.0 cm
200 meters	/	10.0 - 100.0 m	/	5 per sec	/	10.0 cm
500 meters	/	25.0 - 250.0 m	/	2 per sec	/	25.0 cm
1000 meters	/	50.0 - 500.0 m	/	1 per sec	/	50.0 cm

The scales used during a survey are controlled from the ship and are selected by the operator to provide optimum resolution for various depths and survey objectives.

TABLE 2.

APPENDIX B

Description of Transponder Stations

Name: Puu Amikopala, Molokai
Latitude: $21^{\circ} 07' 52.496''$
Longitude: $157^{\circ} 11' 31.010''$
Elevation: 419 meters
Hawaii Zone 2 : X= 320,978
 Y= 290,103

Notes: Permission for access to this site on West Molokai must be obtained from Molokai Ranch (phone: 553-5115 on Molokai). Permission to use the microwave tower must be obtained from Aeronautical Radio Inc. (phone: 552-0080 on Molokai or 836-0001 in Honolulu).

The position first used for this site was obtained from Air Inc. and turned out to be for an older tower located at the site which had been removed after the present tower was constructed. During Phase 1 the position of this site was adjusted twice. The final position which was used in all the Phase 2 work was determined by translocation of Transit satellite data. The final position was 108 feet NNW of the initial position, 113 feet NE of the position used for most of the Phase 1, Maui to Molokai, work and 138 feet ENE of the position used for the Phase 1, Kaiwi Channel, work. Figure B1-1 shows the transponder positioned on a leg of the Air Inc tower.

Name: Kewela Water Tank
Latitude: $21^{\circ} 04' 34.070''$
Longitude: $156^{\circ} 57' 47.578''$
Elevation: 87 Meters
Hawaii Zone 2 : X= 398,894
 Y= 269,881

Notes: This station is located on the top of a Maui County water tank located in the Kewela Plantation subdivision, inland of the Kewela fishpond, on the coast of East Molokai.

Permission to use this site was obtained from the Office of Water Supply in Kaunakakai (phone: 553-5857 Molokai). After translocation the final position of this station was 29 feet NW of the position used during Phase 1. Figure B1-2 shows the transponder attached to the rail at the top of the water tank.



FIGURE B1-1

The transponder mounted on the
Air Inc. tower at Puu Amikopala, Molokai.

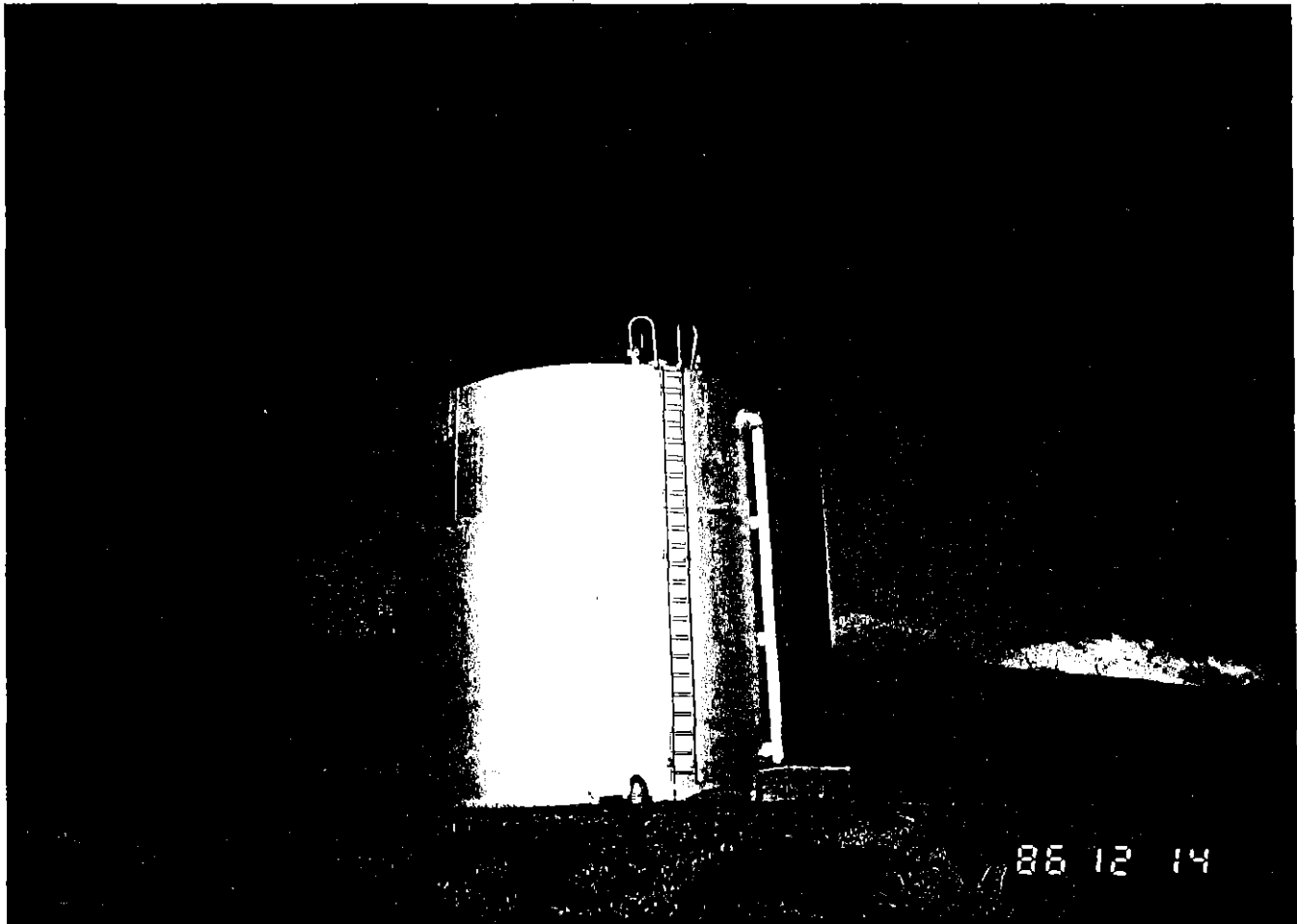


FIGURE B1-2

The transponder atop
a water tower at Kewela, Molokai.

Name: Puu Laina
Latitude: $20^{\circ} 53' 57.257''$
Longitude: $156^{\circ} 40' 15.278''$
Elevation: 198 meters
Hawaii Zone 2: X= 498,551
Y= 205,535

Notes: This site is at triangulation station Laina, located on State-owned property leased to Pioneer Mill Company. Permission to use the site had to be obtained from both the Department of Land and Natural Resources (phone: 548-6460 Honolulu) and Pioneer Mill Co (phone: 661-0592 Maui). Figure B1-3 shows the trisponder attached to the triangulation station at Puu Laina.

Name: McGregor Point Light
Latitude: $20^{\circ} 46' 50.428''$
Longitude: $156^{\circ} 31' 32.652''$
Elevation: 15 meters
Hawaii Zone 2: X= 548,142
Y= 162,493

Notes: The site used was at the seaward side of the tower supporting the McGregor Point light, approximately 5 feet offset from the actual triangulation station position.

Name: Makena
Latitude: $20^{\circ} 39' 30.278''$
Longitude: $156^{\circ} 26' 46.784''$
Elevation: 5 meters
Hawaii Zone 2: X= 575,327
Y= 118,119

Notes: This site is the center of an old gun mount located on a rocky point north of Makena landing. Permission to use the site was obtained from the property owner, James Campbell (phone: 949-8205 Honolulu). Figure B1-4 shows the trisponder set up on a tripod at Makena.

Name: Koko Head 3
Latitude: $21^{\circ} 15' 58.185''$
Longitude: $157^{\circ} 42' 24.456''$
Elevation: 195 meters
Hawaii Zone 2: X= 145,825
Y= 339,977

Notes: This is a triangulation station. Permission to get access to the site was obtained from the City and County of Honolulu Parks department (phone: 955-1551)

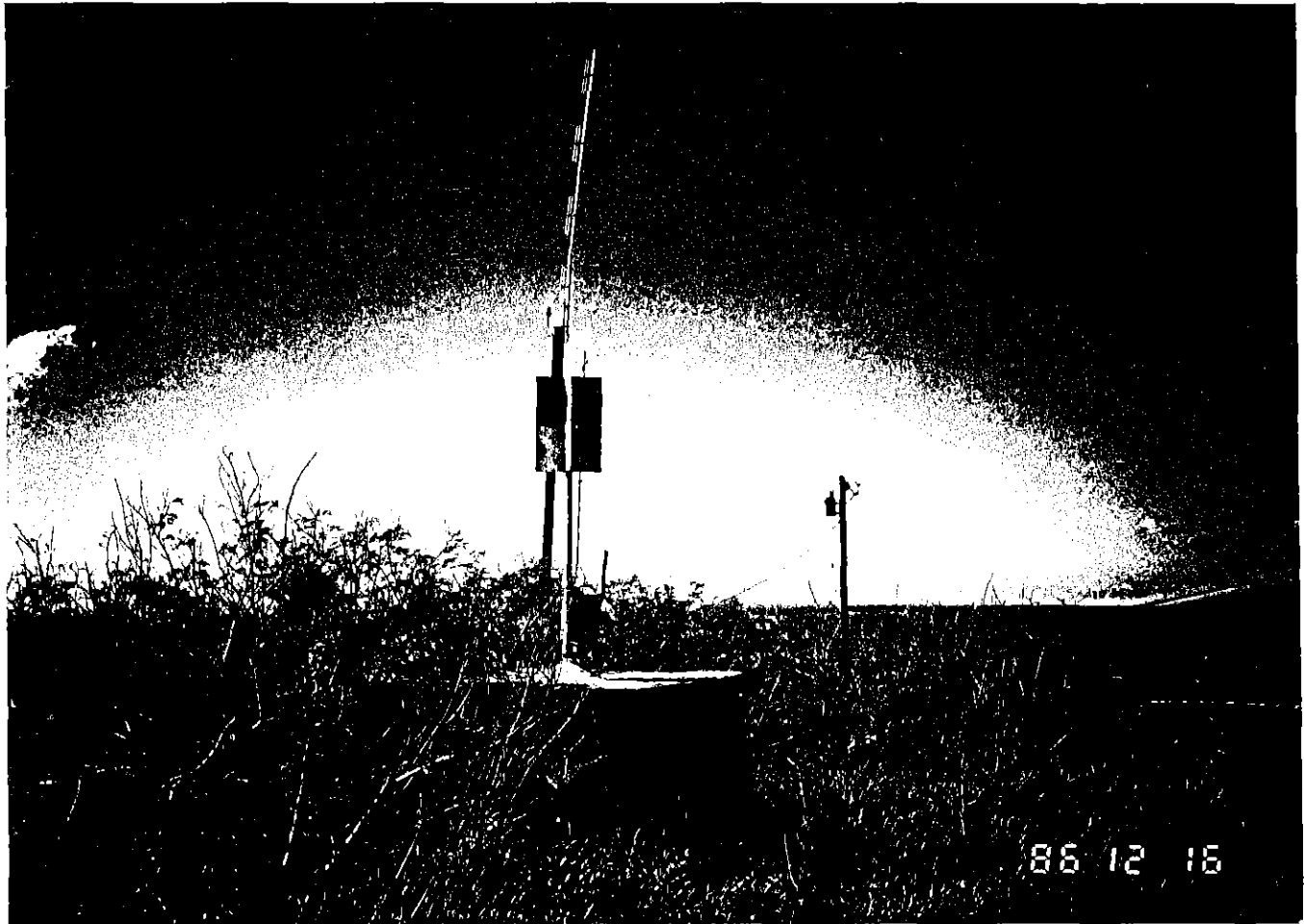


FIGURE B1-3

The transponder attached to the base of a
triangulation flag at Puu Laina, Maui.

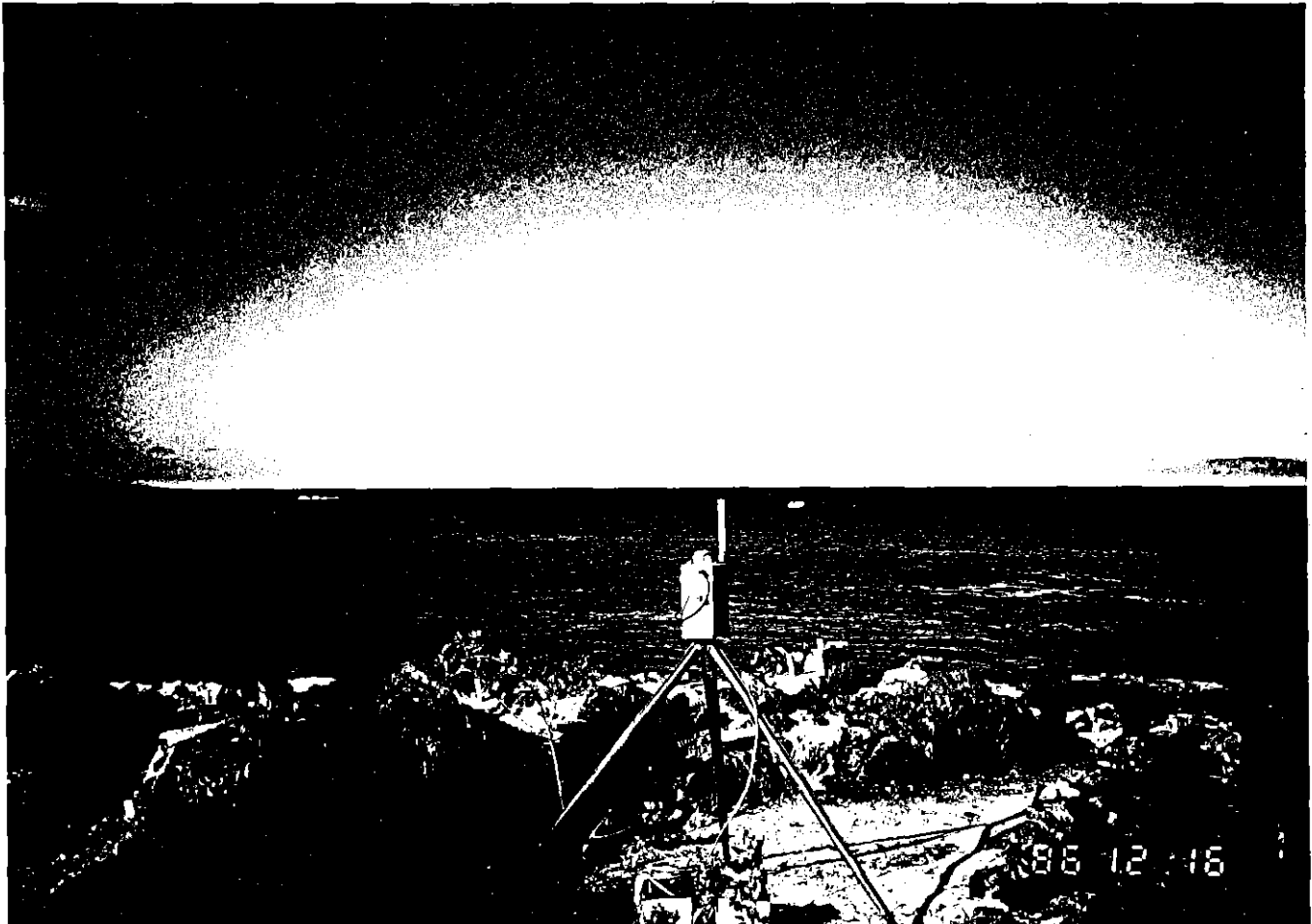


FIGURE B1-4

The transponder on a
tripod at Makena, Maui.

Name: Makapuu Point Light
Latitude: $21^{\circ} 18' 47.052''$
Longitude: $157^{\circ} 39' 08.712''$
Elevation: 128 meters
Hawaii Zone 2: X= 164,448
 Y= 356,899

Notes: This site is on the fence surrounding the Makapuu Light House. The site is 22 feet from the center of the light house on a bearing of 015° . Permission for access to the site during Phase 1 was obtained from the Aids to Navigation Branch of the U. S. Coast Guard (phone: 546-7130). Prior to Phase 2, the property surrounding the light house was turned over to the State of Hawaii and permission for access to the site had to be obtained from both the Coast Guard and the State Parks Division of the Department of Land and Natural Resources of the State of Hawaii (phone: 548-2627)

Name: Bellows Tower
Latitude: $21^{\circ} 22' 02.848''$
Longitude: $157^{\circ} 42' 45.642''$
Elevation 25 meters
Hawaii Zone 2: X= 144,068
 Y= 376,788

Notes: The site was situated on the top level of a tower constructed behind the beach on Bellows Air Force Station, Waimanalo, Oahu, by the University of Rhode Island. Permission to use the site was obtained from The University of Rhode Island (phone: (401) 792-6256) and permission for access to Bellows from the Base Commander (phone: 259-5961). This site position was obtained by satellite navigation translocation; the translocated position was 80 feet SW of the position used in phase 1.