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in Support of Disposal Site Designation
in the Rhode Island Sound Region

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During the period 4 September to 14 October 1987, field operations were conducted in selected areas of Rhode Island Sound (RIS) and Narragansett Bay to gather information for a feasibility assessment of offshore dredged material disposal sites. A total of four discrete areas were studied; three in RIS (Brenton Reef, Brenton-A, and Brenton-B) and one in Narragansett Bay (Prudence). Field operations included bathymetric, side scan and sub-bottom surveys, sediment-profile photography (REMOTS®), and sediment sampling for physical and benthic community analyses.

The physical boundaries of the historic disposal mound at the Brenton Reef disposal site had not changed since the last (1981) survey of the area; the mound was a well-defined feature centered just inside the western boundary of the disposal site with a diameter of roughly 1600 meters and a minimum depth at the apex of 25.5 meters. The areas of Brenton-A and Brenton-B were characterized by extensive glacial drift deposits. A relict channel system that drained the landward side of the recessional moraine was observed in sub-bottom profiles trending northeast-southwest through these two areas. The Prudence Island site side-scan data revealed mound-like features (< 2 m in height; 10 -20 m in diameter) on an otherwise uniform surface.

The benthic communities around the Brenton Reef disposal mound showed a full recovery in population density since the cessation of disposal operations. Dense ampeliscid beds were observed on the ambient seafloor within and outside the site as well as on the edge of the mound; a mobile sand community dominated the mound central area where a distinct transition in sediment grain size occurred. The density of lobster traps on and around the disposal mound attested not only to the benthic community recovery but to the enhanced fishery resource which exists at the site.

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1.0 INTRODUCTION

During the period 4 September to 14 October 1987, field operations were conducted in selected areas of Rhode Island Sound (RIS) and Narragansett Bay to gather information for a feasibility assessment of offshore dredged material disposal sites. A total of four discrete areas were studied; three in RIS (Brenton Reef, Brenton-A, and Brenton-B) and one in Narragansett Bay (Prudence). Two of these areas (Brenton Reef and Prudence) are former disposal sites. The Brenton Reef site, centered at 41° 23.470'N, 71° 18.126'W, is located in RIS approximately 6 nautical miles south of Newport, RI (Figure 1-1). This site was last used for disposal in 1971 and was last studied in 1981 under the DAMOS program (SAIC, 1981). Prudence, centered at 41° 23.470'N, 71° 18.126'W, is located in the East Passage of Narragansett Bay southeast of Prudence Island (Figure 1-2); disposal last occurred at this site in 1966. The two remaining areas, named Brenton-A and Brenton-B, are located in RIS approximately 10 nautical miles south-southeast of Newport, RI (Figure 1-1). Brenton-A is centered at 41°16.673'N, 71° 15.633'W, while Brenton-B is centered at 41° 19.690'N, 71° 12.021'W. These two areas were studied because preliminary examination of bathymetric charts revealed topography indicative of a depositional basin.

Field operations included bathymetric, side scan and sub-bottom surveys, sediment-profile photography (REMOTS®), and sediment sampling for physical and benthic community analyses. Results from sub-bottom surveys performed by the University of Rhode Island in the vicinity of Brenton-A and Brenton-B were interpreted in conjunction with SAIC survey results; the seismic stratigraphy and surficial seafloor texture in each of the four study areas were characterized. Approximately 75 kilometers (47 miles) of high-resolution sub-bottom reflection (Uniboom) profiles were examined to determine geologic structure. Surficial textural characteristics were inferred from 100 kilometers (62 miles) of side scan sonar observations. Grain size analyses of surface grab samples, carried out by the Corps of Engineers, New England Division, augmented the textural observations.

The primary objectives of these investigations were to:

- Determine the areal extent of the historic mound formed by dredged sediment within the Brenton Reef disposal site.

- Determine the bottom elevations/topography, physical (including sub-bottom) characteristics, and sediment types for all specified areas.

- Determine the benthic community structure at stations inside and outside the historic Brenton Reef Disposal Area.

- Compare the above findings at the historic Brenton Reef Disposal Site with those found during the 1978 study, to determine the extent of physical change in the dredged material deposit and to determine changes in biological conditions.

2.0 METHODS

2.1 Navigation

The precise navigation required for all field operations was provided by the SAIC Integrated Navigation and Data Acquisition System (INDAS). A detailed description of the INDAS system and its operation can be found in DAMOS Contribution #60 (SAIC, 1989). Positions were determined to an accuracy of ±3 meters from ranges provided by a Del Norte Trisponder® System. Shore stations were established over known benchmarks at Point Judith and Beavertail Lights.

2.2 Bathymetry

Precision bathymetric surveys were performed at each of the four study areas using a Raytheon DE-719® Precision Survey Fathometer with a 208 kHz transducer and a Raytheon SSD-100® digitizer, as described in DAMOS Contribution #60 (SAIC, 1989). This system allows depth to be determined to a resolution of 3.0 centimeters (0.1 feet) with an accuracy of ±15 cm at the depths encountered in this study. The fathometer was calibrated by adjusting the speed of sound to the value observed on the digitizer. The actual speed of sound was determined from the water temperature and salinity data obtained using an Applied Microsystems® CTD probe. These values were used during later analysis of the bathymetric data.

The Brenton-A survey was run northeast to southwest at 715 meter lane spacing with 8 lanes 8500 meters long (Figure 2-1). The Brenton-B survey was run west-southwest to east-northeast at 740 meter lane spacing with 7 lanes 6300 meters long (Figure 2-1). The Brenton Reef disposal site survey was run northeast to southwest at 50 meter lane spacing with 49 lanes 2100 meters long (Figure 2-1). This narrower lane spacing was required for comparison with the 1978 bathymetric survey. The Prudence survey was run north-northeast to south-southwest at 300 meter lane spacing with 4 lanes 3150 meters long (Figure 2-2).

During bathymetric data analysis, each survey area was divided up into a number of rows and columns of cells in a matrix. Each of these cells was centered along a survey lane, with dimensions equal to the lane spacing in a perpendicular direction and to one half of the lane spacing in a parallel direction. As the survey data were read into the computer, the depth data from fixes falling within a given cell were weighted with respect to their spatial offset from the center of the cell, an average was calculated, and the resulting depth value was assigned to that cell. Prior to these calculations, each individual data point was corrected for sound velocity variations, transducer draft, and tidal amplitude. This depth matrix was then used to generate depth contour charts. The accuracy of the depth measurements assigned to each cell was affected by the instrument accuracy of the fathometer (0.5% of indicated depth), the number of depth measurements in that cell, the vertical motion of the research vessel, the difference in depth between the center of the grid cell and the actual position of the vessel, and the accuracy in the prediction of the change in tidal height for the duration of the survey. Error analysis of the depth measurements was performed with respect to the conditions at the time of the surveys, and it was determined that the error on the depths presented in the contour plots for the Brenton Reef disposal site is approximately ± 8 cm.

2.3 Side Scan Sonar and Sub-bottom Surveys

A Klein Associates Model 520® side scan sonar system was used in this project; this system consists of a 100 kHz towfish interfaced to a 48 centimeter (19 inch) wet paper recorder through a lightweight Kevlar® tow cable with simultaneous dual-channel recording of the side scan sonar at variable ranges. During the surveys, a position fix was printed every minute and a mark was made on the recorder simultaneously. These were later used to determine the position of individual side scan targets. Position data were also recorded every second on magnetic disk by the INDAS. Towfish layback (distance behind ship) was estimated from catenary curves provided by Klein Associates for various speeds and checked by comparison of bottom features observed during the bathymetric survey.

The side scan sonar surveys were run concurrently with the bathymetric surveys at the Brenton-A, Brenton-B, and Prudence areas. The lane spacing at each of the three areas (Figures 2-1 and 2-2) was chosen to provide the minimal acceptable coverage for the side scan sonar system. The width of the area covered by the side scan was controlled by the towfish height above bottom and the settings on the instrument. While the side scan yielded the most economical broad-scale physical characterization of the bottom, spatial bathymetric detail was limited with the wide survey lane spacing.

The side scan sonar survey at the Brenton Reef Disposal Site could not be performed due to the density of lobster pots in the area. However, a sub-bottom survey, using an ORE, Inc. Model 1032® sub-bottom profiling system, was run concurrently with the precision bathymetric survey at this site to better define the extent of the historic disposal mound. The ORE system included a transceiver capable of outputting signals of 10 kw at frequencies from 1 to 12 kHz that would allow optimal penetration of the sediment. The over-the-side vehicle contained a 3.0 to 7.0 kHz transducer and a 12 kHz transducer. Synchronous printout of the position and marking of the record was accomplished in the same manner as during the side scan surveys at the other areas.

The side scan data from the Brenton-A, Brenton-B, and Prudence areas and the sub-bottom data from the Brenton Reef site were analyzed and interpreted by Dr. Nancy Neff, a geologist at the University of Rhode Island (URI). In addition, Dr. Neff analyzed and integrated results from approximately 75 km of high resolution sub-bottom reflection (Uniboom) profiles in the vicinity of the Brenton-A and Brenton-B areas in order to describe the sedimentological history of each area. These Uniboom profiles had been obtained previously by URI scientists as part of a project sponsored by the Minerals Management Service (MMS).

2.4 REMOTS® Sediment Profile Photography

REMOTS® photos were obtained at the Brenton Reef disposal site using a Benthos Model 3731® Sediment-Profile Camera (Benthos, Inc., North Falmouth, MA). The REMOTS® camera is designed to obtain <u>in-situ</u> profile images of the top 15-20 cm of sediment. A detailed description of REMOTS® camera operation and image analysis is presented in DAMOS Contribution #60 (SAIC, 1989).

The purpose of the REMOTS® survey conducted on 13-14 October was to map the areal extent of the historically-deposited sediment and to evaluate sediment types and benthic habitat conditions at the Brenton Reef site. Stations were located in an irregular grid centered near the western disposal site boundary to allow evaluation of the areal limits of the historically-deposited sediment (Figure 2-3). One out of two REMOTS® photographs was analyzed from each grid station, and three replicate photographs were analyzed at each of two reference stations (SE-REF and WEST-2) located outside but near the disposal site.

2.5 Sediment Sampling and Analysis

A 0.1 m^2 Smith-McIntyre grab sampler was used to collect a total of 12 sediment samples at the Brenton A site, 15 samples at the Brenton B site (Figure 2-1), and 9 samples at the Prudence site (Figure 2-2). In addition, 10 sediment samples for grain size and chemical analyses were obtained in and around the Brenton Reef historic disposal site (Figure 2-4). The exact locations of the samples at each surveyed area were determined after examination of the side scan records; stations were located to verify the sediment type associated with different acoustic reflectance patterns. Visual observations were recorded for each sample describing the physical and biological conditions and the apparent redox layer thickness. Three polycarbonate plastic core liners (6.5 cm. ID) were pushed into each sediment grab sample to a minimum depth of 10 cm and extracted; the three cores were combined into a polyethylene bag and refrigerated for subsequent grain size analysis at the NED laboratory.

2.6 Benthic Community Sampling and Analysis

Quantitative benthic samples were obtained with a 0.1 m^2 Smith-McIntyre grab at 12 "transect" stations in and around the historic Brenton Reef disposal site (Figure 2-4). Mr. Sheldon Pratt from URI participated in the field sampling and supervised the preservation, sorting, and identification of organisms.

One grab per station was placed in a five gallon bucket, labelled, and brought to shore without treatment. In the laboratory, organisms were relaxed by mixing 8% $MgSO_4$ into sandy samples and holding silty samples overnight in stagnant conditions. The material was sieved to 0.5 mm with filtered seawater and the residue preserved in 10% formaldehyde with 0.2% rose bengal stain. After fixation, samples were separated into a number of fractions by sieving with 2.0, 1.0, and 0.5 mm screens both by successive decantation in tap water and suspension in "Ludox" colloidal silica solution (density 1.3 gm/ml). Material retained on the 2.0 mm screen was sorted in glass trays without magnification; all other fractions were sorted with binocular microscopes at 7.5x and 6.6x.

Samples from three stations (stations 3, 11, and 12) had large numbers of individuals along with fine amphipod tube detritus of similar density, requiring an excessive amount of time to sort (50+ hours; approximate sorting time ranged between 4 - 6 hours for an average sample). Consequently, it was necessary to split these samples. Nested sieves were used to remove organisms by "Ludox" flotation prior to splitting the fine sieve fraction. This greatly reduced the number of individuals subject to splitting error and improved the accuracy of the final counts. For example, the ratios of <u>A. agassizi</u> and of all individuals in splits from sample 12 were 0.73:1 and 0.99:1, respectively. The numbers of <u>A. agassizi</u> found in a 1/4 split of the fine detritus fraction of this sample was 13. The actual number counted in the coarser sieve fractions which were not split in the sample was 2,685; the calculated total of 2,737 could not be more than a few percent different than the true count.

With the exception of Rhynchocoela and Oligochaeta, most organisms were identified to species. Very small or damaged individuals were assumed to be the same species as identified individuals and were not recorded as unknown species.

Individuals from each sample were combined and preserved in 70% alcohol and a reference collection made (retained at URI). Sieve residue volume and composition were recorded, and residue aliquots were preserved and archived.

3.0 RESULTS

3.1 Brenton Reef Historic Disposal Site

3.1.1 Bathymetry

Depths in the area surveyed at the Brenton Reef site ranged between 25.5 and 32.5 meters (Figure 3-1). The historic disposal mound occurred as a well-defined feature centered just inside the western disposal site boundary. This broad, circular mound had a diameter of roughly 1600 meters and a minimum depth of 25.5 meters at its apex. The mound flanks occupied much of the western half of the disposal site and extended approximately 500 meters outside the western disposal site boundary before ambient depths of approximately 31-32 meters were encountered. The southwest flank of the mound exhibited a much steeper slope than the northern and eastern flanks.

Even though the August 1978 bathymetric chart at Brenton Reef (Figure 3-2) did not include the flanks of the mound west of the disposal site boundary, comparison with the 1987 chart (Figure 3-1) indicates very little physical change over the major portion of the mound. As in 1987, the mound in 1978 occurred as a broad, circular feature covering the western half of the disposal site, with a minimum depth of 25.5 m at the peak. In the earlier survey, the southeast slope of the mound was also much steeper than the slope to the north. At the time this was attributed to spillage and short dumping from scows. Overall, no significant changes in bottom elevations and in the areal extent of the disposal mound appear to have occurred in the 9 year period between the August 1978 and October 1987 bathymetric surveys.

3.1.2 Seismic Stratigraphy

The sub-bottom profile survey performed at the Brenton Reef site did not reveal any distinct or notable sub-bottom acoustic features at or in the vicinity of the historic disposal mound other than the disposal mound itself (Figure 3-3). The mound was easily distinguished as a surface feature distinct from the original pre-disposal horizon; the sub-bottom data provided no additional information other than to verify results obtained from the precision bathymetric survey.

3.1.3 Surface Textural Characteristics

Sediment samples taken for grain size and chemical analyses at the Brenton Reef site (Figure 2-4) were not analyzed but archived at the NED laboratory. However, an accurate characterization of surface sediment textures at the site is possible based on the REMOTS® survey results. The REMOTS® photographs indicated historically-deposited dredged material in the western quadrant of the disposal site which extended approximately 500 meters beyond the western disposal site boundary (Figure 3-4). This material occurred at some stations in a distinct layer from 3 to 12 cm thick and occupied an area having an east-west diameter of roughly 1300 meters and a north-south diameter of about 2000 meters.

The sediments comprising the historic deposit showed a range in grain-size from very fine sand (4-3 phi) to granule and larger (< -1 phi) (Figure 3-5). For example, at station E-6 near the center of the deposit, both medium sand (2-1 phi) and granules (-1 to -2 phi) were found to exceed the depth of prism penetration in replicate images (Figure 3-6). At other stations located near the center of the mound and at those on the flanks of the mound, a sand-over-mud or cobble-over-mud stratigraphy was noted (Figure 3-7 A and B). Penetration of the camera was prevented by large cobbles at station E-5, located just north of the disposal mound apex.

The obvious gradations in the grain size of surface sediments at the Brenton Reef site, from coarse cobble to sand, sand over mud, and mud were the result of both historic dredged material deposition patterns as well as near-bottom kinetic regimes. Cobbles and coarse sands at stations closest to the mound apex (Figure 3-6, bottom image) reflected a higher-energy environment which may be related to the elevation of the mound above ambient depths. At such stations, it is likely that finer-grained fractions had been winnowed and redeposited on the flanks of the mound, resulting in the observed pattern of sand over mud stratigraphies at flank stations (Figure 3-7 A and B) which in turn grade into silt-clay as distance and depth from the mound peak increases. Shell lag deposits (Figure 3-8) and near-surface sands (Figure 3-9) provide evidence of the winnowing of fines in response to erosional forces near the mound apex. These results are comparable to those obtained in the 1978 bathymetric survey at Brenton Reef, when the top of the disposal mound was described as having a sand surface layer covering silty dredged material, and the mound flanks had exposed mud (Naval Underwater Systems Center, 1979).

Sediment at REMOTS® grid stations off the dredged material mound and at all reference stations consisted of very fine sand-silt-clay (i.e., mud) (Figures 3-4, 3-5 and 3-10). This sediment, having a grain size major mode in the range >4 to 3 phi, presumably characterizes the ambient bottom unaffected by disposal. It is possible that at some stations a fraction of this fine-grained sediment represents material eroded from the disposal mound which became deposited in areas of lower topography surrounding the mound. Deposition and accretion of these fines would be enhanced by the presence of extensive ampeliscid amphipod assemblages in the area (Figure 3-11); dense amphipod tubes act like a series of baffles projecting up from the bottom and serve as very effective sediment traps. Cobble material located at stations East-1 and G-9 to the east of the center of the disposal site (Figures 3-4 and 3-5) may be either naturally-occurring or the result of historic disposal activity taking place away from the main dredged material mound.

The majority of small-scale surface boundary roughness values at both grid stations and reference stations at the Brenton Reef site fell within the range 0.08 to 1.8 cm (Figure 3-12). The wider range in values at the grid stations (0.08 to 5.4 cm) was due to the much larger sample size compared to the reference stations, where values only ranged between 0.48 and 1.28 cm. There was no statistically significant difference in the boundary roughness at the grid stations (mean = 1.5 cm) versus that at the reference stations (mean = 0.85 cm). Most of the small-scale surface roughness was biogenic in origin, reflecting both extensive sediment excavation by burrowing organisms and sediment accretion around dense mats of amphipod tubes at many stations (Figure 3-11). It is possible that the foraging activities of fish feeding on the amphipods also contributed to increased small-scale surface boundary roughness at some stations.

3.1.4 Benthic Community Structure

A general characterization of biological conditions and benthic community structure at the Brenton Reef site was possible based on the results of the REMOTS® survey. For example, the frequency distributions of mean apparent Redox Potential Discontinuity (RPD) depths for the grid and reference stations were both centered at the 5 cm class interval (Figure 3-13). The values of mean apparent RPD depth for the grid stations did not differ significantly from those at the reference locations. Extensive past DAMOS sampling in Long Island Sound has shown that RPD depths greater than 3.5 cm are characteristic of relatively "healthy" areas which have not experienced recent disturbance or stress factors. Overall, RPD values at both the grid and reference stations were well in excess of 3.5 cm, with values below this threshold occurring only at a few random stations (Figure 3-14).

At several stations with coarser-grained sediments, mean apparent RPD depths exceeded the depth of the prism penetration.

The infaunal successional stage was indeterminate at a cluster of stations located on the center of the historic disposal mound (Figure 3-15). At these stations, relatively coarse sediments or cobbles prevented the prism from penetrating deep enough to adequately detect any deposit-feeding organisms which might have been present at depth. Other stations on the actual disposal mound were characterized by Stage I or Stage II successional seres. At these stations, extensive recolonization by the local mud-dwelling Stage III organisms may have been prevented by the presence of relatively mobile sands (in response to the higher energy regime) or otherwise coarse-grained disposed sediment at the surface.

Evidence of the indigenous Stage II and Stage III assemblages was widespread at all other grid stations and at the reference stations. A remarkable number of images showed large and extensive sub-surface burrows (Figure 3-16), which were most likely due to the burrowing activities of lobsters (given the density of lobster traps in the area at the time of the survey) and the thalassinid shrimp <u>Axius</u>. In addition to the burrows, many images had tubes of deposit-feeding polychaetes visible at the sediment surface (Figure 3-17), as well as feeding voids as evidence of head-down, deposit-feeding Stage III taxa at depth (Figure 3-18). Ampeliscid amphipods, classified as Stage II organisms, occurred in conjunction with the Stage III taxa at stations throughout the site (Figure 3-19). Some REMOTS® images showed only a few amphipod tubes at the sediment surface (Figure 3-17); the amphipods also occurred in dense assemblages or "mats" of tubes (Figures 3-11 and 3-20). As a result, the majority of off-mound grid stations, as well as the reference stations, had a Stage II on III successional designation (Figure 3-15). Overall, the REMOTS® photographs revealed an extremely high density and diversity of organisms in this area.

The REMOTS® Organism-Sediment Index could not be calculated at a cluster of grid stations at the center of the historic disposal mound (Figure 3-21). This was because either the successional stage was indeterminate or the prism penetration was inadequate at these stations. An OSI value of 11 was calculated for most of the other grid stations and for the reference stations. This was reflected in the frequency distributions of OSI values for these two sets of stations, which have shown that the lowest OSI value for any station was 9 (Figure 3-22). These OSI values indicate a benthic habitat of the highest quality and reflect the general site characteristics of a deeply depressed RPD and a persistent, stable infaunal assemblage representing an "equilibrium" condition.

A more detailed characterization of the benthic community structure at Brenton Reef resulted from analysis of the grab samples from the twelve "transect" stations (Figure 2-4). Descriptions of sample residues from these stations are given in Table 3-1. Samples from stations on or close to the disposal mound (3 through 10) had larger volumes than edge samples (1,2,11,12) with the exception of sample 6, in which well-sorted fine sand was not retained by the sieve. Bay scallops (Aequipecten irradians), jingle shells (Anomia simplex), oysters (Crassostrea virginica), and other estuarine shells were abundant in samples 1 through 10; these samples also contained rounded pebbles and small rock fragments. All samples contained fine detritus from terrestrial plants. Most of the residue in samples 11 and 12 consisted of the flat, flexible tubes of ampeliscid amphipods.

Previous observations of the site, the gross appearance of the sample, and the sample residues suggested that the sediment at stations 1 and 2 consisted of fine-grained material which may have been deposited both during disposal operations and during subsequent erosion of the disposal mound. Samples on the mound (3 through 10) varied from relatively unmodified estuarine sediments to winnowed sand and/or shell lag deposits. The presence of shells of offshore species, frosted sand grains, and glauconite grains in samples 11 and 12 indicated that the ambient bottom has not been covered by disposal materials.

The number of organisms recovered and the time required to initially sort each sample are also shown in Table 3-1. The most time-consuming samples were 2 and 3 where very large numbers of small polychaetes had to be separated from fine plant debris. The fine portion of samples 11 and 12 contained a mass of very small tubes and fragments of ampeliscid tubes which slowed sorting. The least amount of time was required for sample 7 in which organisms could be separated from sand and pebbles using suspension and flotation.

The number of species per sample ranged between 38 and 64, but the total for all samples was 135, reflecting that different habitat types with unique assemblages of organisms were sampled (Table 3-2). The large number of species (28) being represented by only 1 or 2 individuals is another result of limited replication of samples from different habitats (Table 3-3). The number of species per sample is similar to those found in other stable-bottom shelf habitats, and the large total number of species is similar to that found in studies of the Massachusetts Bay Disposal Site (SAIC, 1987).

The number of individuals per sample varied from 598 to 5,342 (5,980 - 53,420/m^2). The higher densities reflected the small size of many of the dominant species and the large number of juveniles present; during the normal course of events, many of these smaller forms would suffer mortality during winter storms and summer predation.

More than half of the individuals in samples 10, 11, and 12 were the amphipod _Ampelisca agassizi_. The bivalve _Nucula annulata_ made up a similarly high proportion of individuals in samples 1 and 2. The small polychaete _Prionospio steenstrupi_ was numerically important in habitats suitable for _A. agassizi_.

Most of the major taxonomic groups were well represented in these samples. Polychaetes were dominant in number of species (73) and also had the largest number of individuals. There were 19 species of amphipods and 16 species of bivalves, with one very abundant species in each group. The number of species (3) and individuals (14) of gastropods were relatively small.

Inspection of counts for dominant and subdominant species indicated that groups of species could be categorized according to their association with other species and their abundance in a given habitat type (Table 3-4). Some species listed in Table 3-4 had their highest density in one habitat. Most other relatively abundant species were found in a combination of habitats; very few were ubiquitous.

The response of _Ampelisca agassizi_ to historic disposal activities is of special interest, because dense populations have the potential to determine the makeup of the remaining community and to modify sediment grain size distribution as well as the boundary layer oxygen profile. The presence of large numbers of _A. agassizi_ on disposed sediment at stations 3 and 10 indicated that this species can colonize dredged material which was physically suitable (i.e., not silt or mobile sand).

Several species with greatest density on silty bottom may be indicators of disturbance. _Capitella capitata_ and genus _Polydora_ species are known to be adapted to high levels of organic matter and low oxygen and to be resistant to physical and chemical stresses. _Cossura longocirrata_ has been found on other offshore disposal areas.

With the exception of sample 7, all samples supported large numbers of polychaetes, amphipods, and thin-shelled bivalves which are eaten by fish, crabs, and lobsters. Most of the polychaetes and ampeliscid amphipods present were of a size range eaten by juvenile rather than adult fish.

It appears that the unreplicated samples taken during this survey provided a good description of the benthic community of Rhode Island Sound in the vicinity of the historic disposal site. Replication within stations would have given no more information than was obtained; conditions can change on the scale of meters between ripple marks on the disposal mound, as well as vary predictably with elevation. The combination of previous experience, precision bathymetry, and REMOTS® photography made it possible to place each station in the context of major gradients.

3.2 Brenton-A, Brenton-B, and Prudence Areas

3.2.1 Bathymetry

Depths at the Brenton-A area ranged between 34 and 40 meters (Figure 3-23). The western portion of the area surveyed contained a closed depression having a maximum depth of 39.5 meters; it appears that this depression was formed by the 37 meter contour, even though the survey did not extend far enough to the southwest to confirm this. Smaller and shallower depressions having maximum depths of 38.5 and 40 meters occurred in the eastern portion of the region.

The range in depths at the Brenton-B area was between 26 and 36 meters (Figure 3-24). The northern half of this region consisted of a relatively large, elliptical depression which appeared to be formed by the 32 meter contour and which had a maximum depth of 36 meters. In the southern half of the area, there was a much shallower, irregularly-shaped depression which appeared to be formed by the 35 meter contour.

Depths at the Prudence historic disposal site ranged between 17 and 31 meters (Figure 3-25). This area was characterized by a relatively long (roughly 2500 meters) and narrow elliptical depression which trended northeast-southwest, roughly parallel to the eastern shoreline of Prudence Island. The depression, formed by the 21 meter contour, had a maximum depth of 31 meters. The walls of this depression were much steeper on the seaward (i.e., eastern) side compared to the landward (i.e., western) side.

3.2.2 Seismic Stratigraphy

Rhode Island Sound: In the vicinity of areas Brenton-A and B, sub-bottom profiles revealed two major acoustic units in the upper 40 m of section (maximum depth represented by the width of the record). The lower unit, >20 m thick, exhibited a diversity of acoustic reflector patterns from chaotic to laminated (Figure 3-26). This unit, exposed at the seafloor over half of the survey area, was inferred to be glacial drift and has been recognized by other workers including Needell et al. (1983a and b). The chaotic, discontinuous reflector pattern may represent one or more of the following: till, moraine, or ice-deformed drift. Continuous, flat-lying to gently-dipping reflectors suggest stratification characteristics of glacial outwash or glacial lake deposits. Where not exposed, the top of this unit was marked by a high-amplitude, continuous reflector that was noted to truncate underlying reflectors. This unconformity was irregular and incised with depressions up to 14 m in depth (Figure 3-27). Depressions were infilled with the basal part of the overlying acoustic unit. In general, this upper unit was well-laminated. Internal reflectors were continuous, parallel, and flat-lying to dipping. Onlap fill and cut-and-fill structures were noted within the deeper depressions. The upper unit was inferred to consist of post-glacial fluvial, estuarine, and marine deposits of gravel, sand, silt, and clay.

The closed depressions noted within Brenton-A and B (Figures 3-23 and 3-24) are thought to be surface expressions of a relict, post-glacial drainage system that directed flow to the southwest along the landward side of the Charlestown-Buzzards Bay recessional moraine. The unconformity observed between the two seismic units discussed represents the stream-cut surface of this relict system. The irregular 20 fm (120 ft) bathymetric contour in the southeastern half of Brenton-A does not reflect a subsurface drainage system; rather, this depression was the result of modified surface relief of the glacial drift deposit.

Narragansett Bay: The Holocene stratigraphy in Narragansett Bay, as interpreted from seismic profiles, has been reported in detail by McMaster (1984). In East Passage, the trunk valley was infilled by >20 m of glacial drift. These deposits were cut by the post-glacial fluvial unconformity and overlain by as much as 10 m of estuarine sand, silt, and clay. An 8.4 m vibracore obtained from a location approximately 0.7 km south of the disposal site off Prudence Island yielded fine-grained (silt), Holocene marine sediments up to 7,000 years in age (McMaster and Friedrich, 1985). Paleomagnetic analyses indicated that the upper 1.5 m of core material had been highly disturbed due, presumably, to human activity.

3.2.3 Surface Textural Characteristics

Brenton-A: Four textural bottom types were mapped at the Brenton-A area based on side scan sonograph interpretations and grain size data from NED (Figures 3-28 and 3-29, Tables 3-5 and 3-6). Unit 1, which predominated in this area, consisted of a relatively uniform and featureless (no bedforms) silt-sand-gravel surface with, occasionally, scattered boulders. This unit characterized much of the northeast-southwest trending, 37 m closed contour depression and extended to the southeast through the central portion of the region. Unit 2 was found to either side of unit 1, in slightly shallower depths. This unit was characterized by sand with gravel depressions of approximately 1 m relief. Dimensions of these depressions varied greatly. The average feature appeared approximately 50 m by 50 m, but some were linear (10-20 m wide by 40-50 m long) with no preferred orientation.

These depressions acted as "windows" to the underlying substrate as the sand cover appeared to consist only of a thin ($\leq$ 3 m) veneer. Along the two northernmost survey lines, some depressions were noted to exhibit a pattern subtly suggestive of bedform development (Figure 3-28). Sandy gravel to gravelly sand patches with occasional boulders characterized Unit 3, found primarily in one area to the southeast. Along the southeast perimeter of Brenton-A, a coarser unit was observed. Unit 4 consisted of gravel, sand and boulders with occasional megarippled sediment patches and sandwave forms (note the classification used herein, after Boothroyd and Hubbard, 1975, defines megaripples as bedforms with spacing of 0.6 - 6.0 m; forms of spacing >6 m are sandwaves). Bedform crest orientations, mapped where observed, aligned predominantly west-northwest to east-southeast (Figure 3-28). Location of stations and results of grain size analyses (Figure 3-29 and Table 3-6) confirmed the side scan interpretation; the major mode for most stations was sand or gravel, with the exception of the furthest station to the south (50% sand, 50% silt-clay).

<u>Brenton-B</u>: Five textural bottom types were observed on side scan sonographs from the Brenton-B area (Figure 3-30 and Table 3-5). Bedforms characterized all but two of the bottom types mapped. Unit 1, comparable in texture to Unit 1 in Brenton-A, represented a megarippled sand field. Bedform distribution was fairly ubiquitous; forms averaged 1 m in wavelength (spacing). This pattern was observed along the axis of the 35 m closed contour depression in the northern half of the survey area. Unit 2 was marked by sand with megarippled, gravelly sand depressions. This unit was comparable to Unit 2 in Brenton-A; however, the coarse-grained "windows" consistently exhibited bedforms. This bottom type was found primarily in the northwest corner of the area, along the flanks of the surface depression. Brenton-B Unit 3, observed in the southeastern corner, exhibited the same texture as Unit 3 in Brenton-A: sandy gravel to gravelly sand patches with occasional boulders. Unit 4 in Brenton-B was also analogous to that mapped in Brenton-A; however, bedform development was more widespread in Brenton-B. This surface unit (Unit 4) predominated, and was observed in the northeast corner on a bathymetric high and throughout much of the southern half of the area. Unit 5 represented uniform sand (no bedforms) and characterized a depression in the southeast quadrant of the surveyed region. Bedform crest orientations in Units 1, 2, and 4 were aligned similarly to those observed in Brenton-A (Figure 3-30). Results of grain size analyses (Figure 3-31 and Table 3-7) again confirmed the major modal sediment grain size to be sand or gravel; only one station had a predominant silt-clay fraction (53%) with a sizeable sand component (46% sand, 1% gravel).

<u>Prudence</u>: Side scan observations revealed four different bottom types within the historic disposal site off Prudence Island (Figure 3-32 and Table 3-5). However, as will be discussed, the differentiation appeared unrelated to depositional history or the

present circulation regime. Unit 1, which characterized the west side (and greater depths) of the area, was a sandy silt marked by numerous surface "mounds". These features appeared approximately 10-20 m in diameter and < 2 m in height. Most notably along line 4, they were found to surround shallow depressions. Unit 2 represented a similar substrate with less frequent occurrences of the moundlike features. Numerous trawl marks, fish pots, and a few gravel patches were also noted (Figure 3-32). Unit 3 was a featureless, silty sand to sandy silt bottom and occurred in two isolated areas. Unit 4 marked an anomalous gravel deposit in the southwest corner of the site. Results of grain size analyses indicated the area consisted primarily of sand and silt-clay (Figure 3-33 and Table 3-8); the silt-clay component predominated at the majority of stations.

4.0 DISCUSSION

4.1 Topography of the Brenton Reef Historic Disposal Site

One of the primary objectives of this study was to determine the areal extent of the historical dredged material deposit at the Brenton Reef disposal site. This was readily delineated by the precision bathymetric and REMOTS® surveys (Figures 3-1 and 3-4). The only additional evidence of dredged material presence outside the discrete mound and flanks in the western quadrant of the site was a small elliptical area located near the eastern site boundary (Figure 3-4). Based on the bathymetry, REMOTS®, and benthic community data, the disposal mound showed a physically stable configuration that has not changed in the nine years since the last comprehensive survey.

4.2 Bottom Topography and Sediment Characteristics

4.2.1 Geological History

Another objective of this study was to determine bottom elevations and topography, physical characteristics (including sub-bottom), and sediment types for the different study areas. Interpretation of the bathymetry, side scan, and sub-bottom results at the Brenton-A, Brenton-B, and Prudence sites is clarified by a review of the geologic history of the area. Upland areas of Rhode Island are composed primarily of Paleozoic crystalline rocks overlain by unconsolidated glacial deposits. The bedrock surface continues beneath Narragansett Bay and offshore, dipping to the south and southeast. In Rhode Island Sound, 15 - 20 km south of the mouth of the Bay, the bedrock is unconformably overlain by a seaward-thickening and seaward-dipping erosional remnant of ancient (Cretaceous) coastal plain strata (McMaster et al., 1968). The landward extent of the coastal plain deposits is marked by a prominent, north-facing, and highly-incised cuesta. This feature is the result of extensive fluvial erosion during the Tertiary (2.5 - 65 million yr B.P.). Stream flow deepened the valleys extending south from Narragansett Bay and carved north-flowing valleys into the coastal plain escarpment. An intervening lowland was created which directed stream flow to the west. This pre-glacial landscape was greatly modified during the Pleistocene, when New England was glaciated by at least two ice advances (Schafer, 1961; Schafer and Hartsborn, 1965; McMaster and Ashraf, 1973 a, b, and c). Glacial ice widened and deepened valleys as far as 50 km offshore. Extensive glacial drift, consisting of both stratified and unstratified tills, moraines, and outwash plains, was deposited throughout the region. Two prominent series of glacial end moraine deposits can be traced across the inner shelf and coastal uplands (Schafer, 1961; Schafer and Hartshorn, 1965; Sirkin, 1976 and 1982) (Figure 4-1). The older, southernmost terminal moraine is the Ronkonkoma-Vineyard-Nantucket Moraine which extends across Long Island, Block Island, Martha's Vineyard, and Nantucket Island. Submerged extensions are indicated in Rhode Island Sound by the irregular submarine topography (Figure 1-1). This moraine line is believed to mark the terminal position of the Late Pleistocene ice lobes. During glacial retreat (approximately 16,000 yr B.P.), several series of subparallel moraines were formed, the most prominent of which is the Harbor Hill-Charlestown-Buzzards Bay Moraine (Figure 4-1). This younger moraine overlies the southern shore of Rhode Island and extends to western Cape Cod. Similarly, submerged expressions are revealed by irregular bathymetric configurations from Point Judith to the Elizabeth Islands (Figures 1-1 and 4-1).

As the ice retreated, topographic highs, created by moraine-capped coastal plain deposits, prohibited drainage of meltwaters to the south. Freshwater lakes developed between the retreating ice and the terminal moraines. Valleys were infilled with glaciolacustrine sediments and outwash deposits. Prior to sea level rise, the lakes are believed to have drained through a breach in the moraine, exposing the post-glacial surface to renewed stream cutting. The glacial terrain controlled the drainage pattern which directed stream flow south out of the Bay and southwest along the landward side of the moraine deposits. During the Holocene, as the rising sea submerged the inner shelf, estuaries and salt marshes infilled valleys and lowlands (approximately 10,000 - 12,000 yr B.P.). Estuarine sedimentation progressed up the trunk valleys of the Bay (9,000 yr B.P.) while waves and currents reworked the glacial drift offshore. Presently in Rhode Island Sound (in non-valley areas), Holocene deposits form only a thin veneer over the glacial terrain. These deposits consist of the coarser components of the glacial source material: sand, gravel, and boulders. In the Bay, the Holocene sequence is up to 15 m thick. Net nontidal circulation (the result of mixing fresh and salt water) has contributed to the infilling of valleys by silt deposition. Southeast of Prudence Island, surface sediments have been mapped as sand-silt-clay (McMaster, 1960) and are also characterized as gas-are also characterized as gas-bearing sediments (McMaster, 1984). Valley basins, such as the one in East Passage, are favorable sites for the trapping of interstitial gas bubbles that are produced by the decomposition of organic matter.

Sediments within areas Brenton-A and Brenton-B are composed of sand, gravel, and boulders derived from the reworking of the extensive glacial drift deposits. A relict channel system, trending northeast-southwest through the two areas, is buried by up to 14 m of inferred fluvial estuarine and marine silt, sand, and gravel. This system was rendered inactive after submergence by the last marine transgression. An offshore surface expression of the system persists due to incomplete infilling prior to the marine submergence. Bathymetric contour configurations elsewhere throughout the survey areas reflect the antecedent relief of the glacial terrain.

4.2.2 Side Scan Sonar Observations

Side scan sonar observations revealed the poorly sorted, coarse material associated with the glacial deposits. Sand, gravel, and scattered boulders characterized most of the textural units (Table 3-5). Side scan data also indicated that recent sand deposits, winnowed from the glacial and post-glacial sediments, occurred in a thin ($\leq$ 3 m) patchy veneer over the coarser-grained material. Underlying topographic relief, bed roughness, turbulence, and bottom stress contributed to the shape and distribution of these sand deposits. Units 1, 2, and 5 (Brenton-B) represented this potentially depositional sand veneer surface. Units 3 and 4 represented highly reworked drift surfaces from which, perhaps, the sand was derived.

Active bedload erosion, transport, and deposition were indicated, most notably in the Brenton-B area, by the megaripple and sandwave forms. These forms are produced by current speeds in excess of 50 cm/sec (1 kt). Given that average fairweather current speeds are reported to be less than 0.6 kt in this area (Spaulding, 1979), it is presumed that these forms occurred episodically in response to storm-driven currents. When active, megaripple migration produces a reworking of approximately the upper 30 cm of sediment. Sandwaves are capable of reworking the upper 1 m of sediment cover. During fairweather periods when the forms would be inactive, sandwaves would be expected to persist while megaripples would be expected to degrade in form. Swift et al. (1979) report that this is the case in similar water depths off Long Island, NY. It is interesting to note that the preferred orientation of both forms, in Brenton-A and B, indicated that net sediment transport was to the south-southwest. Predominant northeasterly storm winds are capable of producing a south-southwesterly current due to the effects of geostrophic flow. The paucity of bedforms in the Brenton-A area, in comparison to the widespread distribution in

Brenton-B, is not fully understood. This marked difference may be related to subtle differences in relief (maximum depths in Brenton-A exceeded those in Brenton-B by 3 m), or the resolving capability of the sonar system. More bedforms may have been present in Brenton-A but, due to their size and/or orientation, may not have been observed. Ripples, classified as forms with wavelengths <0.6 m, may have existed over surfaces that appeared featureless in the sonographs. These forms are known to occur on the inner shelf in response to oscillatory wave action. The threshold velocity for formation is 10 - 20 cm/sec, depending on the grain size. Ripple migration results in a reworking of the upper few to 10 cm of sediment.

With the exception of a few isolated gravel patches, the surface texture at the Prudence site was a uniform, silty sand to sandy silt (Table 3-8). Seismic data and core analyses indicated that this unit was greater than 8 m in thickness. Side scan data suggested that there was much human activity in this area (trawl marks, fish pots, etc.). The moundlike features observed at the site did not appear to be wave- or current-generated, and probably were created when the site was historically used for dredged material disposal.

4.3 Benthic Community Structure

A final objective of this study was to determine the benthic community structure inside and outside the Brenton Reef historic disposal site and compare the findings with those found during the 1978 study. There appeared to be four distinct infaunal communities at the Brenton Reef disposal site, related most likely to gradients in sediment grain-size and organic matter. Stations 1 and 2 (Figure 2-4) consisted of fine-grained material derived primarily from disposal operations and dominated by the amphipod *A. agassizi*, the bivalve *N. annulata*, and the polychaete *P. quadrilobata*. A transition through two different communities associated with winnowed sand/shell lag deposits was found as one moves up the flanks of the mound to the mound center (stations 3-8). Community dominants of the polychaetes *A. suecica*, *L. fragilis*, *P. steenstrupi* and *T. annulosus* gave way to the mobile sand community dominated by the amphipod *B. serrata*. Moving off the mound on to the ambient seafloor consisting of fine sand, the highest densities of the amphipod *A. agassizi* were found along with *N. annulata*, *P. steenstrupi*, and the thalassinid shrimp *A. serratus*.

One problem with comparing results from the present survey with historical data is the difference in sieve size used to process the benthic samples. While the use of a 0.5 mm sieve (as used in the present study) is the accepted standard today, one practical drawback to using a sieve finer than 1 mm is the tremendous increase in the number of individuals retained for sorting. Consequently, it was necessary to split several samples from the 1987 survey (stations 3, 11, and 12). Care was taken to maximize the accuracy of the final counts through the use of nested sieves and the removal of organisms by "Ludox" flotation prior to splitting the fine sieve fraction. However, splitting causes uncertainty about the density and diversity of less abundant species and requires increased time for sample preparation and record keeping. These factors will have to be taken into account in planning future studies at this site. The use of a smaller sampler may be justified at stations where high densities of organisms are found. Although most of the species examined in this study are abundant in regional shelf habitats, a surprising number have been renamed recently, are being re-examined, or have been misidentified in older studies. These changes need to be considered in the detailed comparison of the counts obtained here with the previous surveys.

Disposal of a large volume of dredged material from the Providence River Improvement Project was carried out between late 1967 and early 1971 at the Brenton Reef site. Benthic invertebrates were sampled at the disposal site on seven occasions between 1970 and 1979. Five surveys carried out by the University of Rhode Island are listed below. In each of these, 0.1 m^2 grab samples were sieved to 0.75 mm. Additional samples were taken in 1978 and 1979 by the DAMOS program using 1 mm sieves.

		Number of Stations	**Number of Samples**	**Report**
URI/COE	September 1970	6	17	Saila, Pratt, Polgar, 1972
URI/COE	December 1971	11	33	Pratt, Saila, Sissenwine, 1973
URI/Sea Grant	December 1973	11	44	
URI/EPA	Summer 1974	13	55	
URI/EPA	October 1975	4	12	
DAMOS	April 1978	2	6	Annual Data Report, May 1979 (NUSC, 1979)
DAMOS	Summer 1979	2	10	Annual Report, 1980 (NUSC, 1980)

The data obtained in the URI studies was difficult to compare in detail with 1987 data because a different sieve size was used, the data were not computerized, and some problems of identification, sample dates, and locations were not resolved.

Because of the temporal and spatial variation in materials deposited and subsequent temporal changes at the mound apex from erosion, it was more appropriate to group samples by sediment type for comparison rather than by station location alone. For most historical surveys there was at least some grain size and sediment contaminant data. Some of these data have been published; the large amount of data collected by the EPA as part of "Operation Dumptrack" is available only as a paper printout.

Although a variety of sampling plans was used in the different studies (Figures 4-2 and 4-3), the site center, edges, and a reference site on fine sand east of the disposal mound were sampled on each occasion. Some of the characteristics of the invertebrate assemblages at the center and reference site are summarized in Table 4-1 and reviewed below.

<u>Number of individuals</u>: At the site center a small number of individuals were found during active disposal operations. Numbers rose to around 300 per 0.1 m^2 during the first year of recovery and remained at these levels through 1975. Numbers at the reference station were about five times higher, but more than half of the individuals represented were <u>Ampelisca agassizi</u>.

In 1987, the lowest density of individuals was 598 on sandy substratum. Full recovery in numbers had occurred on dredged material on the edges of the disposal site by 1987.

<u>Number of species</u>: At the site center, the number of species was 26 per sample after one year of recovery. This high diversity (relative to the small number of individuals present) was due to the heterogeneity of sediment texture, resulting in a mixture of species normally found on a number of different substratum types. Mean species number was higher at the reference station where the subdominants of the <u>Ampelisca</u> community make up a stable, possibly biologically-accommodated assemblage. Most of the increase in species numbers from the 1987 samples was due to improved taxonomy rather than the use of a smaller sieve size. With the exception of one coarse sand sample (Station 7), there was no difference between the number of species in samples from center, edge, and reference areas in 1987.

<u>Ampeliscid density</u>: In each survey, dense populations of <u>Ampelisca agassizi</u> (amphipod crustacean) were found adjacent to the disposal site. While shallow water <u>Ampelisca</u> species are subject to large fluctuations in density, <u>A. agassizi</u> remains dominant over wide areas through replacement of the adult population once a year. Small scale variation in density within beds (observed by divers) as well as predator foraging can be invoked to explain the high variance seen in Table 4-1.

<u>A. agassizi</u> had not recolonized the center or edges of the disposal site by 1975; it was not altogether surprising that

this deposit-feeding animal was absent from the wave-rippled sand in the site center (another ampeliscid, Byblis serrata, is found on sandy bottom). In 1975, it was not clear whether the absence of A. agassizi on the silty disposal material edges was a result of failure to colonize or due to sediment toxicity. By 1987, dense populations of A. agassizi had colonized dredged material at mound edge stations (3 and 10). This may be the result of processes which have made the sediment either more attractive or less toxic to A. agassizi.

Changes in other species: The density and distribution of the more than 100 species found in the Brenton Reef study area follow a variety of patterns reflecting substratum requirements, feeding types, response to disturbance, breeding cycles, and natural variability. Data on natural history are lacking for many of the shelf species which are present. A few of the long-term changes observed are listed here:

A. **Capitella sp.** (deposit-feeding polychaete), an opportunistic species often characterized as a "pollution indicator", was found in moderate numbers on dredged material in 1974 and 1972 (maximum 59 per $0.1m^2$), but was rare or absent in subsequent samples.

B. **Tharyx spp.** (deposit-feeding polychaete), which can be abundant in organic sediments, was an early colonizer and increased in density on the site edges up to 1987.

C. **Prionospio steenstrupi** (suspension-feeding polychaete) naturally present in ampeliscid beds was also an early colonizer of site edges.

D. **Scalibregma inflatum** (deposit-feeding polychaete) has increased steadily in density at all dredged material stations up to the most recent survey.

E. **Phoronis muelleri** (tube-dwelling, suspension-feeding phoronid) was an early colonizer but never became numerous. This species was an early colonizer at some disposal sites in central Long Island Sound.

F. **Arctica islandica** ("ocean quahog", suspension-feeding bivalve) juveniles were abundant on dredged material in 1971 and 1973, possibly as the result of reduced predation, but has been less abundant since.

G. **Nephtys incisa** (deposit-feeding polychaete) was uniformly distributed in moderately high densities (25 per $0.1m^2$) in 1971-1973, but decreased in subsequent samples.

H. **Periploma papyratium** (bivalve) also found in silty sediments, colonized dredged material edges after 1973.

I. Rhepoxynius hudsoni - A free-burrowing amphipod related to a species used in sediment toxicity testing, was found in moderate numbers on sandy dredged material in 1974 and 1987.

A group of species found on natural silty bottom (the bivalve Nucula spp. and the anemones Ceriantheopsis americana and Edwardsia elegans) had increased in density southwest of the site in sediments which may be the result of dredged material disposal operations.

The general pattern of faunal distribution presently found in the Brenton Reef disposal area was established within four years after large-scale disposal ended. Between 1974 and 1987, population numbers increased on dredged material, but the general pattern of species number and community types has remained the same. Throughout the area, sediment grain size and organic matter content are probably the most important determinants of faunal makeup; the impact of sediment contaminants in the dredged material on the recovery process is harder to assess.

The process of recovery of continental shelf benthos from disturbance and pollution is still largely unknown. Previous studies of benthos from offshore disposal areas in the New York Bight and Massachusetts Bay have not filled this data gap because of continuous releases of a great variety of materials, the spatial complexity of the sites, and, in the case of New York, the additional confounding variable of poor water quality. Such variables do not exist at the Brenton Reef Site, as virtually all the introduced material came from a single dredging operation, there has been a long period of recovery, and water quality remains very high. This consistency at the Brenton Reef Site provides an environment where the processes of long-term recovery of continental shelf benthos can be assessed and analyzed.

5.0 SUMMARY

The physical boundaries of the historic disposal mound at the Brenton Reef disposal site had not changed since the last survey of the area; the mound was a well-defined feature centered just inside the western boundary of the disposal site with a diameter of roughly 1600 meters and a minimum depth at the apex of 25.5 meters.

The areas of Brenton-A and Brenton-B were characterized by extensive glacial drift deposits. A relict channel system that drained the landward side of the recessional moraine was observed in sub-bottom profiles trending northeast-southwest through these two areas.

Surface sediments in both Brenton-A and Brenton-B were composed of sand, gravel, and boulders derived from wave and current reworking of the glacial drift deposits. Coarse, gravelly, boulder-strewn areas (units 3 and 4) were found adjacent to areas characterized by a thin ($\leq$ 3 m), patchy sand veneer (units 1, 2, and 5). Depressions or "windows" in this veneer revealed that the sand overlies the coarse, gravelly surface. Megaripples and sandwaves, which occur in response to current speeds in excess of 50 cm/sec (1 kit), were observed in both areas, but were more widespread in Brenton-B. These forms are capable of reworking the upper 30 cm (megaripples) to 1 m (sandwaves) of surface sediment. Bedform orientation indicated a net transport direction to the south-southwest. It is believed that these forms developed in response to northeasterly storm winds. Subtle differences in relief, producing subtle differences in hydraulic regime, or the resolving capability of the side scan system may account for the disparity between bedform observations in the two locations.

The historic dredged material disposal site southeast of Prudence Island lies in the East Passage trunk valley, a prominent branch of the pre-glacial drainage system. Glacial drift and Holocene estuarine sedimentation have infilled the valley. Data indicated that at least the upper 8 m of sediment consisted of silt and sand, of which the top 1.5 m had been highly disturbed (mixed). Side scan data revealed mound-like features (< 2 m in height; 10 - 20 m in diameter) on an otherwise uniform surface. These forms did not appear to be wave- or current-generated. Trawl marks and fish pots observed on the sonographs were evidence of man's activity in this area.

Based on these results, it appeared that areas Brenton-A and Brenton-B did not contain any "quiescent" silt-clay depositional basins; these were found only in the historical Prudence Island Disposal Site. There appeared to be a silt-clay facies to the south of the existing disposal mound at the Brenton Reef site, but the steep gradient in bathymetry, grain-size, and biological community type on the historical mound indicated that the seafloor would experience a different hydraulic regime with a 3-5 meter elevation above ambient depths (33 meters).

The benthic communities around the Brenton Reef disposal mound showed a full recovery in population density since the cessation of disposal operations. Dense ampeliscid beds were observed on the ambient seafloor within and outside the site as well as on the edge of the mound; a mobile sand community dominated the mound central area where a distinct transition in sediment grain size occurred. The density of lobster traps on and around the disposal mound attested not only to the benthic community recovery but to the enhanced fishery resource which exists at the site.

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TABLE 3-1

Description of Sample Residues, Rhode Island Sound Disposal Area, October 1987. Constituents are Listed in Order of Abundance. A "+" Indicates Split Samples.

Station	Residue Vol. (cm^3)	Constituents	Organisms Recovered	Time To Sort (hours)
1	400	pebbles, terrestrial plant detritus, estuarine shells, gray medium sand, polychaete tubes	1,794	17.25
2	300	estuarine shells, plant detritus, polychaete tubes	5,342	50
3	1,300	scallop shells, other estuarine shells, plant detritus	2,415	19.25+
4	1,600	medium sand, scallop and jingle shells, fine shell hash	703	10.5
5	1,500	medium sand, oyster shells, pebbles	875	18.25
6	600	medium sand, estuarine shells, fine shell hash	815	23
7	4,100	coarse sand, pebbles	598	4
8	1,100	medium sand, estuarine shells, pebbles	983	16.5
9	1,100	coarse sand, estuarine shells, little plant detritus	1,609	21.5
10	1,300	granules, pebbles, estuarine shells, amphipod tubes	3,432	19.25
11	900	amphipod tubes, fine sand, offshore shells	4,299	17.5+
12	500	amphipod tubes, fine sand, offshore shells	4,675	27.25+

TABLE 3-2

Summary of Species Counts, Brenton Reef Historic Disposal Site, October 1987

	STATION NUMBER											
	1	2	3	4	5	6	7	8	9	10	11	12
SPECIES												
Total per station	56	51	62	60	51	54	38	64	58	57	51	47
Total for study = 135												
INDIVIDUALS												
Total per station	1794	5342	2415	703	875	815	598	983	1609	3432	4299	4675
Polychaetes	515	2084	1360	529	388	206	525	827	1305	584	574	1442
Mollusca	1074	2077	96	38	74	96	10	50	12	67	548	208
Amphipods	100	890	881	91	386	486	39	73	239	2737	3101	2928
Ampelisca agassizi	86	887	828	5	5	.	13	4	117	2530	2869	2737
Nucula annulata	977	1911	16	8	2	9	5	12	6	34	418	128
Prionospio steenstrupi	47	74	668	22	37	6	43	224	640	190	348	1220
Tharyx acutus	23	764	46	41	80	27	79	130	96	23	26	11

TABLE 3-3

Species Counts for the Twelve Stations Sampled at the Brenton Reef Historic Disposal Site, October 1987

SPECIES	STATION NUMBER 1	2	3	4	5	6	7	8	9	10	11	12
CNIDARIA												
Ceriantheopsis americanus	4	10	1	.	.	.	.	.	1	.	.	.
Edwardsia elegans	43	49	.	.	.	.	.	.	.	.	.	.
RHYNCHOCOELA												
Cerebratulus lacteus	.	.	.	5	.	.	.	.	.	1	.	.
Lineus sp.	.	.	.	.	.	.	.	.	.	.	3	1
Micrura sp.	17	28	4	2	2	.	.	2	4	13	4	6
Rhynchocoela spp	1	5	2	1	.	6	.	1	1	1	.	.
Tubulanus pelucidus	6	26	.	2	.	.	3	.	.	.	.	.
PHORONIDA												
Phoronis muelleri	14	140	1	.	.	.	.	.	.	.	.	.
ANNELIDA												
Oligochaeta spp.	10	3	28	2	5	.	2	2	3	7	49	35
POLYCHAETA												
Aglaophamus circinata	.	.	.	7	2	10	.	.	2	.	.	.
Ampharete arctica	.	.	1	1	.		1	1	.	.	.	1
Ammotrypane aulogaster	.	.	1	.	.	.	.	.	.	1	1	2
Anthrobothrus gracilis	14	15	4	.	.	.	.	1	3	12	9	9
Aricidea jeffreysii	11	18	169	175	5	67	181	62	91	14	30	15
Asychis elongata	.	.	.	.	.	.	.	.	.	.	.	7
Brada v	.	.	3	.	.	.	.	.	.	.	1	.
Brada g	.	.	.	.	.	.	.	.	.	2	.	.
Capitella capitata	.	10	2	.	.	.	.	.	.	.	.	.
Chaetozone setosa	.	.	.	1	.	.	.	4	.	.	.	.
Chone infundibuliformis	2	29	.	1	.	.	.	.	1	7	5	3
Cirrophorus lyriformis	.	.	8	5	18	7	5	6	15	.	.	.

TABLE 3-3, CON'T

STATION NUMBER

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
Cossura longocirrata	36	48	2	.	.	.	.	.	.	.	1	.
Drilonereis longa	1	.	9	1	1	.	.	3	1	3	3	3
Drilonereis magna	.	.	.	.	.	.	.	.	.	.	.	1
Eteone trilineata	1	4	.	.	.	.	.	.	.	.	.	.
Euchone rubrocincta	.	1	.	10	8	3	4	8	3	.	1	.
Euchone incolor	10	21	2	.	.	1	.	1	1	2	1	8
Euclymene torquata	16	1	48	5	.	1	.	.	19	49	30	16
Euclymene zonalis	2	.	.	5	11	.	2	6	.	2	2	1
Exogone hebes	1	.	2	15	10	3	8	17	14	7	32	70
Flabelligerida sp	.	.	.	.	.	.	.	.	.	1	.	.
Glycera dibranchiata	.	.	.	5	.	4	1	3	2	.	.	.
Glycera robustum	.	.	.	.	1	.	.	.	.	.	.	.
Goniada maculata	.	.	.	.	.	.	.	.	.	1	.	.
Goniadella gracilis	.	.	.	.	19	.	51	6	3	6	.	.
Harmothoe extenuata	.	.	4	.	.	.	4	2	.	3	1	1
Hartmania moorei	.	.	.	.	.	.	.	.	.	1	.	.
Laonice cirrata	.	.	1	.	.	.	.	.	.	1	.	.
Leiochone dispar	.	.	.	20	14	.	2	.	.	.	.	.
Leitoscoloplos robustus	.	.	.	2	.	.	.	.	.	.	2	5
Lumbrineris acuta	.	.	1	.	.	.	.	.	.	1	.	.
Lumbrineris fragilis	.	.	1	9	20	1	17	7	1	.	.	.
Lumbrineris impatiens	32	79	24	35	22	7	.	67	76	19	13	.
Mediomastus ambiseta	29	165	46	3	2	2	1	2	49	22	3	9
Myriochele heeri	1	.	.	.	.	.	.	.	.	.	.	.
Nephtys incisa	14	19	9	.	.	.	.	.	1	.	1	.
Nereis grayi	.	.	2	.	.	.	.	.	1	3	10	.
Nerinides tridentata	.	1	.	.	.	.	.	.	.	.	.	.
Ninoe nigripes	21	20	38	5	.	3	.	11	27	57	13	17
Owenia oculata	17	18	1	.	.	.	.	1	1	.	5	3
Paranaitis speciosa	.	4	.	.	.	.	.	.	.	.	.	.
Paraonis gracilis	28	43	25	.	1	.	.	2	75	7	11	17
Pectinaria gouldii	.	.	.	.	.	.	.	.	1	.	.	.
Phyllodoce maculata	.	.	1	4	6	4	.	13	2	7	5	6
Pherusa affinis	7	17	.	.	1	1	2	.	4	6	3	.

TABLE 3-3, CON'T

STATION NUMBER

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
Pholoe minuta	46	84	14	1	1	.	5	1	15	30	.	3
Pisione remota	.	.	.	.	.	.	67	.	.	.	.	.
Polycirrus medusa	13	26	6	1	13	3	5	4	1	9	.	.
Polydora quadrilobata	41	357	4	.	.	.	.	.	3	.	.	.
Polydora socialis	.	.	1	.	.	.	.	2	1	1	.	.
Potamilla neglecta	2	3	.	.	.	1	.	.	.	1	.	.
Prionospio steenstrupi	47	74	668	22	37	6	43	224	640	190	348	1220
Sabellaria vulgarus	.	.	.	.	.	.	.	1	.	.	.	.
Scalibregma inflatum	4	1	36	21	77	29	34	71	73	14	5	3
Schistomeringos caeca	.	.	.	14	16	8	3	2	5	.	.	3
Spio fillicornis	.	.	.	.	.	.	3	2	.	.	.	.
Spio pettibonae	30	172	9	.	.	.	.	.	.	.	.	.
Spio setosa	.	.	5	1	17	.	5	.	.	.	.	.
Spiochaetopterus oculatus	.	.	.	.	.	1	.	1	.	.	.	.
Spiophanes bombyx	1	3	6	8	1	12	.	4	.	.	.	.
Sternaspis scutata	22	14	.	.	.	.	.	.	.	.	1	.
Sthenelais boa	1	1	.	2	.	3	.	5	.	.	.	.
Syllis gracilis	.	.	.	.	.	.	.	1	1	.	.	.
Syllis sp	.	.	.	.	1	.	1	.	.	2	.	.
Sabellaraidae sp	.	.	1	.	.	.	.	.	.	.	.	.
Terebellides stroemi	2	1	.	.	.	1	.	.	.	.	.	1
Tharyx acutus	23	764	46	41	80	27	79	130	9	23	26	11
Tharyx annulosus	38	67	158	109	1	.	1	156	76	77	11	7
Tharyx maraoni	1	.	2	.	3	.	.	.	1	3	.	.
Travisa carnea	.	.	.	.	.	1	.	.	.	.	.	.
Trochaeta multisetosa	1	4	.	.	.	.	.	.	.	.	.	.
MOLLUSCA												
Gastropoda												
Acteon punctostriatus	.	.	.	.	.	1	.	.	.	.	.	.
Crepidula sp.	.	.	.	1	.	2	.	4	.	.	.	.
Nassarius trivittata	5	.	.	1	.	.	.	.	.	.	.	.

TABLE 3-3, CON'T

STATION NUMBER

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
BIVALVIA												
Arctica islandica	.	.	.	1	.	2	.	.	.	.	1	.
Astarte undata	.	.	.	.	.	.	.	.	.	.	1	.
Cerastoderma pinnulatum	5	.	1	1	11	2	.	4	.	.	.	4
Crenella glandula	.	.	.	2	.	1	.	1	.	.	16	15
Ensis directus	.	.	.	.	4	3	.	3	.	.	.	.
Lepton	.	.	.	.	.	.	1	.	.	.	.	.
Lucinoma filosa	6	4	.	.	.	.	.	.	.	.	.	.
Lyonsia hyalina	.	.	4	1	17	12	3	17	2	.	.	.
Nucula annulata	977	1911	16	8	2	9	5	12	6	3	418	128
Nucula delphinodonta	4	10	3	3	.	1	.	.	1	8	58	41
Periploma papyratium	71	128	35	5	.	.	1	1	3	25	52	20
Pitar morrhuana	4	14	35	9	6	20	.	.	.	.	.	.
Solemya velum	.	.	.	.	.	1	.	.	.	.	.	.
Spisula solidissima	.	.	2	4	34	41	.	3	.	.	.	.
Tellina agilis	.	.	.	2	.	1	.	5	.	.	.	.
Yoldia sapotilla	2	10	.	.	.	.	.	.	.	.	2	.
ARTHROPODA												
Crustacea												
Cumacea												
Diastylis sculpta	2	1	4	6	1	1	1	10	10	1	.	.
Diastylis quadrispinosa	.	2	.	1	1	.	.	.	.	1	4	3
Eudorella truncatula	7	27	34	22	2	6	5	9	15	15	13	41
TANAIDACEA												
Leptognatha caeca	.	.	.	.	14	2	12	.	.	.	.	.
ISOPODA												
Chiridotea tuftsii	.	.	.	.	.	5	.	1	.	.	.	.
Cirolana polita	.	.	.	.	1	.	.	.	.	.	.	.
Edotea montosa	.	.	.	.	.	.	.	1	12	.	1	.
Pleurogonium spinosissinum	.	.	.	.	.	.	.	.	.	1	.	.
Ptilanthura tenuis	.	.	3	1	.	.	.	1	5	3	1	11

TABLE 3-3, CON'T

STATION NUMBER

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
AMPHIPODA												
Ampelisca agassizi	86	887	828	5	5	.	13	4	117	2530	2869	2737
Ampelisca vadorum	.	.	.	.	2	1	.	.	.	.	.	.
Argissa hamatipes	1	.	.	1	.	1	.	.	.	.	.	.
Byblis serrata	.	.	2	51	272	384	.	13	2	.	.	.
Corophium acutum	.	.	.	.	.	.	.	.	.	1	.	3
Corophium crassicornis	.	.	.	2	8	39	.	4	.	49	11	19
Ericthonius fasciatus	6	2	2	1	5	1	2	4	1	15	110	37
Harpina propinqua	.	.	5	.	.	.	.	.	2	.	2	6
Hippomedon serratus	.	.	.	.	4	1	.	.	.	.	.	1
Jassa falcata	.	.	1	.	1	.	.	.	.	.	.	.
Leptocheirus pinguis	.	.	16	.	2	3	.	2	1	51	14	2
Melita dentata	.	.	.	.	.	.	.	.	1	.	.	.
Monoculoides intermedius	.	.	.	2	.	.	.	1	.	.	.	.
Orchomenella minuta	.	.	24	.	1	.	.	1	.	25	.	1
Photis reinhardii	.	1	2	2	.	.	.	1	3	1	7	13
Phoxocephalus holbolli	.	.	.	.	.	.	2	12	1	5	2	.
Rhepoxynius hudsoni	.	.	.	14	2	27	.	.	.	.	.	.
Unciola irrorata	1	.	1	13	84	29	22	31	110	55	86	109
Stenopleustes inermis	6	.	.	.	.	.	.	.	1	5	.	.
DECAPODA												
Axius serratus	.	.	.	.	.	.	.	1	1	1	.	.
Cancer irroratus	.	.	.	.	.	.	1	1	.	.	.	.
Crangon septemspinosa	1	.	.	.	.	.	.	1	1	.	1	.
Pagurus acadianus	.	.	.	.	.	.	.	2	.	.	.	.
ECHINODERMATA												
Caudina arenata	.	.	.	.	.	1	.	.	.	.	.	.
Echinarchinus parma	.	.	.	3	1	6	.	.	.	.	.	.
CHORDATA												
Botryllus	.	.	1	.	.	.	.	1	.	.	.	.

TABLE 3-4

Groups of Species at the Brenton Reef Site Categorized according to their Association with other Species and their Abundance in a Given Habitat Type.

Greatest density in ampeliscid dominated samples:

Ammotrypane aulogaster	(polychaete)	
Edotea montosa	(isopod)	
Ptilanthura tenuis	(isopod)	
Ampelisca agassizi	(amphipod)	
Photis reinhardii	(amphipod)	
Oligochaeta spp.		
Crenella glandula	(bivalve)	

Greatest density in silty samples:

Nephtys incisa	(polychaete)	Normally found in deep estuarine and shelf silty bottoms
Pholoe minuta	(polychaete)	
Sternaspis scutata	(polychaete)	
Ceriantheopsis americanus	(anemone)	
Edwardsis elegans	(anemone)	
Nucula annulata	(bivalve)	
Yoldia sapotilla	(bivalve)	
Lucinoma filosa	(bivalve)	
Tubulanus pellucidus	(nemertine)	
Cossura longocirrata	(polychaete)	Possible indicators of disturbed habitat
Capitella capitata	(polychaete)	
Owenia oculata	(polychaete)	
Polydora quadrilobata	(polychaete)	
Spio pettibonae	(polychaete)	
Phoronis muelleri	(phoronid)	

Greatest density in sand and shell:

Aglaophamus circinata	(polychaete)	
Cirrophorus lyriformis	(polychaete)	
Goniadella gracilis	(polychaete)	
Leiochone dispar	(polychaete)	
Lumbrineris fragilis	(polychaete)	
Pisione remota	(polychaete)	
Schistomeringos caeca	(polychaete)	
Spio setosa	(polychaete)	
Ensis directus	(bivalve)	
Lyonsia hyalina	(bivalve)	
Spisula solidissima	(bivalve)	
Leptognatha caeca	(tenaiid)	
Byblis serrata	(amphipod)	

TABLE 3-5

Textural Characteristic based on Side Scan Sonograph Observations, Sites Brenton A, Brenton B, and Prudence.

	BRENTON A	**BRENTON B**	**PRUDENCE**
Unit 1	Uniform silt-sand-gravel with scattered boulders	Megarippled sand field (ubiquitous distribution of bedforms; average wavelength 1 m)	Sandy silt, numerous "mounds"
Unit 2	Sand with gravelly depressions (average relief 1 m; some suggestion of megaripples along lines 1 and 2)	Sand with megarippled, gravelly depressions (megaripples 1-6 m wavelength; depressions average 1 m relief)	Sandy silt, scattered "mounds"
Unit 3	Sandy gravel to gravelly sand patches with occasional boulders	Sandy gravel to gravelly sand patches with occasional boulders	Silty sand-sandy silt, featureless
Unit 4	Gravel, sand and boulders with megarippled patches and occasional sandwave forms	Gravel, sand, and boulders with megarippled, gravelly patches, gravelly depressions, featureless sand patches and occasional sandwave forms	Silty sand with gravel
Unit 5		Sand, uniform	

TABLE 3-6

Visual Descriptions and Grain Size Distributions of Sediments from the Brenton-A Study Area. Station Locations are Shown in Figure 3-29.

Station	Visual Description	% Gravel	% Sand	% Silt-Clay
BREN-A-1	olive-grey silty sand RPD=4-5cm dense amphipod mat	0	83	17
BREN-A-2	olive-grey silty sand RPD=2cm worm tubes & Nephtys	6	74	20
BREN-A-3	lt. brown fine sand RPD=IND shell fragments	1	98	1
BREN-A-4	poorly graded gravel RPD=IND	51	48	1
BREN-A-5	cobble & lg. mussels no mud or sand no sample taken			
BREN-A-6	dk. gray silty sand RPD=4 cm many amphipod tubes	1	89	10
BREN-A-7	gray sand w/gravel RPD=IND	20	79	1
BREN-A-8	olive-gray silty sand RPD=IND amphipod & worm tubes	0	87	13
BREN-A-9	lt. brown sand RPD=IND	0	100	0
BREN-A-10	dk. gray silty sand RPD=3 cm many amphipod tubes	0	84	16
BREN-A-11	lt. brown sand RPD=IND sabellid tubes	0	99	1
BREN-A-12	olive-grey silty sand RPD=4-5 cm	0	50	50

TABLE 3-7

Visual Descriptions and Grain Size Distributions of Sediments from the Brenton-B Study Area. Station Locations are Given in Figure 3-31.

Station	Visual Description	% Gravel	% Sand	% Silt-Clay
BREN-B-1	poorly sorted sand w/ gravel RPD=IND polycheate tubes	44	55	1
BREN-B-2	olive-grey silty sand RPD=<1 cm sabellid tubes	0	47	43
BREN-B-3	poorly sorted sand RPD=IND lg. shell fragments	1	98	1
BREN-B-4	olive-grey sand RPD=IND a few amphipod tubes	0	100	0
BREN-B-5	poorly sorted sand RPD=IND worm tubes	0	100	0
BREN-B-6	well-sorted sand RPD=IND amphipod tubes	0	100	0
BREN-B-7	well-sorted sand RPD=IND	0	100	0
BREN-B-8	well-sorted sand RPD=IND amphipod tubes & shells	0	100	0
BREN-B-9	olive-gray sandy silt RPD=1-2 cm numerous sabellid tubes	1	46	53
BREN-B-10	well-sorted gravel RPD=IND a few shell fragments	71	28	1
BREN-B-11	olive-gray silty sand RPD=3-4 cm polycheate & amphipod tubes	2	92	6

TABLE 3-7 (Continued)

Station	Visual Description	% Gravel	% Sand	% Silt-Clay
BREN-B-12	well-sorted sand RPD=IND	0	99	1
BREN-B-13	olive-gray silty sand RPD=1-2 cm amphipod tubes	3	75	22
BREN-B-14	sand w/gravel RPD=IND shell fragments	5	93	2
BREN-B-15	well-sorted sand RPD=IND shells & amphipod tubes	0	100	0

TABLE 3-8

Visual Description and Grain Size Distributions of Sediments at the Prudence Study Area. Station Locations are Given in Figure 3-33.

Station	Visual Description	% Gravel	% Sand	% Silt-Clay
PRUD-1	olive-gray clayey silt RPD=4-5 cm	0	14	86
PRUD-2	cohesive sandy silt RPD=4-5 cm	0	52	48
PRUD-3	olive-gray clayey silt RPD=4-5 cm sulphidic odor	0	6	94
PRUD-4	gray sandy silt RPD=<1 cm worms & amphipods	0	43	57
PRUD-5	cohesive silty sand RPD=2-3 cm shell fragments	5	30	65
PRUD-6	dk. gray clayey silt RPD=IND many old mussel shells	3	40	57
PRUD-7	dk. gray clayey silt RPD=2-3 cm a few worms	0	12	88
PRUD-8	gray sandy silt RPD=4-5 cm shells & worm tubes	2	42	56
PRUD-9	dk. gray sandy silt RPD=IND many old mussel shells	20	72	8

TABLE 4-1

Summary of Community Parameters for Historical Samples Taken at Selected "Center" and "Reference" Stations at the Brenton Reef Disposal Site ($0.1\ m^2$ Grab Samples Sieved to 0.75 mm).

		1970		1971		1973		1974		1975	
		ctr	ref	ctr	ref	ctr	ref	ctr	ref	ctr	ref
Sample Size		3	5	12	3	17	11	19	10	8	3
Individuals	mean	60.3	1717	---	---	330	1385	284	785	380	1678
	s.d.	61.2	1054	---	---	208	675	163	370	330	493
Species	mean	10.7	44.6	26.1	53.3	20	34	27	33	30.1	41.3
	s.d	3	10.4	7.5	9.3	4.6	4.8	4.7	5.9	8.9	8.4
A. Agassizi	mean	0	1190	2.3	2100	50	914	6.2	597	20.7	768
	s.d.	0	1108	4.4	1325	70	549	16.5	267	36.5	324

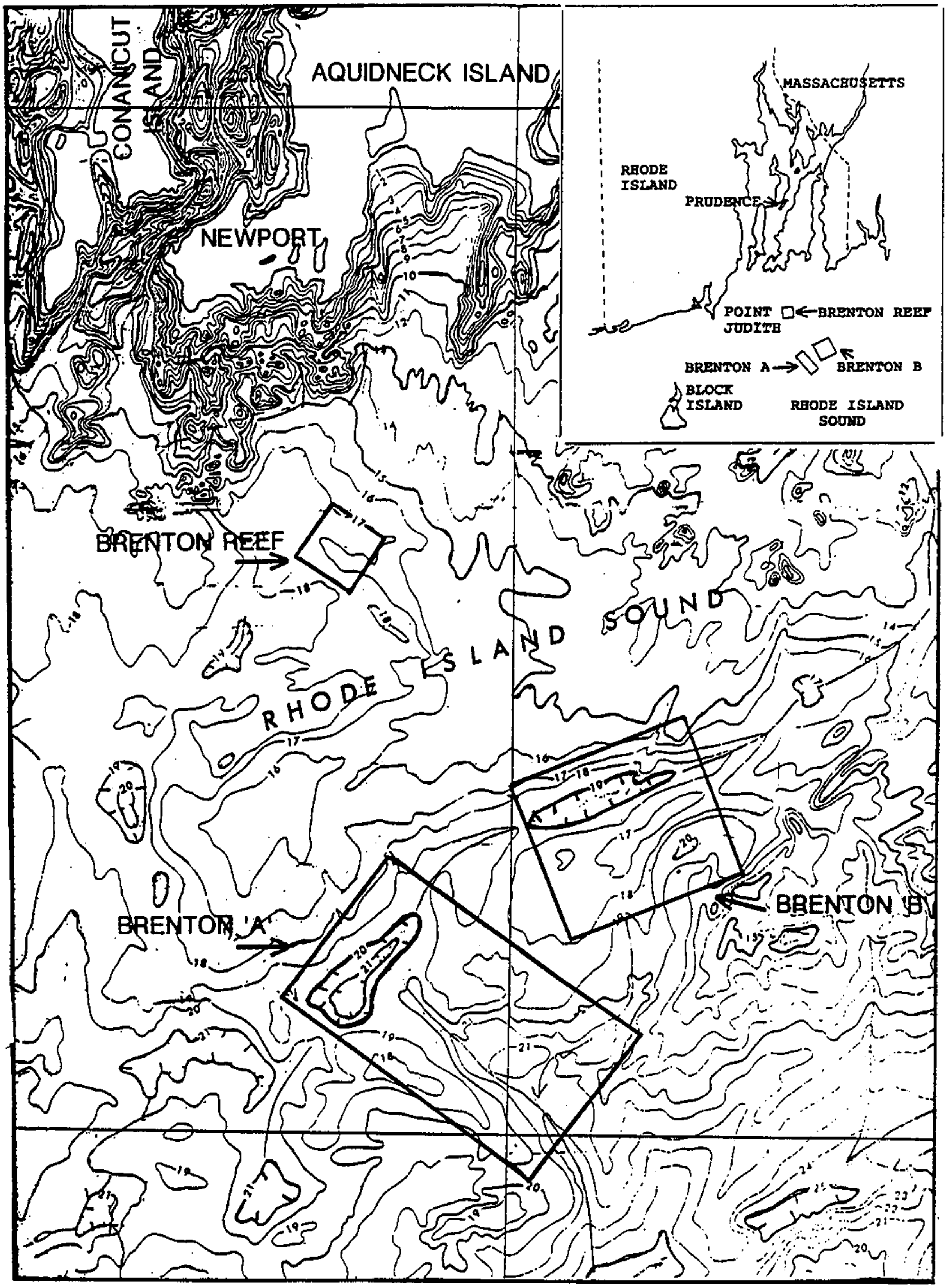


Figure 1-1. Map showing the locations of the Brenton Reef, Brenton-A, and Brenton-B study sites in Rhode Island Sound, south-southeast of Newport, RI.

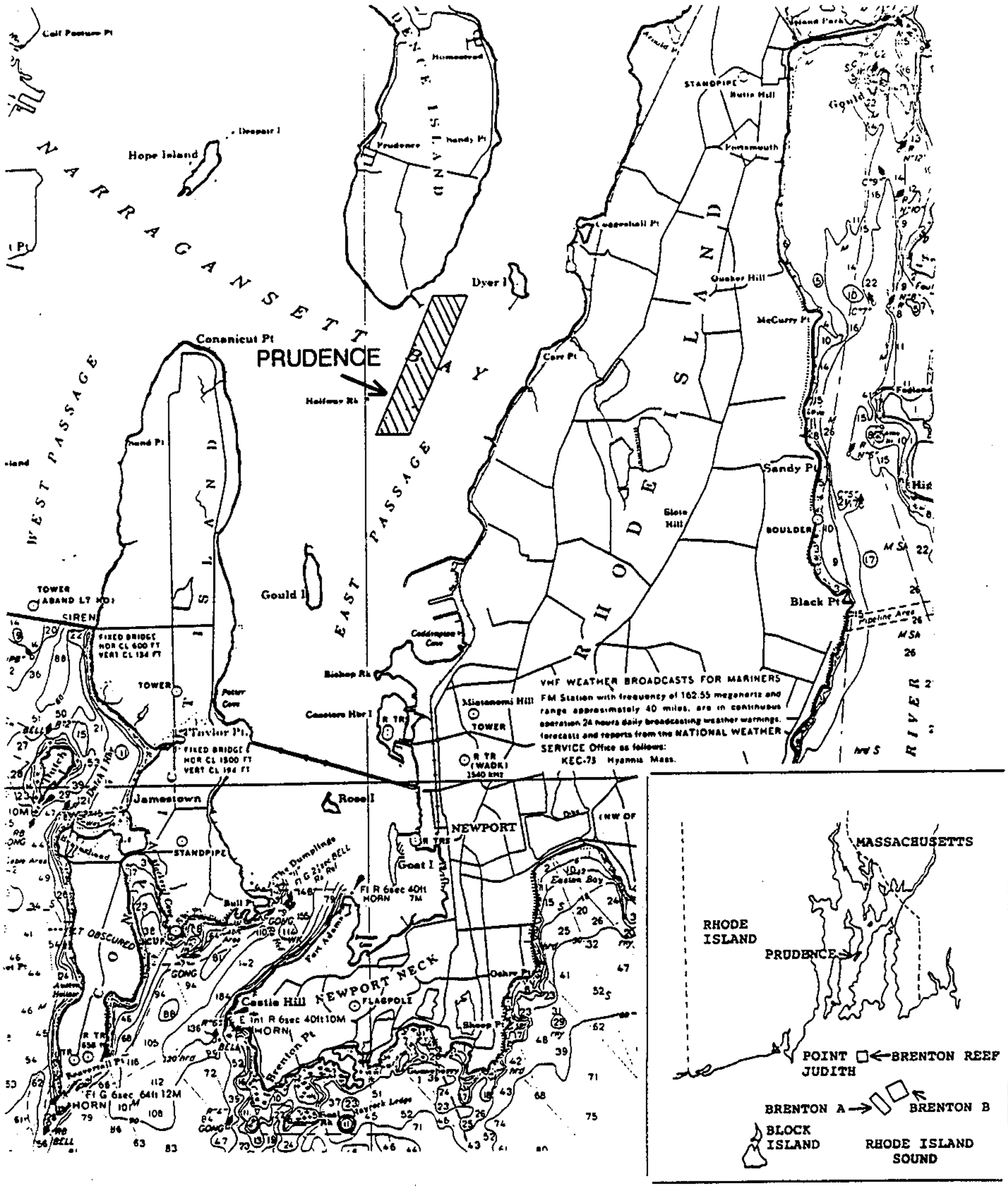


Figure 1-2. Map showing the location of the Prudence study site in the East Passage of Narragansett Bay, southeast of Prudence Island.

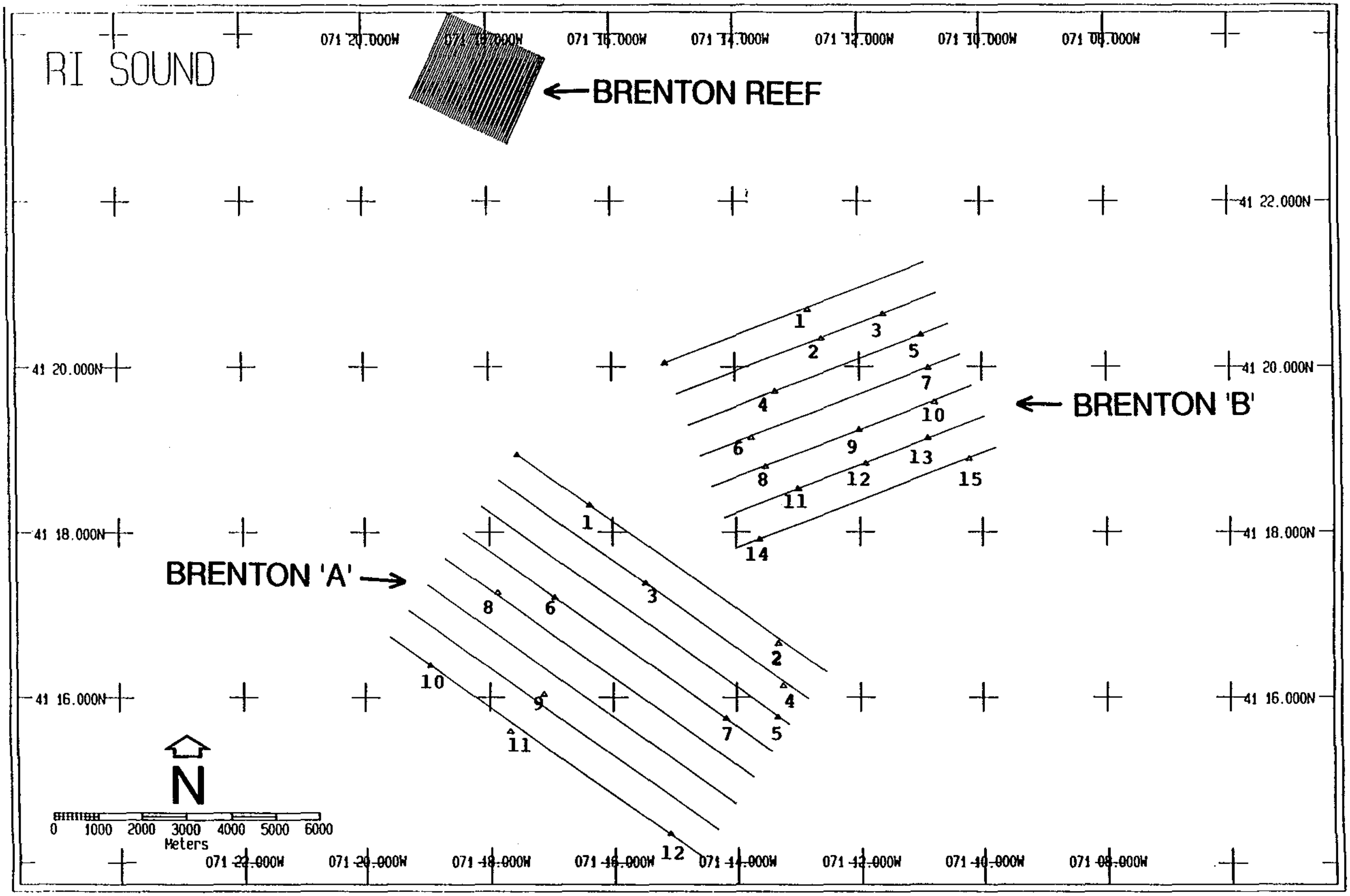


Figure 2-1. Survey lanes for the bathymetric surveys at the Brenton Reef, Brenton-A and Brenton-B study sites. A side-scan survey was run concurrently with the bathymetric survey at both the Brenton-A and Brenton-B sites, and a sub-bottom survey was run concurrently with the bathymetric survey at the Brenton Reef site. The locations and designations of grab sample stations for visual descriptions and grain size analyses of sediments are indicated by the 12 triangles at the Brenton-A and the 15 triangles at the Brenton-B site.

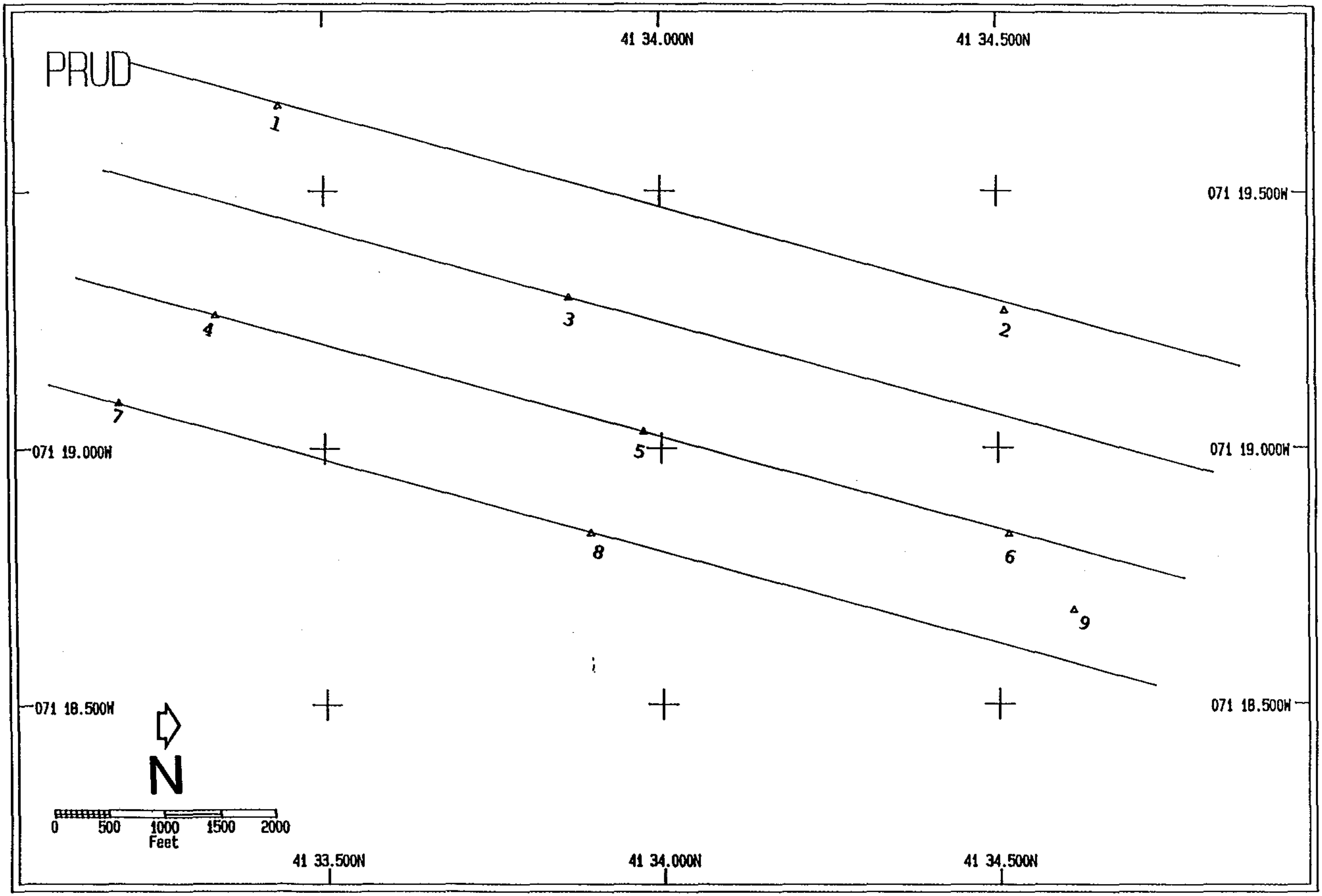


Figure 2-2. Survey lanes for the bathymetric and side-scan surveys at the Prudence study site. The locations and designations of the 9 grab sample stations for visual descriptions and grain size analyses of sediments are indicated by the

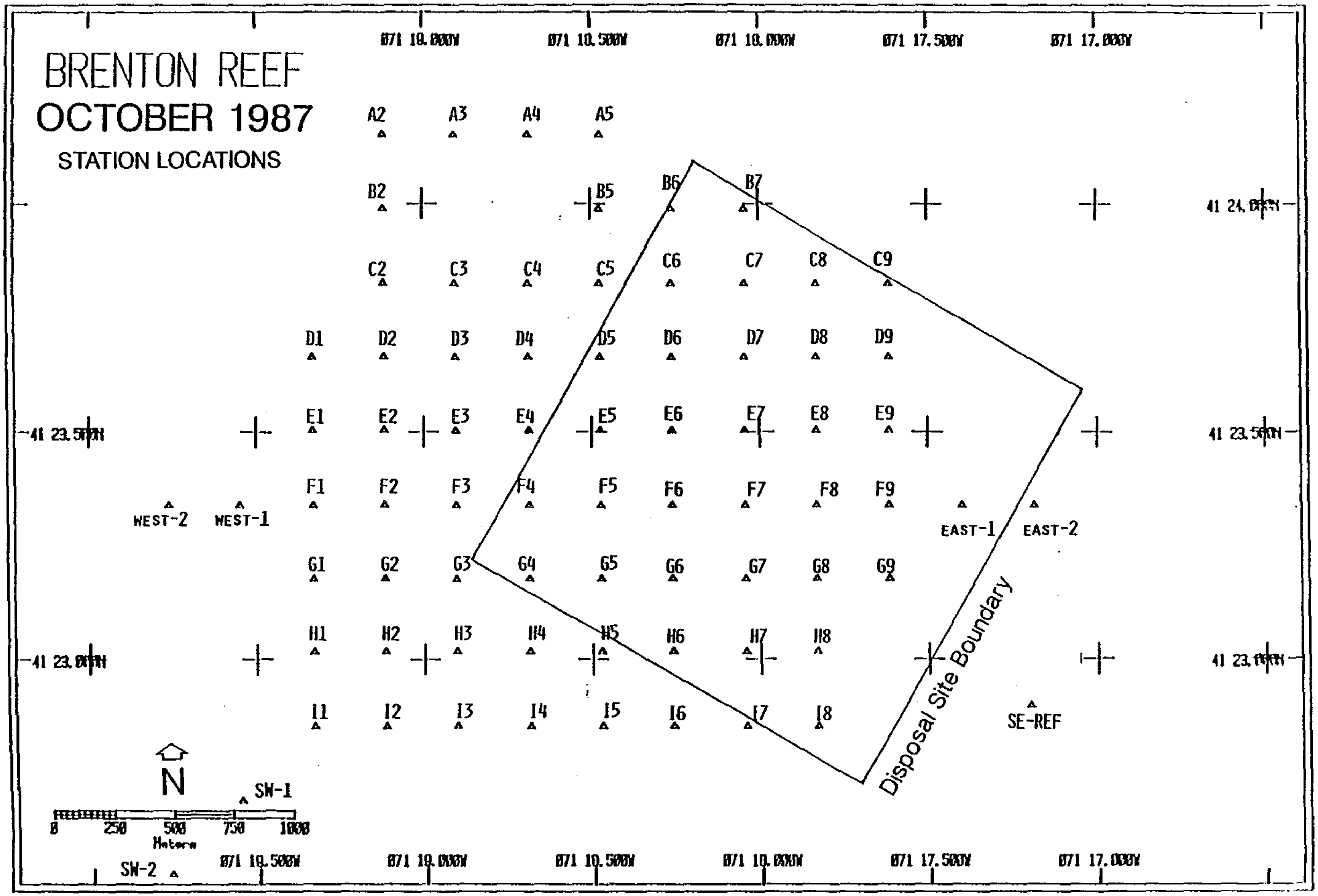


Figure 2-3. Locations and designations of REMOTS® stations at the Brenton Reef Historic Disposal Site, October 1987. Stations SE-REF and West-2 are reference stations.

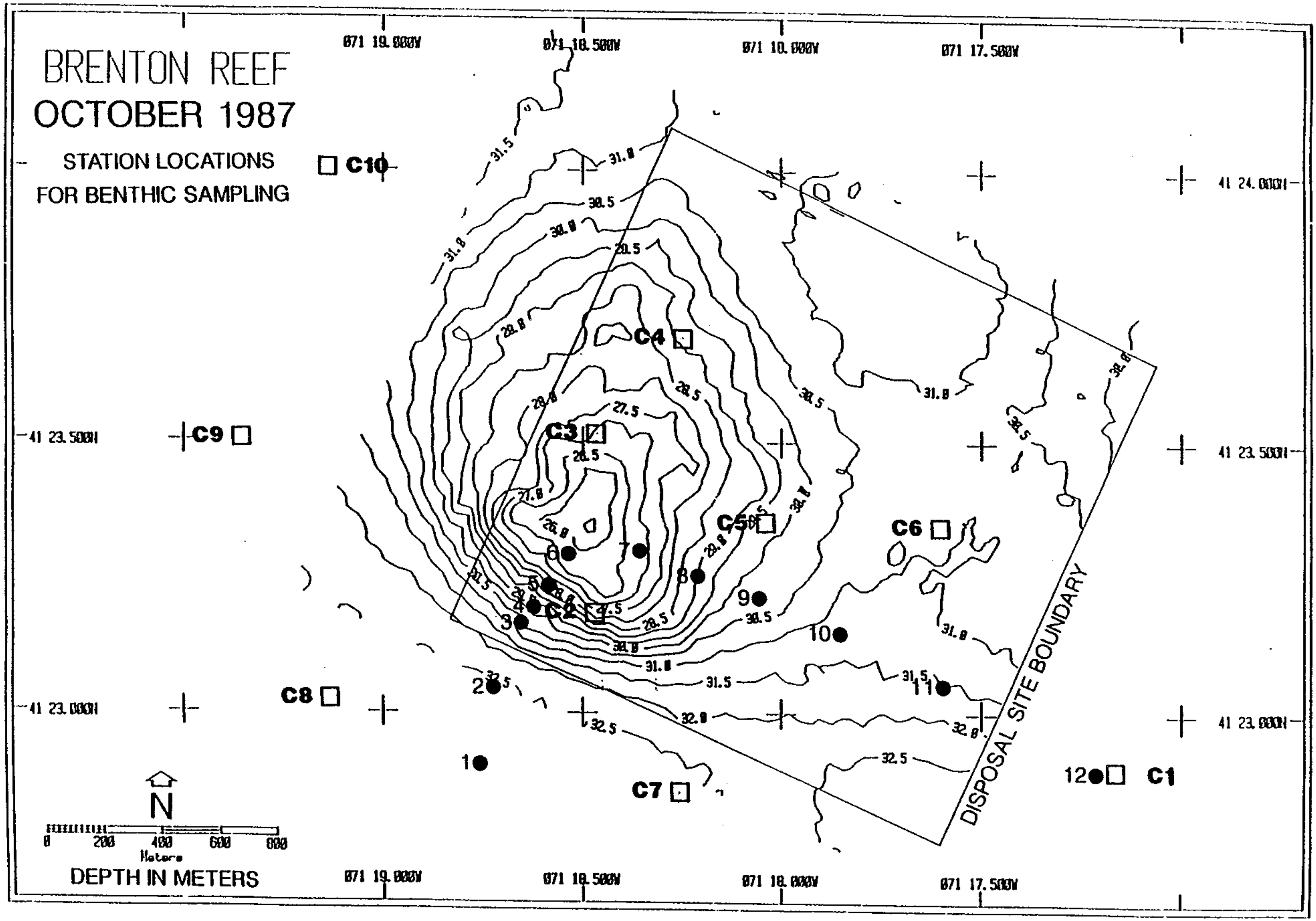


Figure 2-4. Locations of the 10 grab sample stations for grain size and chemical analyses of sediments (stations C1 thru C10 indicated with squares) and locations of the 12 "transect" stations where grab samples for quantitative benthic analyses were obtained (circles) at the Brenton Reef study site in October 1987.

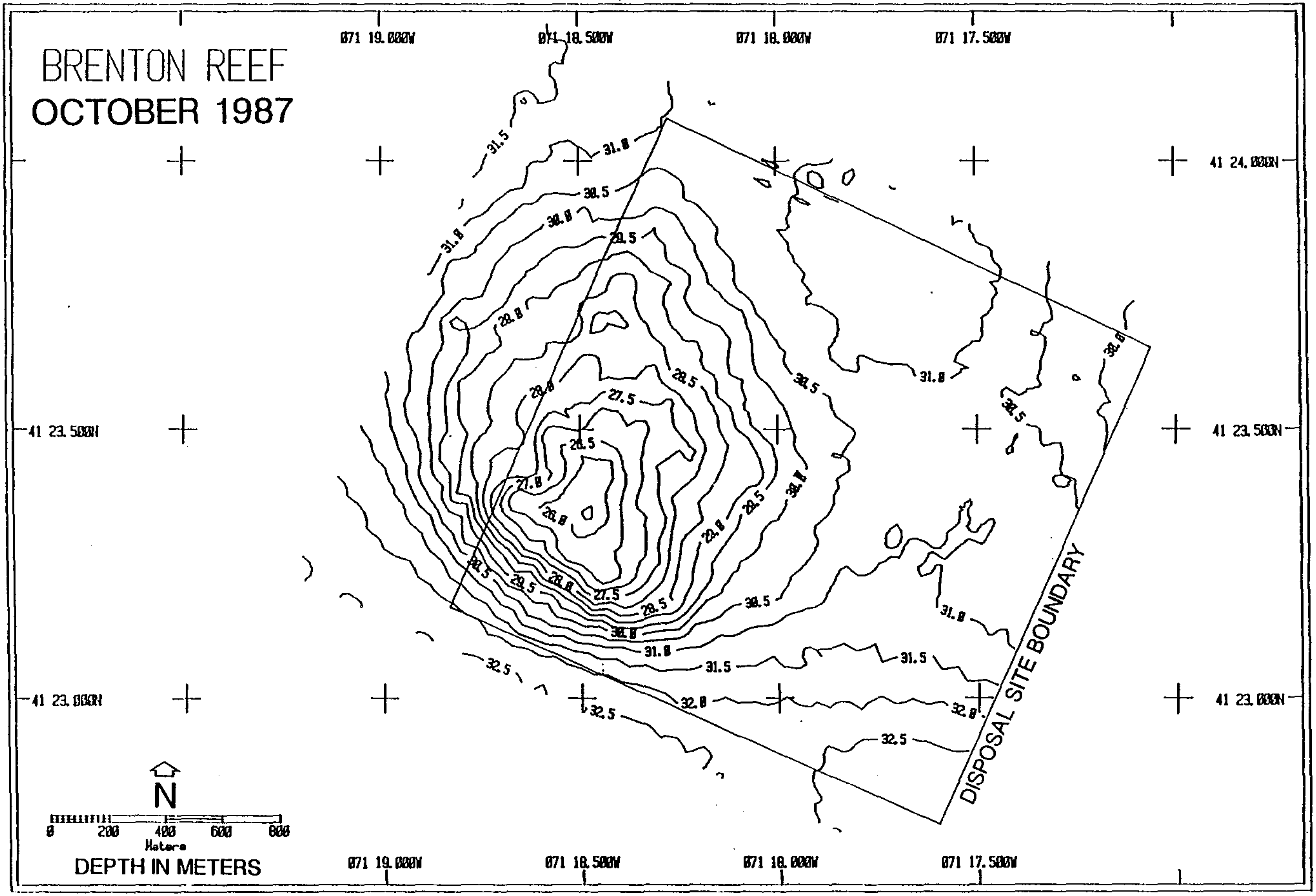


Figure 3-1. Contoured bathymetric chart of the Brenton Reef Historic Disposal Site, October 1987. Depths are in meters.

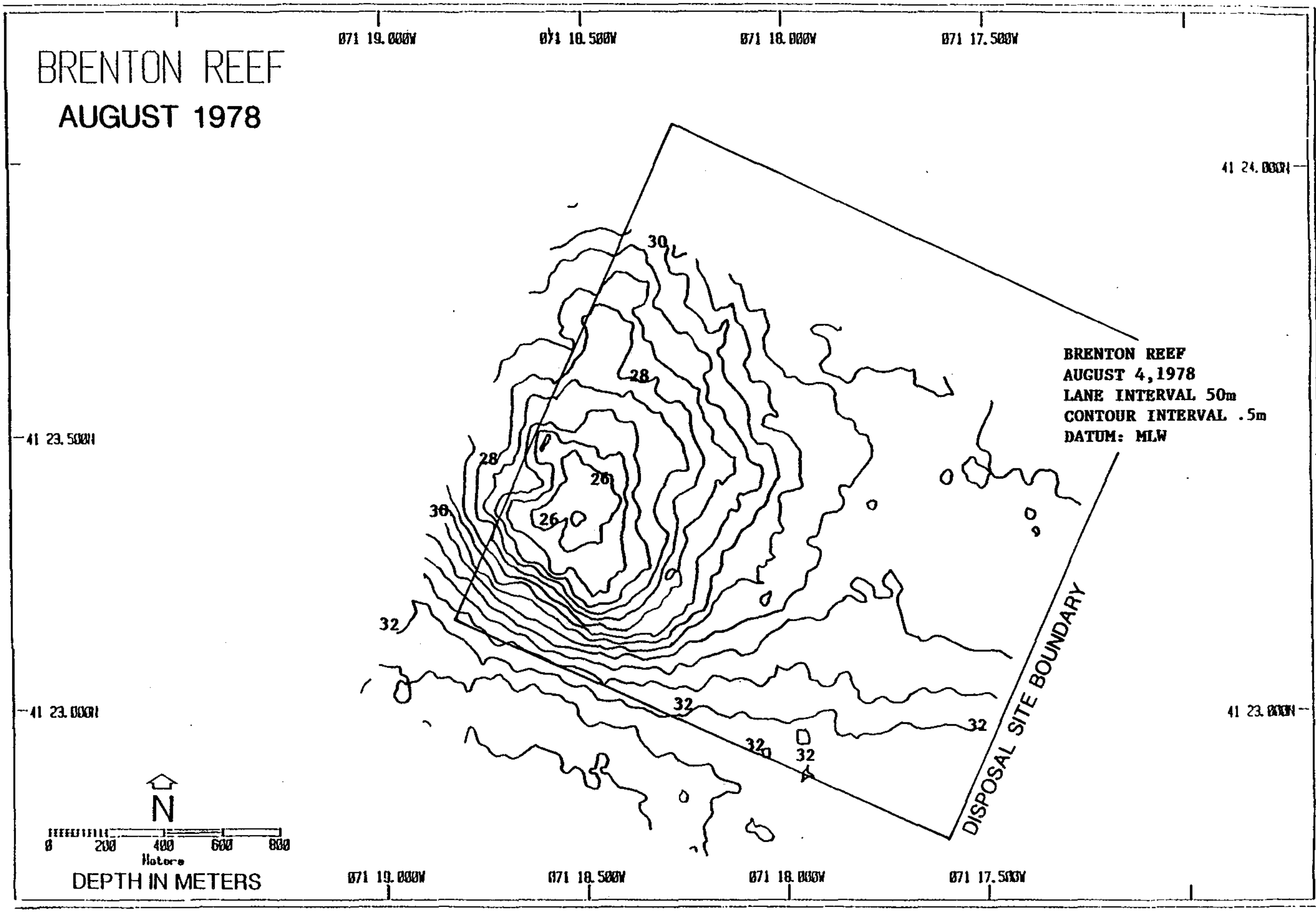


Figure 3-2. Contoured bathymetric chart of the Brenton

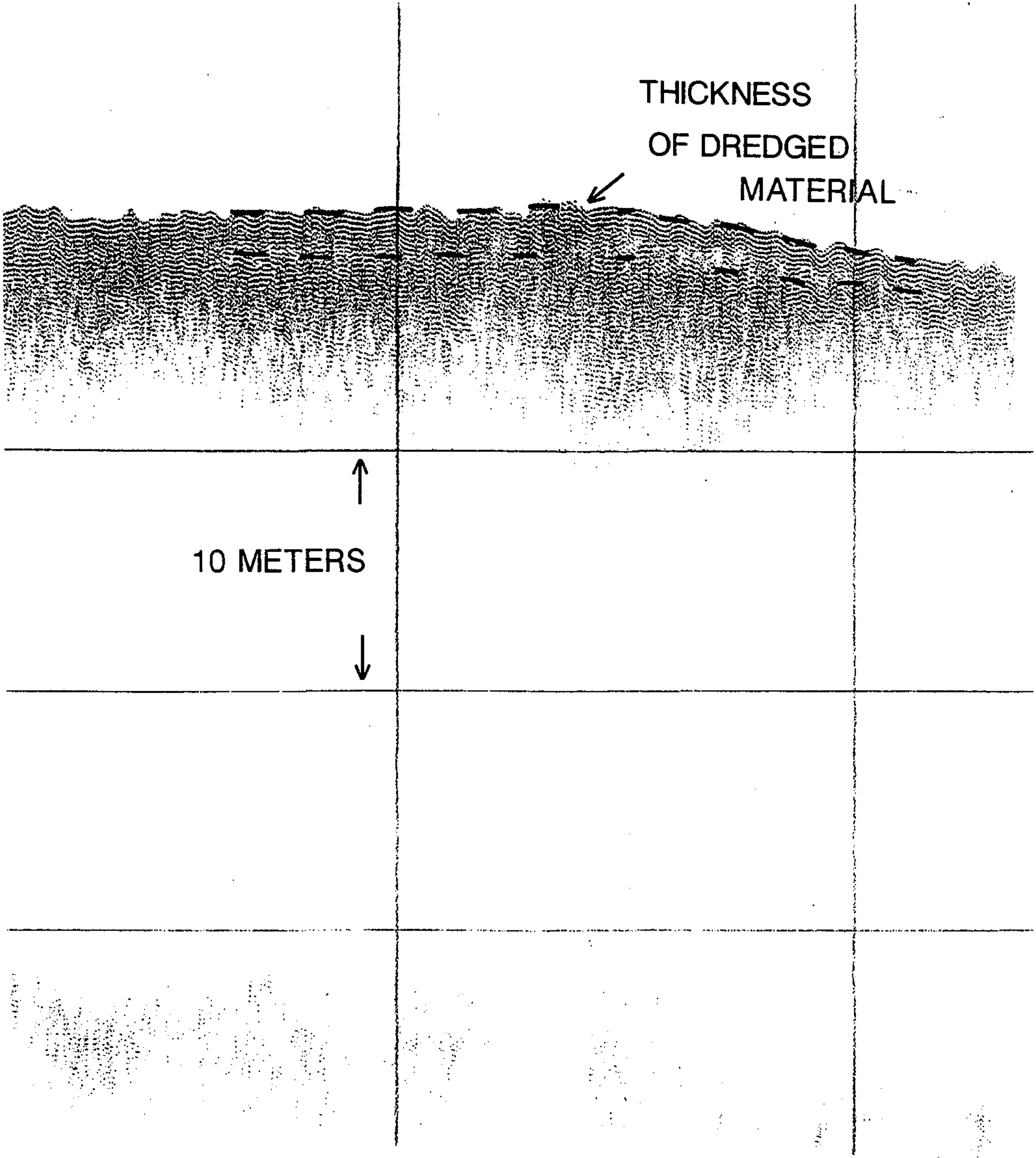


Figure 3-3. A representative seismic profile at the Brenton Reef study site. The historic disposal mound is easily discerned as a surface feature distinct from the original pre-disposal horizon; no distinct sub-bottom acoustic features were noted at or in the vicinity of the mound.

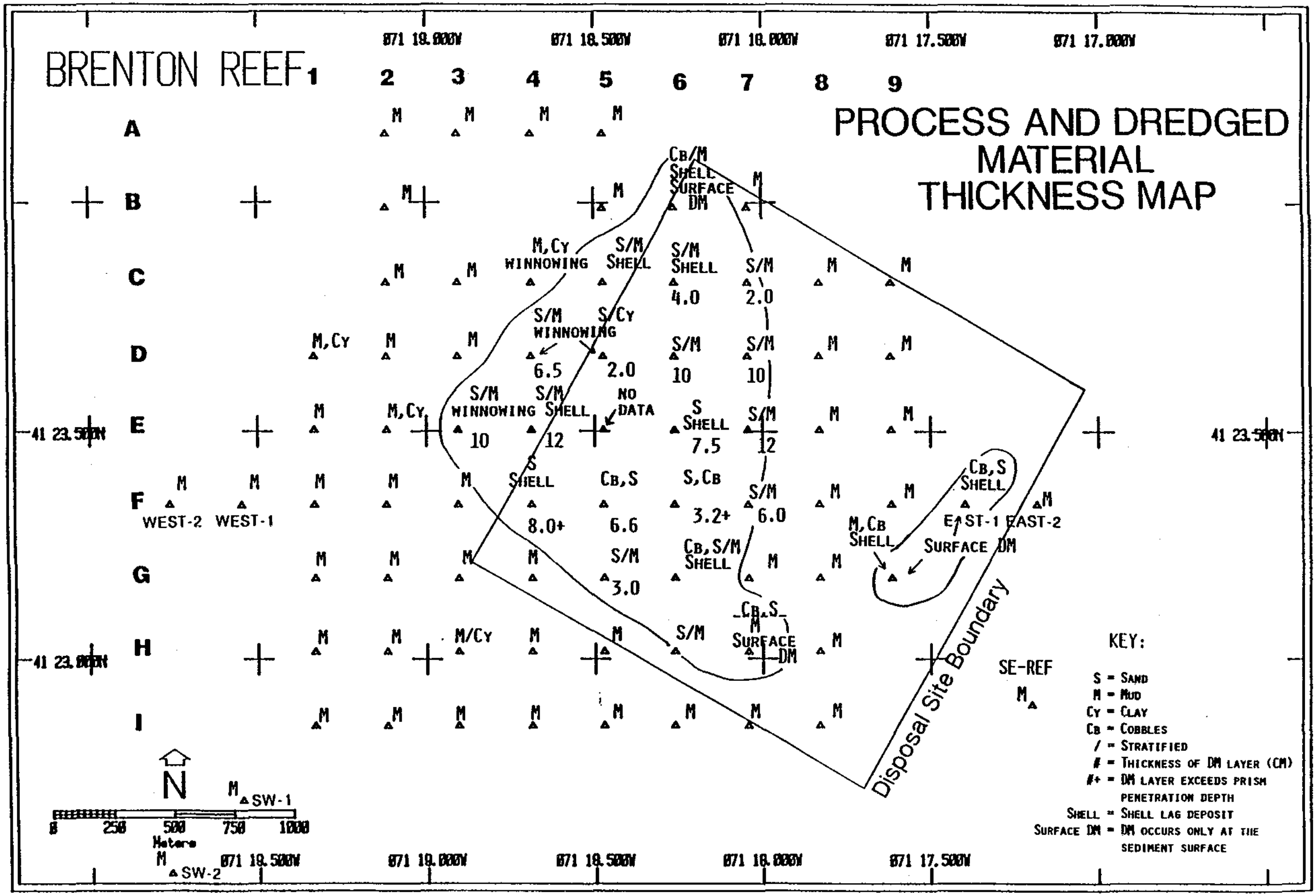


Figure 3-4. "Process" map illustrating the thickness and distribution (contours) of dredged material at the Brenton Reef Historic Disposal Site, October 1987.

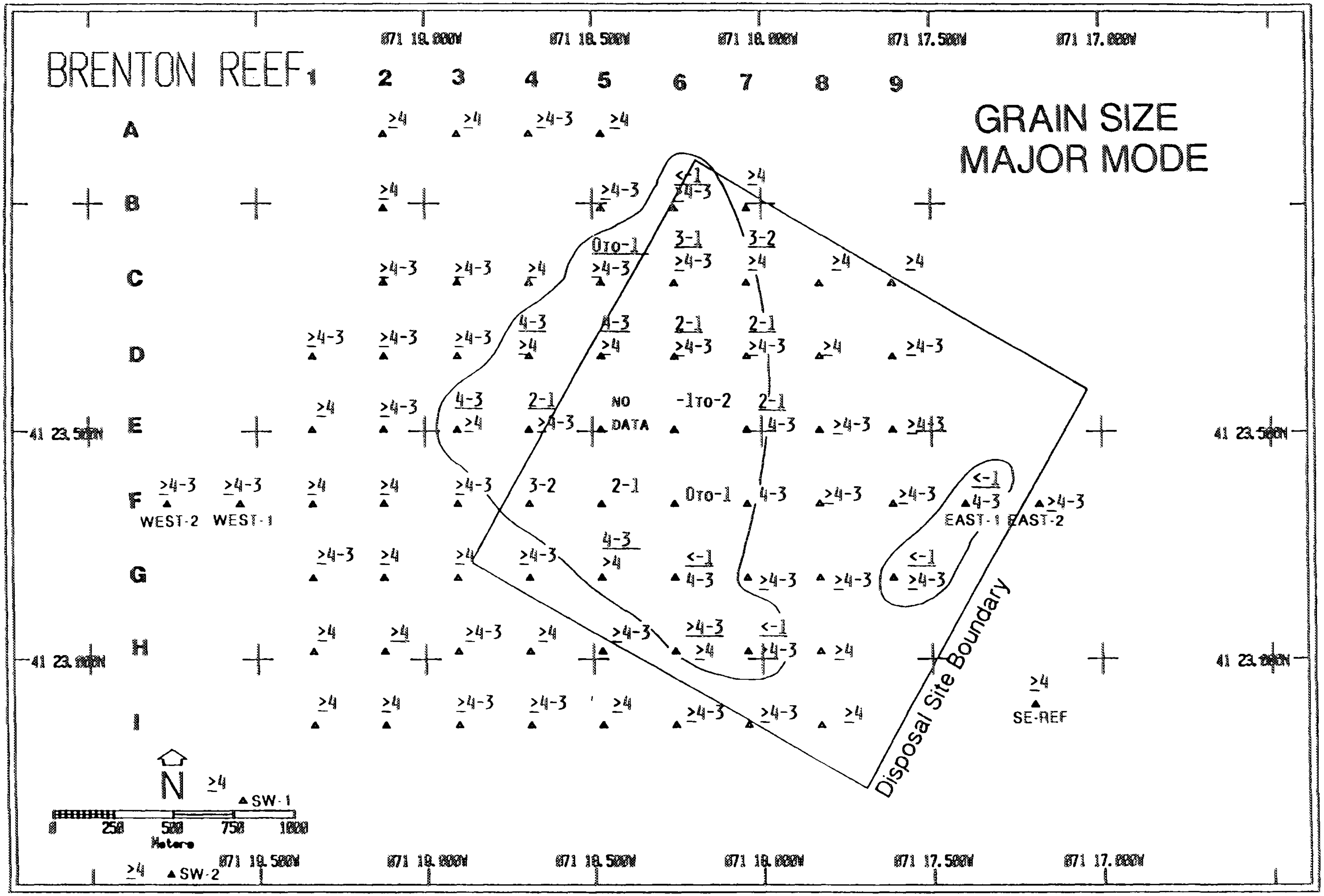
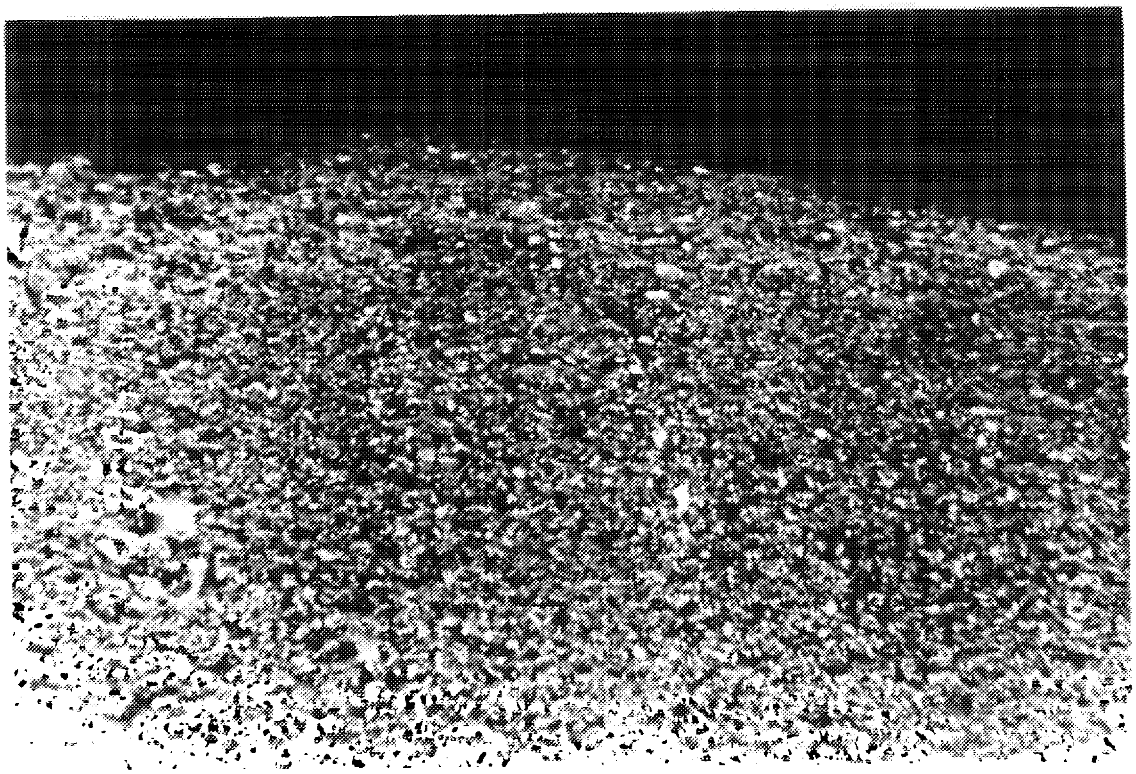


Figure 3-5. Map of grain size major mode (in phi units) of surface sediments at REMOTS® stations at the Brenton Reef study site, October 1987. The contours delimit the distribution of dredged material as mapped in Figure 3-4.



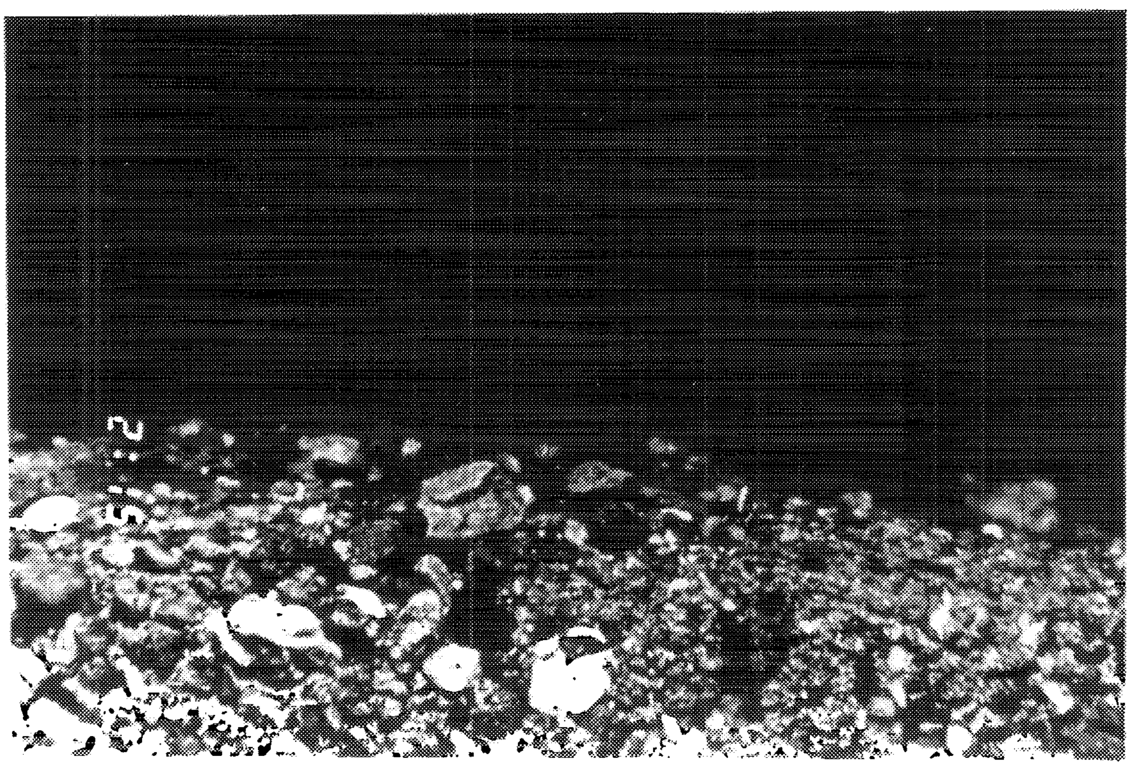


Figure 3-6. Two replicate REMOTS images from station E-6 near the apex of the historic disposal mound at the Brenton Reef site. The top image shows poorly-sorted medium sand (2 to 1 phi) exceeding the depth of prism penetration; the bottom image shows poorly-sorted granules (-1 to -2 phi). Scale of both images = 1X.

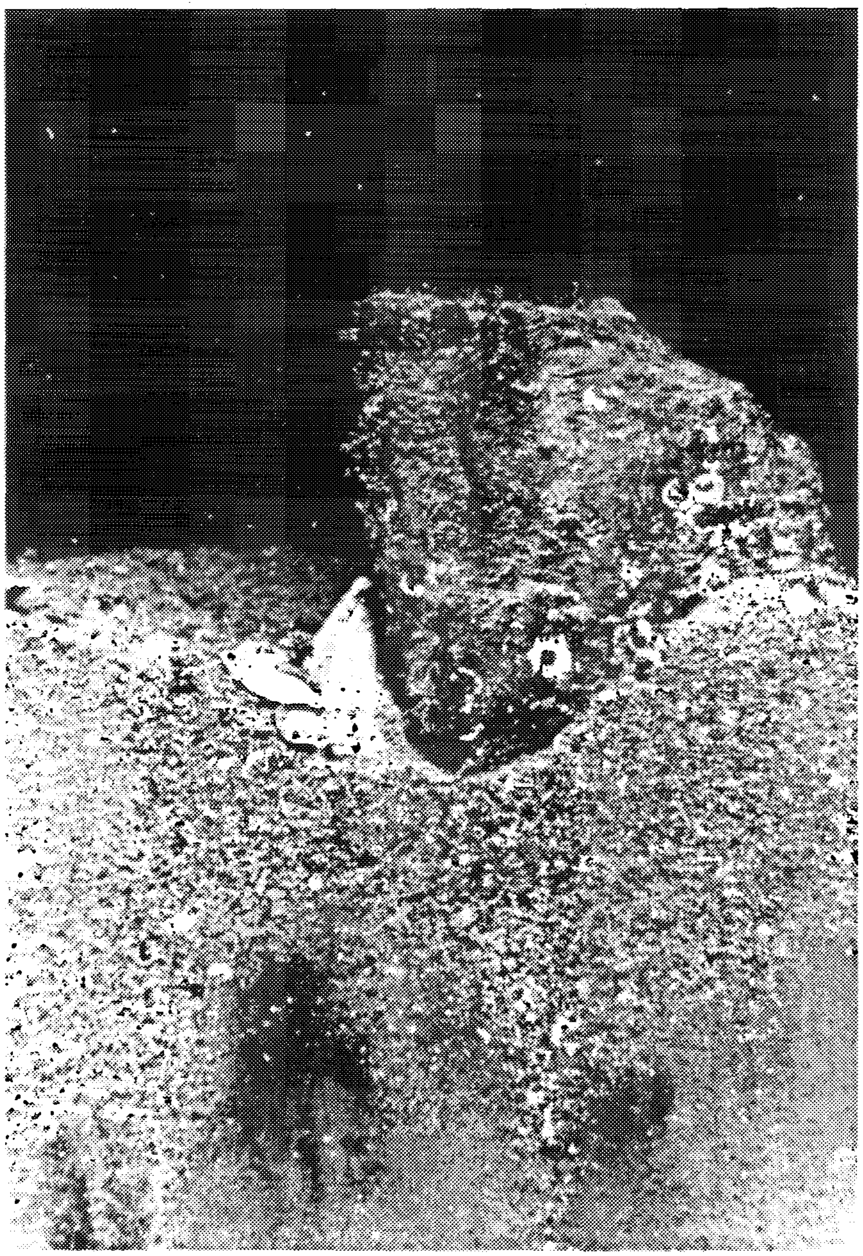


Figure 3-7. Two REMOTS images from the flanks of the Brenton Reef historic disposal mound illustrating sand over mud stratigraphies. Image A from station E-4 (above) shows medium sand (2 to 1 phi) over mud (> 4 phi), as well as a cobble and shell fragments at the sediment surface. Image B from station G-5 (following page) shows fine sand (3 to 2 phi) over mud. Scale of both images = 1X.

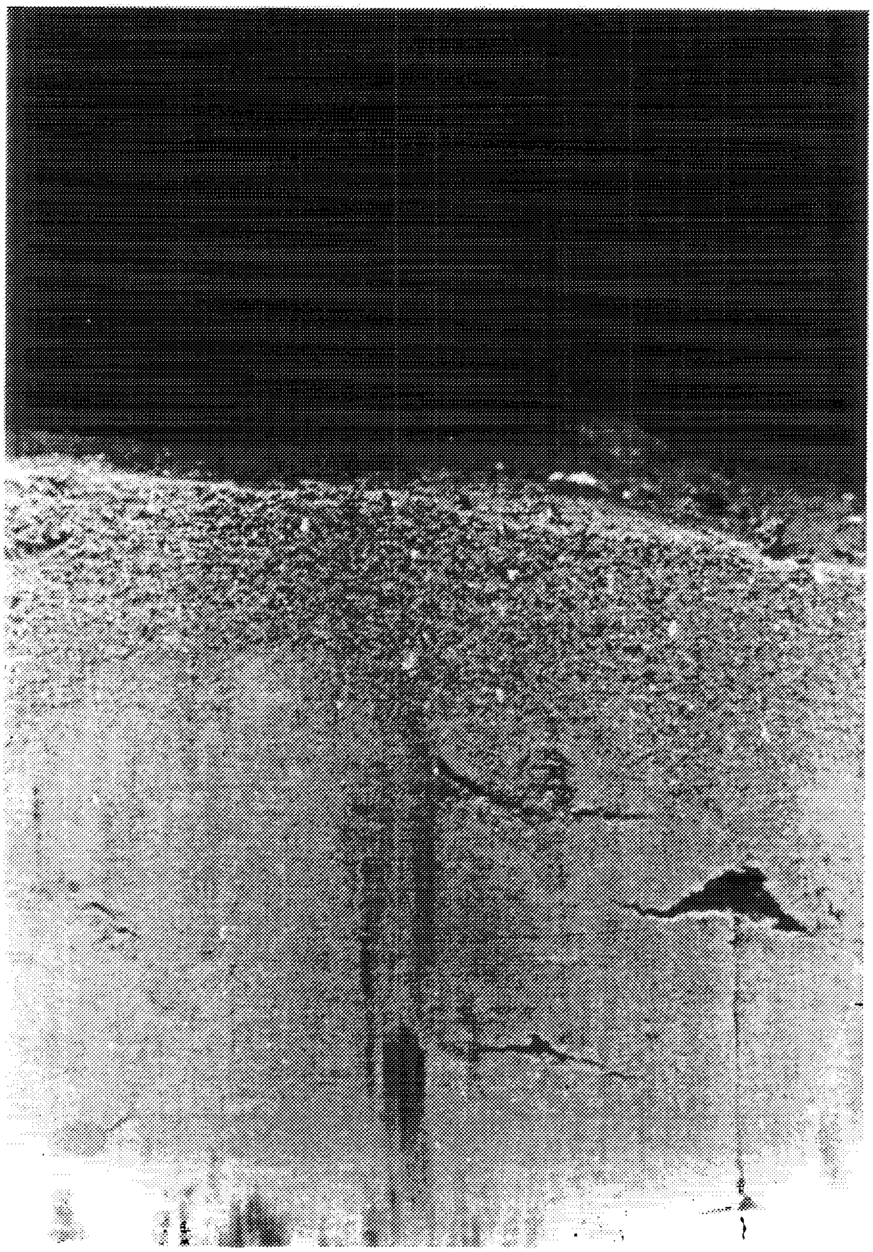


Figure 3-7.(B)

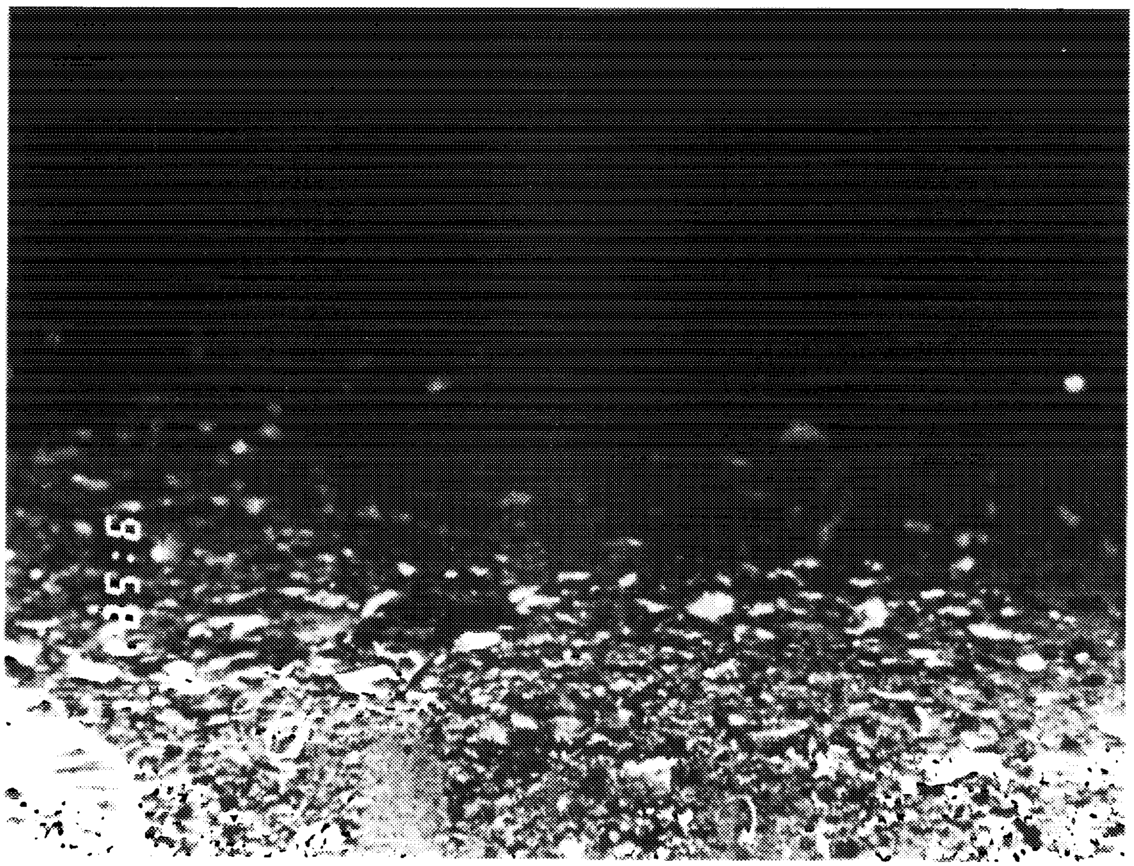


Figure 3-8. REMOTS image from station C-6 near the mound apex showing a shell lag deposit at the sediment surface. Scale = 1X.

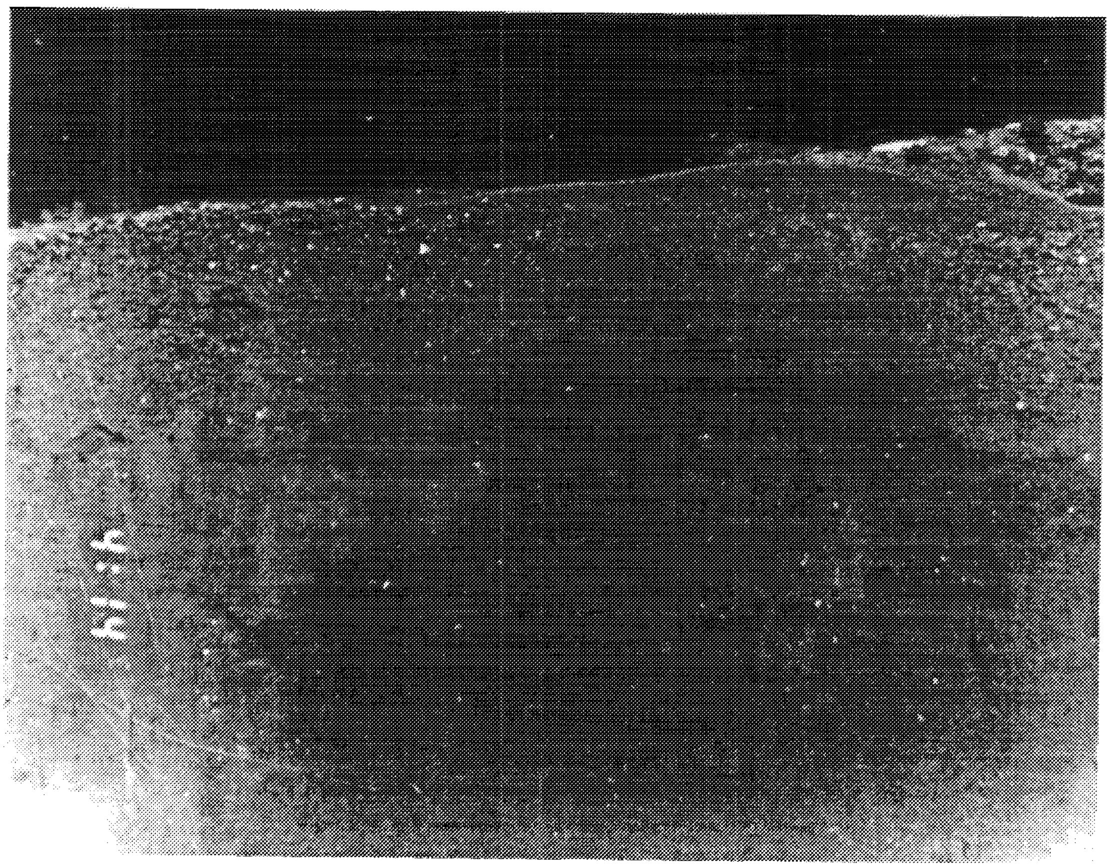


Figure 3-9. Sand is visible at the surface in this REMOTS image from station D-5 near the disposal mound apex. This sand deposit most likely resulted from the winnowing of fines by erosional currents. Scale = 1X.

Figure 3-10. REMOTS image from station SE-REF showing mud (> 4 to 3 phi), representative of sediments found at stations located off the historic dredged material mound. This fine-grained material presumably characterizes the ambient bottom unaffected by disposal. Note also the tube-dwelling amphipods at the sediment surface and the large feeding void at the depth. Scale = 1X.

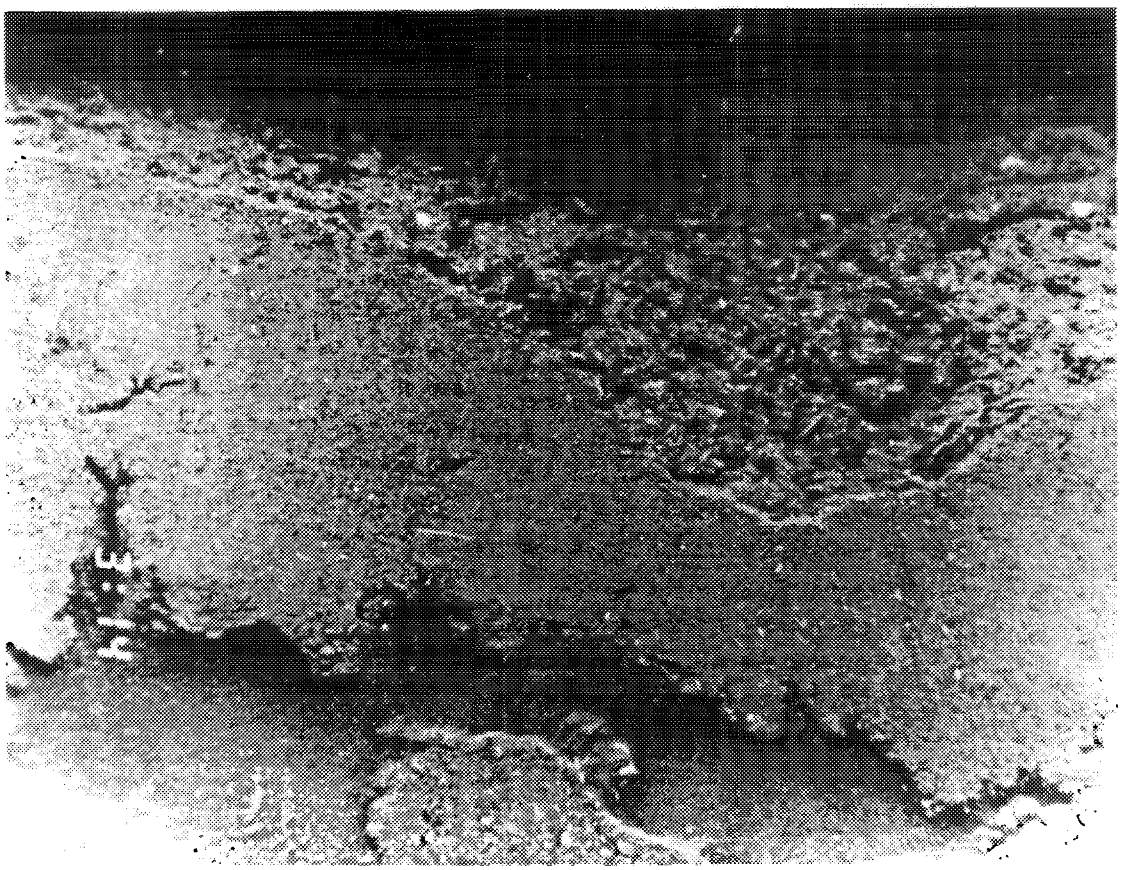
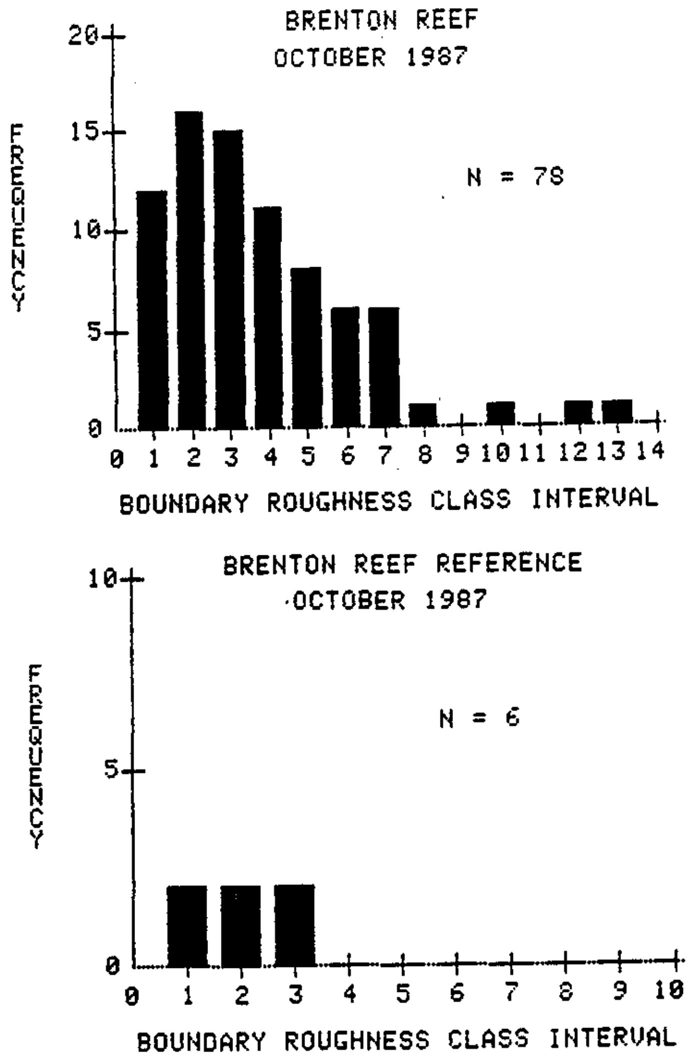


Figure 3-11. A dense assemblage, or mat, of ampeliscid amphipod tubes is visible at the sediment surface in this REMOTS image from station F-8. Note the accumulation of fine-grained material around the tubes, and the large sub-surface burrow. Such stations are given a Stage II on III successional designation. Scale = 1X.



Key

Class Interval	Range of Values (cm)
1	0.0 - 0.6
2	0.6 - 1.0
3	1.0 - 1.4
4	1.4 - 1.8
5	1.8 - 2.2
6	2.2 - 2.6
7	2.6 - 3.0
8	3.0 - 3.4
9	3.4 - 3.8
10	3.8 - 4.2
11	4.2 - 4.6
12	4.6 - 5.0
13	5.0 - 5.4
14	5.4 - 5.8

Figure 3-12. Frequency distributions of small-scale surface boundary roughness values for Brenton Reef REMOTS® grid stations (top) and reference stations (bottom), October 1987.

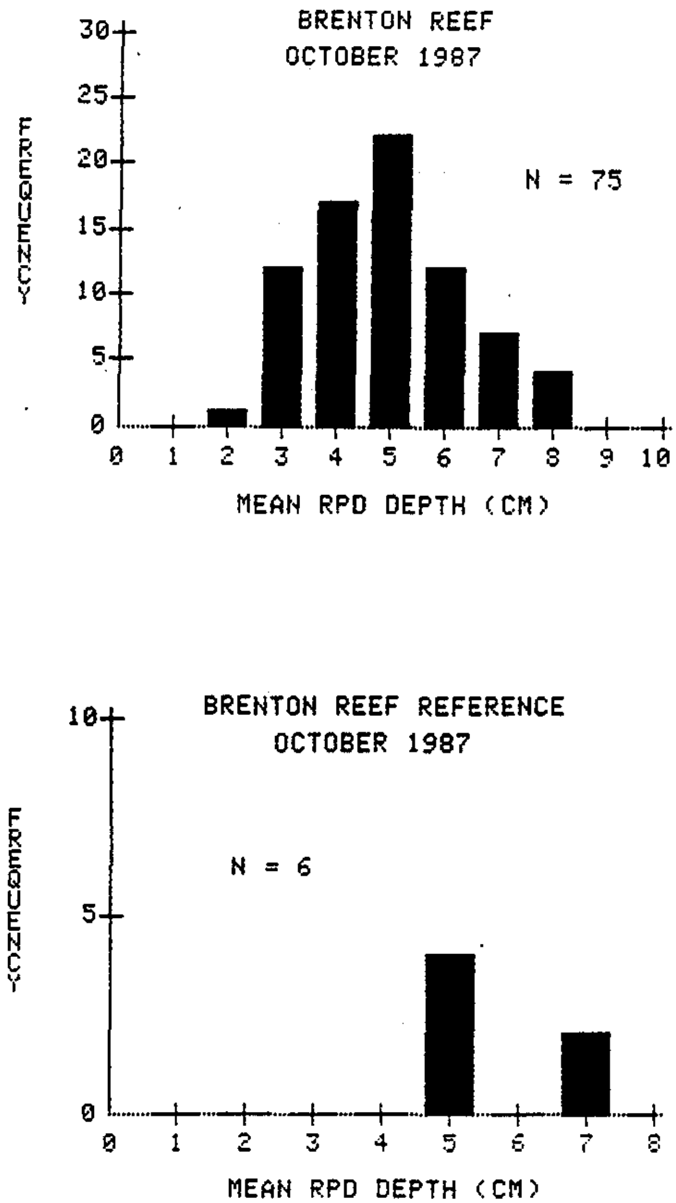


Figure 3-13. Frequency distributions of mean apparent RPD depths for Brenton Reef REMOTS® grid stations (top) and reference stations (bottom), October 1987.

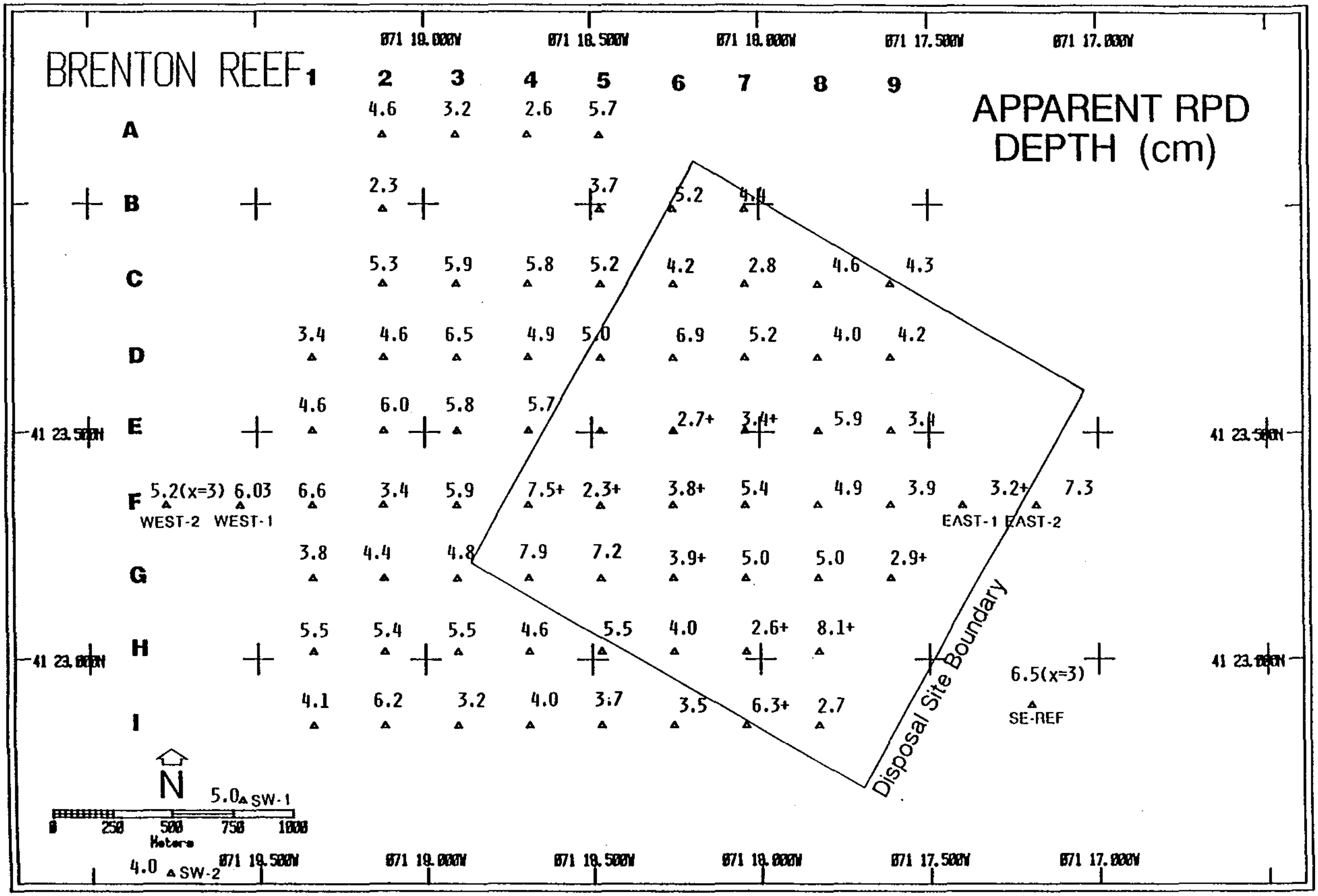


Figure 3-14. The mapped distribution of mean appparent RPD depths at the Brenton Reef historic disposal site, October 1987. A "+" indicates the mean apparent RPD depth exceeded the depth of prism penetration at a given station.

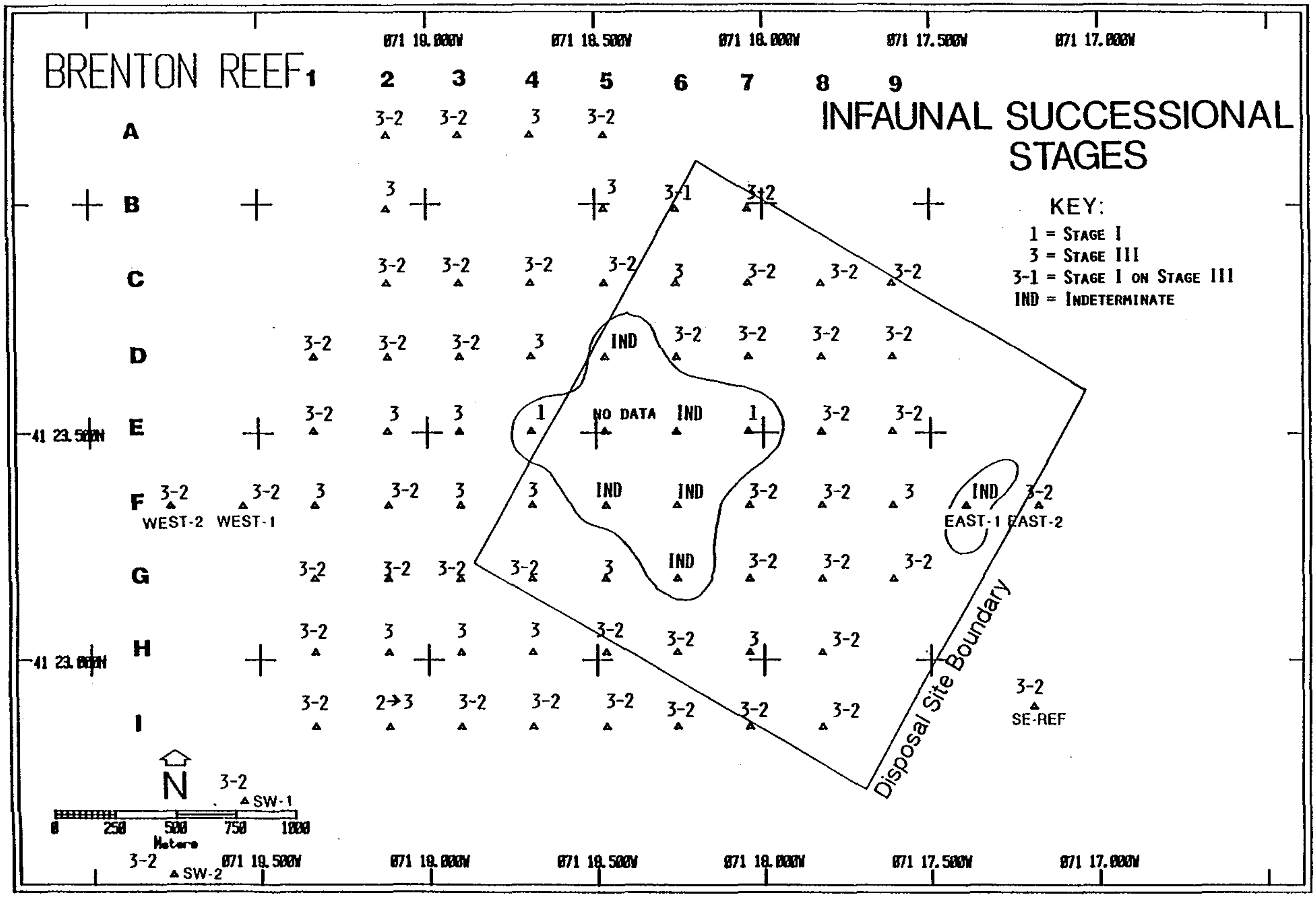


Figure 3-15. The mapped distribution of infaunal successional stages at the Brenton Reef historic disposal site, October 1987. The contours delimit stations where the successional stage was either indeterminate or Stage I.

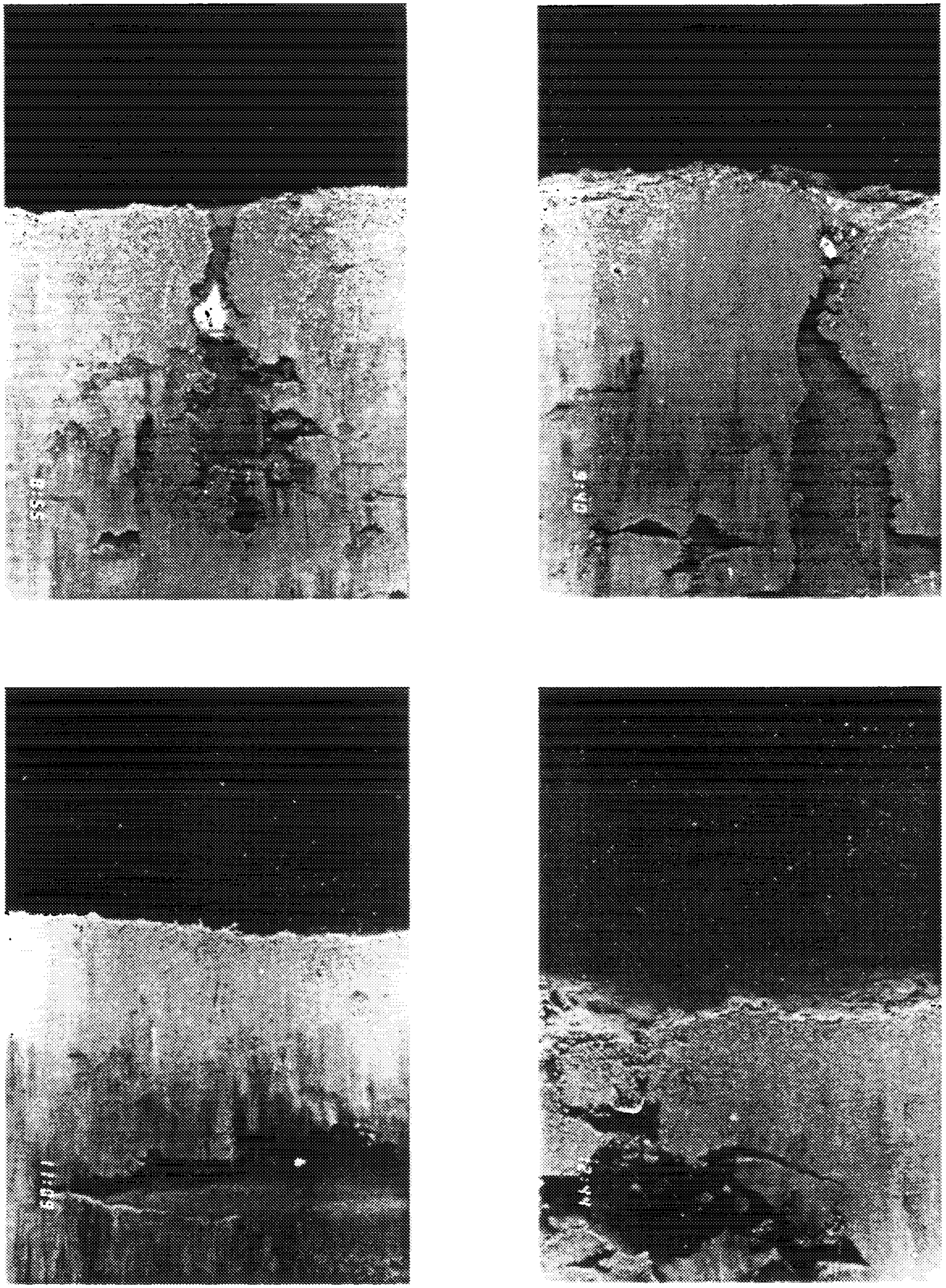


Figure 3-16. Four REMOTS images which illustrate the large and extensive sub-surface burrows which occurred at many stations at the Brenton Reef site (see Figure 3-19). These burrows were most likely due to the burrowing activities of lobsters and the thalassinid shrimp <u>Axius</u>. Approximate scale of all images = 0.43X.

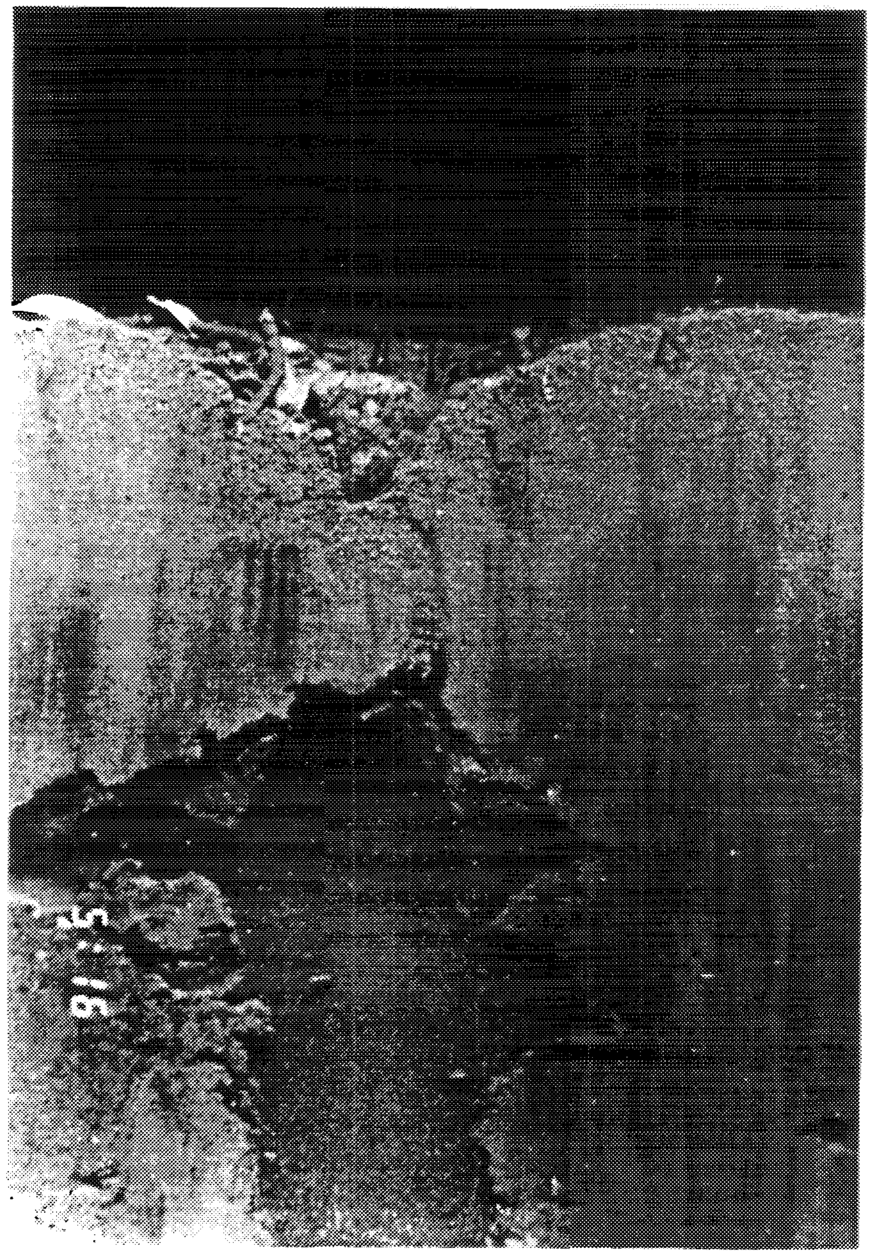


Figure 3-17. REMOTS image from station A-3 showing tubes of deposit-feeding Stage III polychaetes visible at the sediment surface, and a large sub-surface burrow. A few amphipod tubes are also visible at the sediment surface (arrow). Scale = 1X.

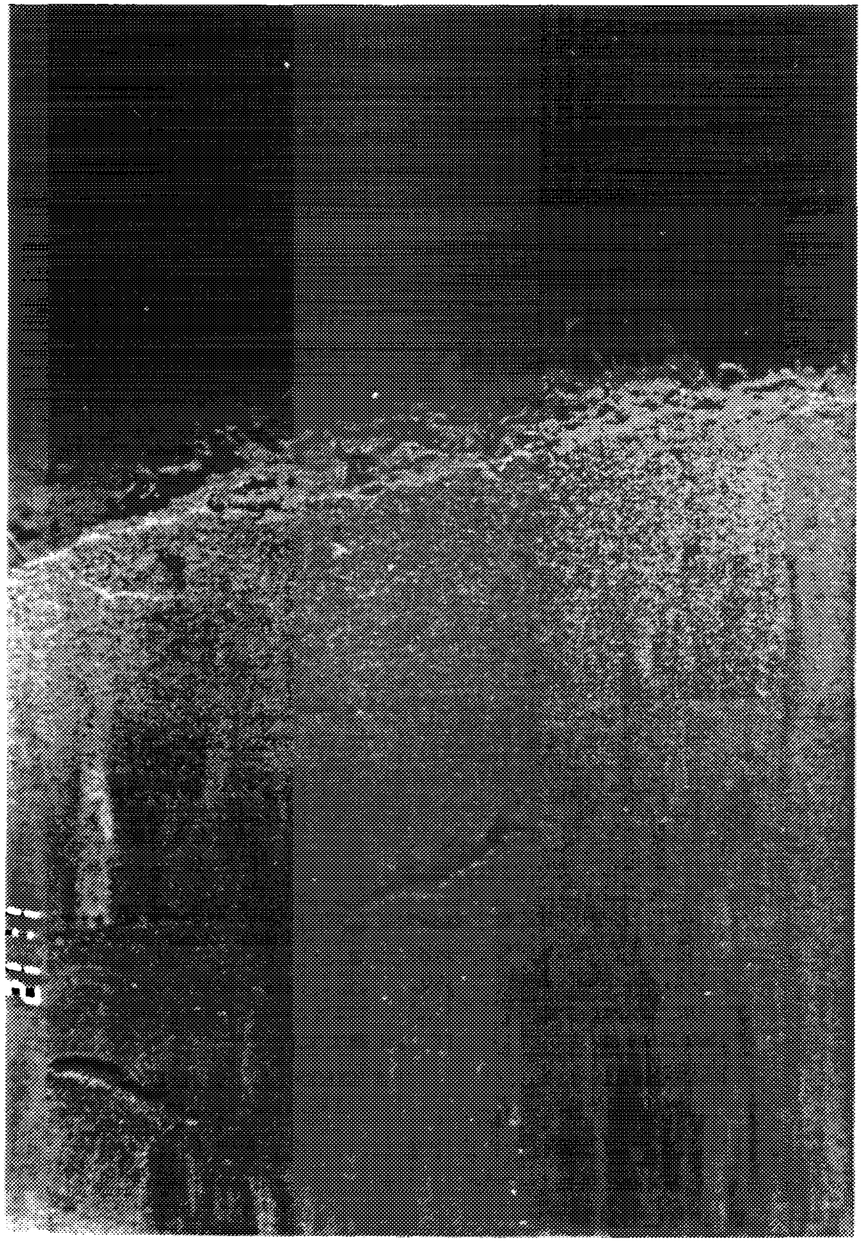


Figure 3-18. Amphipod and polychaete tubes occur at the sediment surface and feeding voids are visible at depth in this REMOTS image from station SW-2. Scale = 1X.

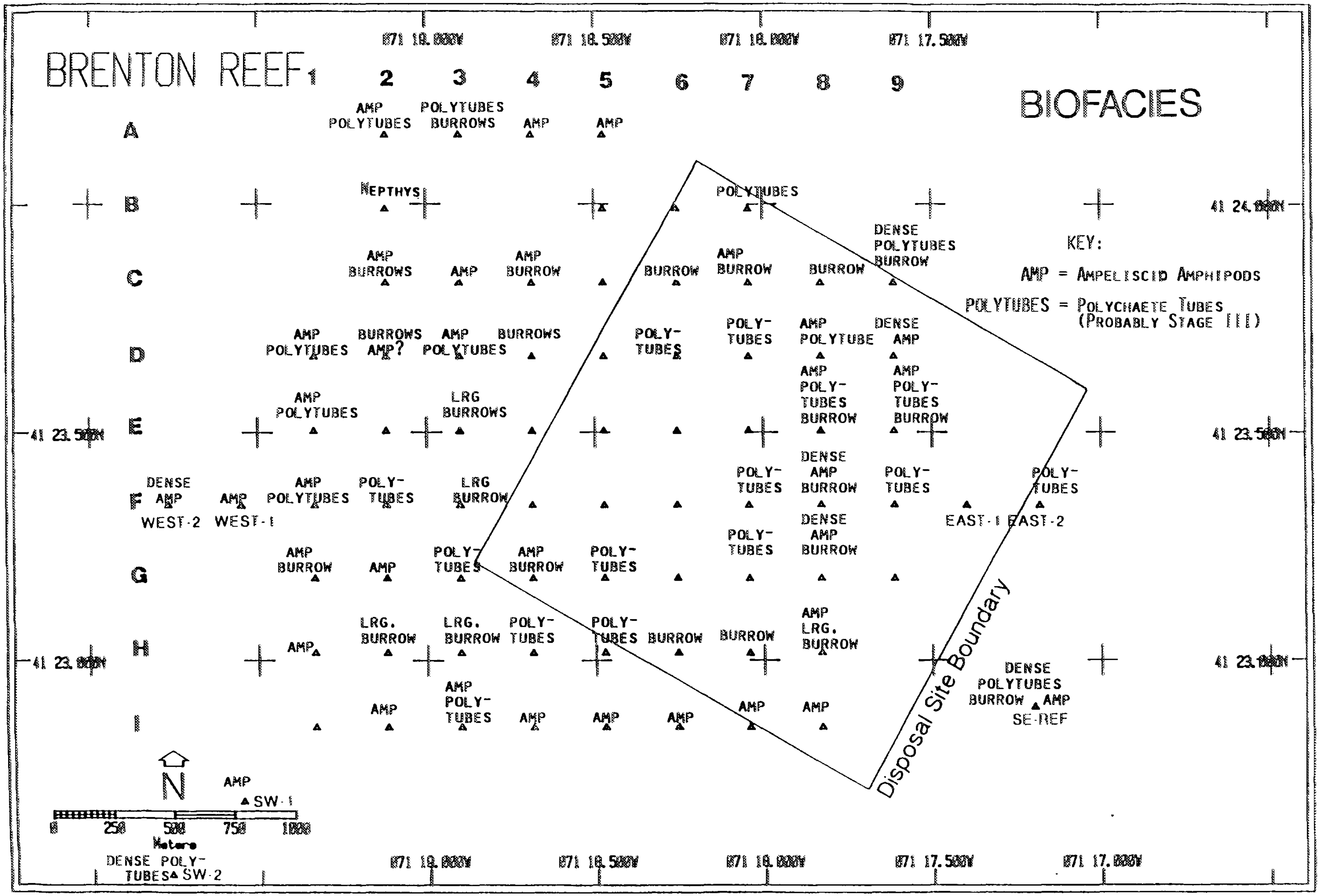


Figure 3-19. Map showing "biofacies" at the Brenton Reef historic disposal site, October 1987.

Figure 3-20. REMOTS image from station G-8 showing a dense mat of ampeliscid amphipod tubes at the sediment surface. The presence of the large sub-surface burrow gives this station a Stage II on III successional designation. Scale = 1X.

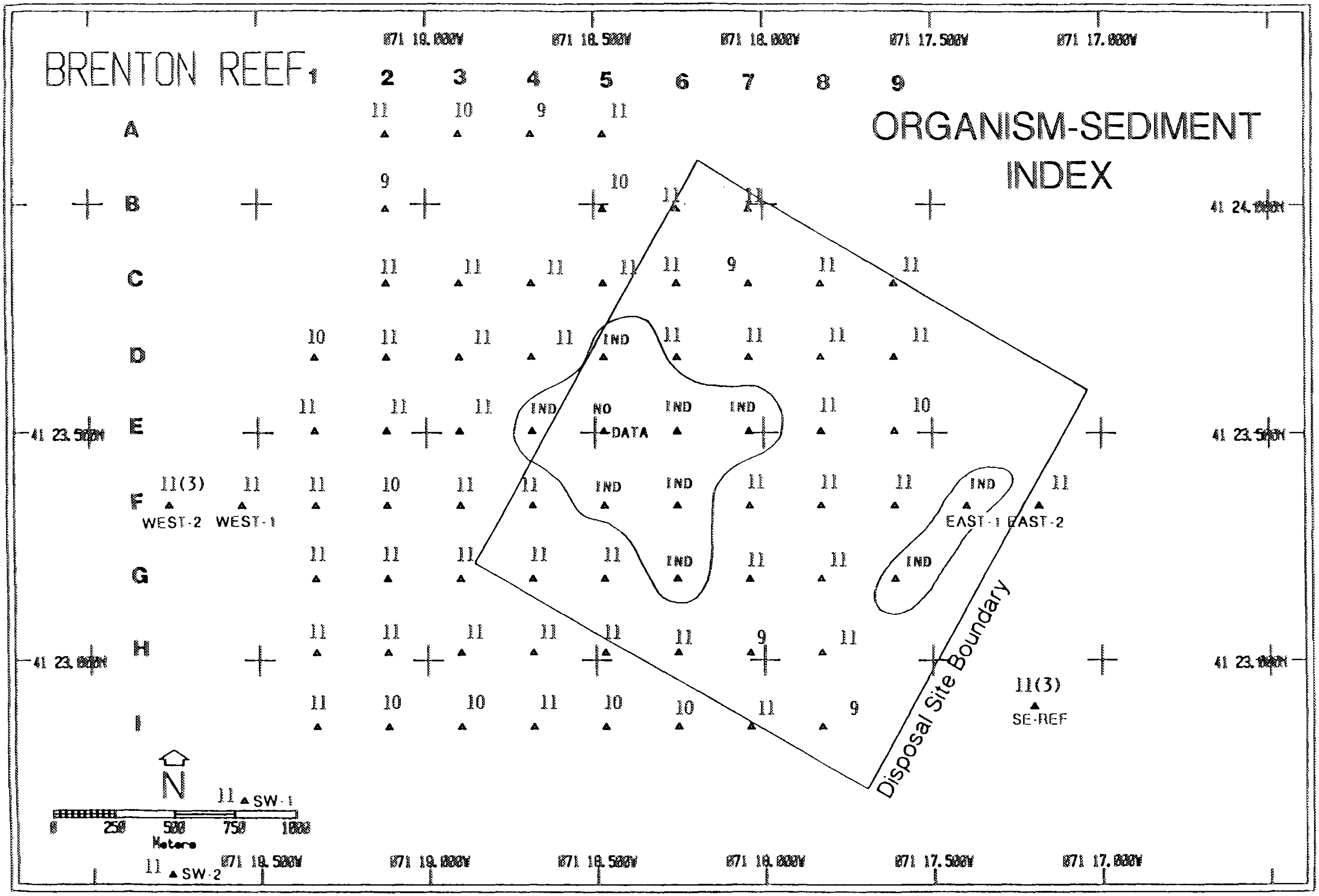


Figure 3-21. The mapped distribution of REMOTS® Organism-Sediment Index values at the Brenton Reef site, October 1987. The contours delimit stations where the OSI could not be calculated due to either an indeterminate successional stage or inadequate prism penetration.

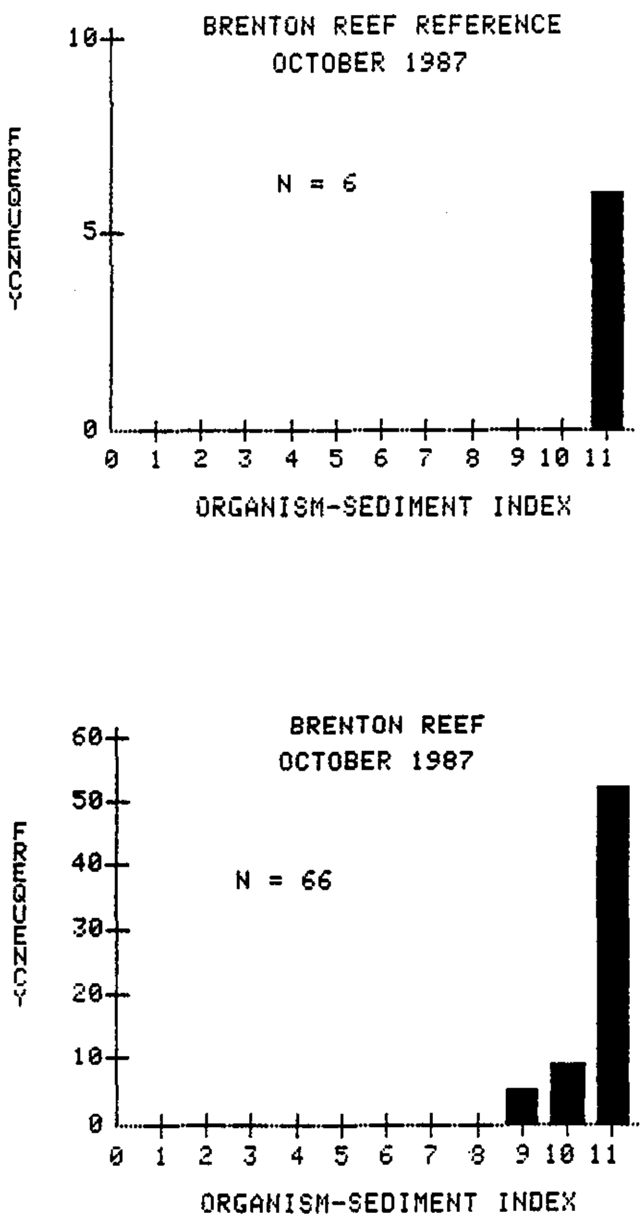


Figure 3-22. Frequency distributions of OSI values for Brenton Reef REMOTS® grid stations (top) and reference stations (bottom), October 1987.

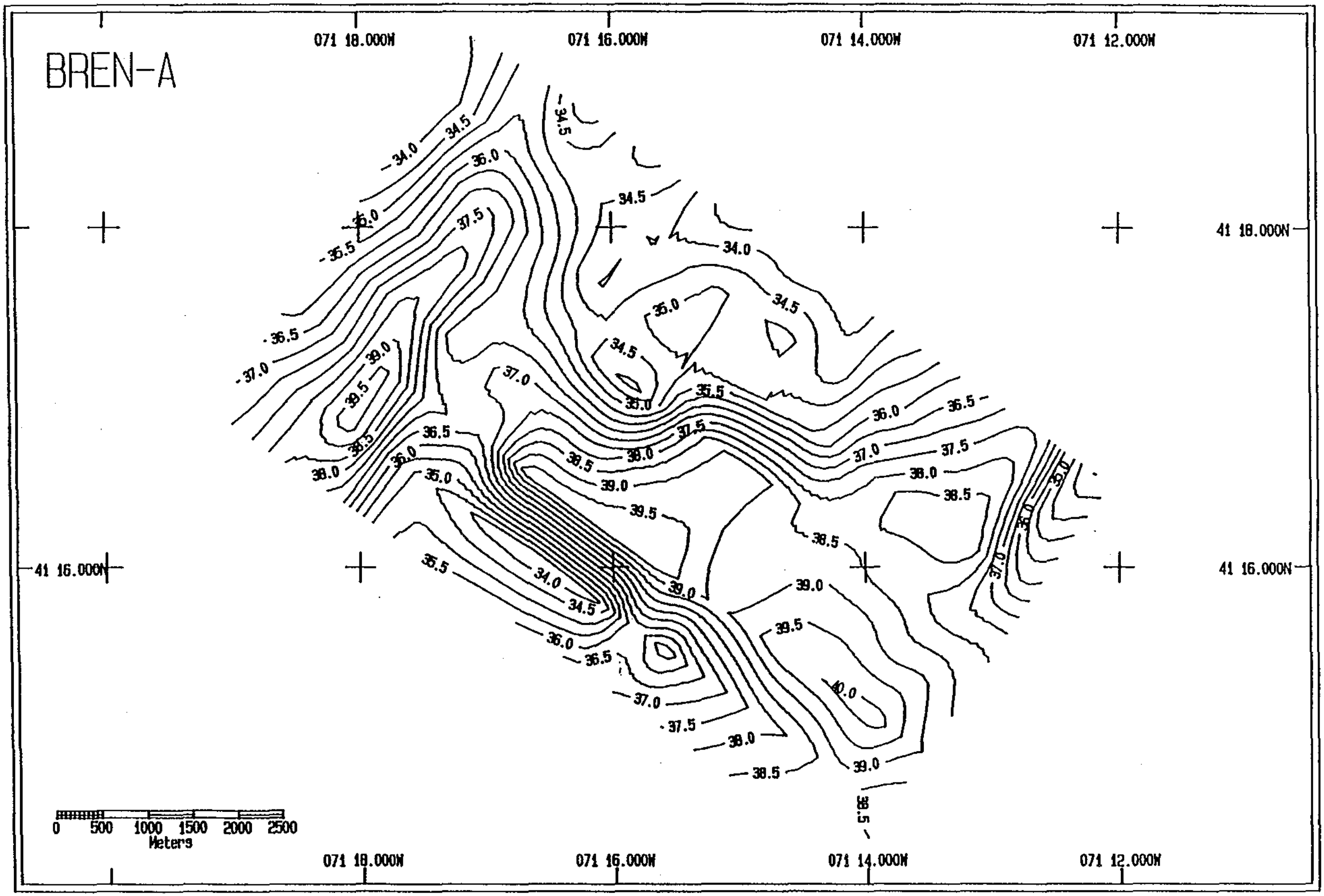


Figure 3-23. Contoured bathymetric chart of the Brenton-A study area, October 1987. Depths are in meters.

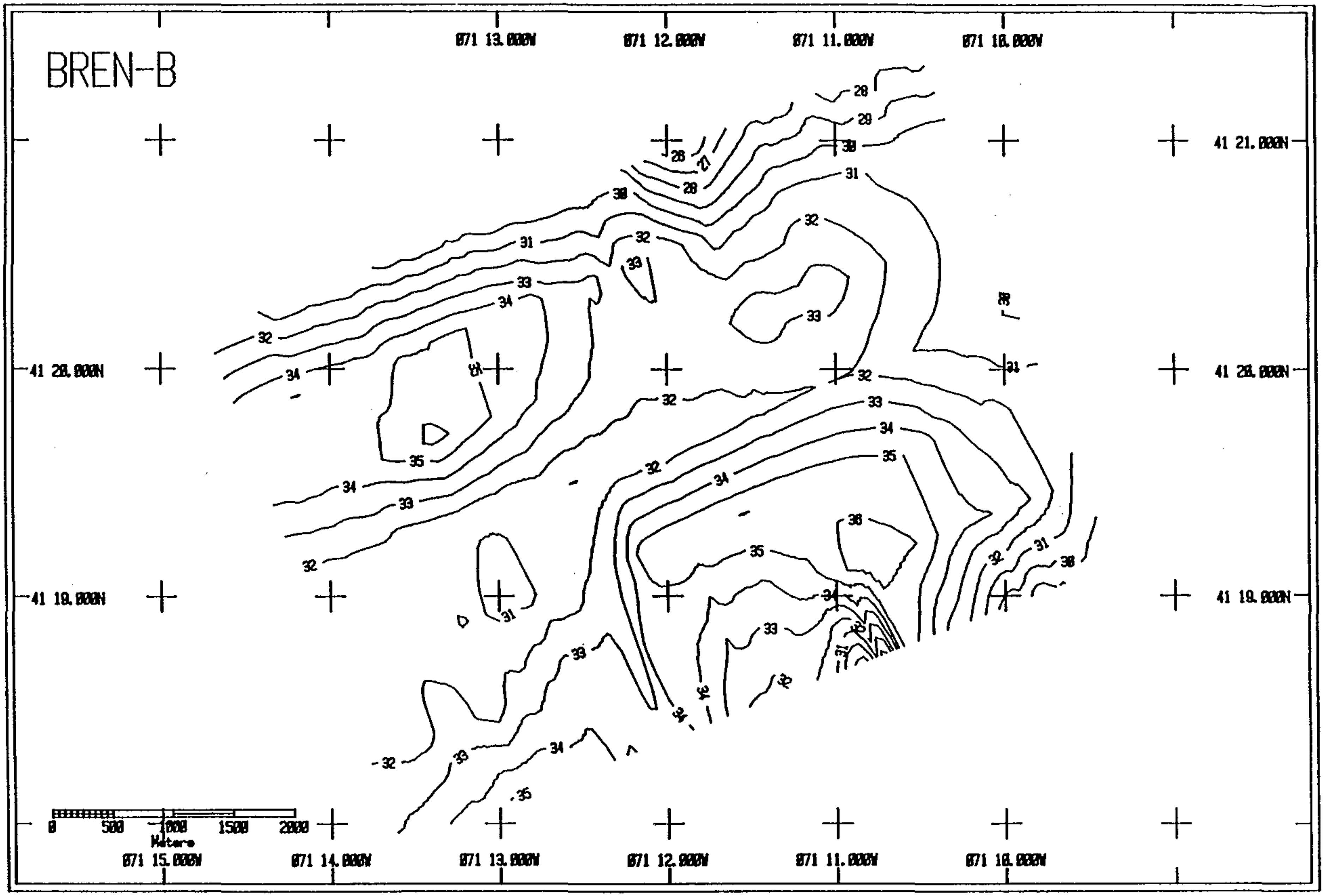


Figure 3-24. Contoured bathymetric chart of the Brenton-B study area, October 1987. Depths are in meters.

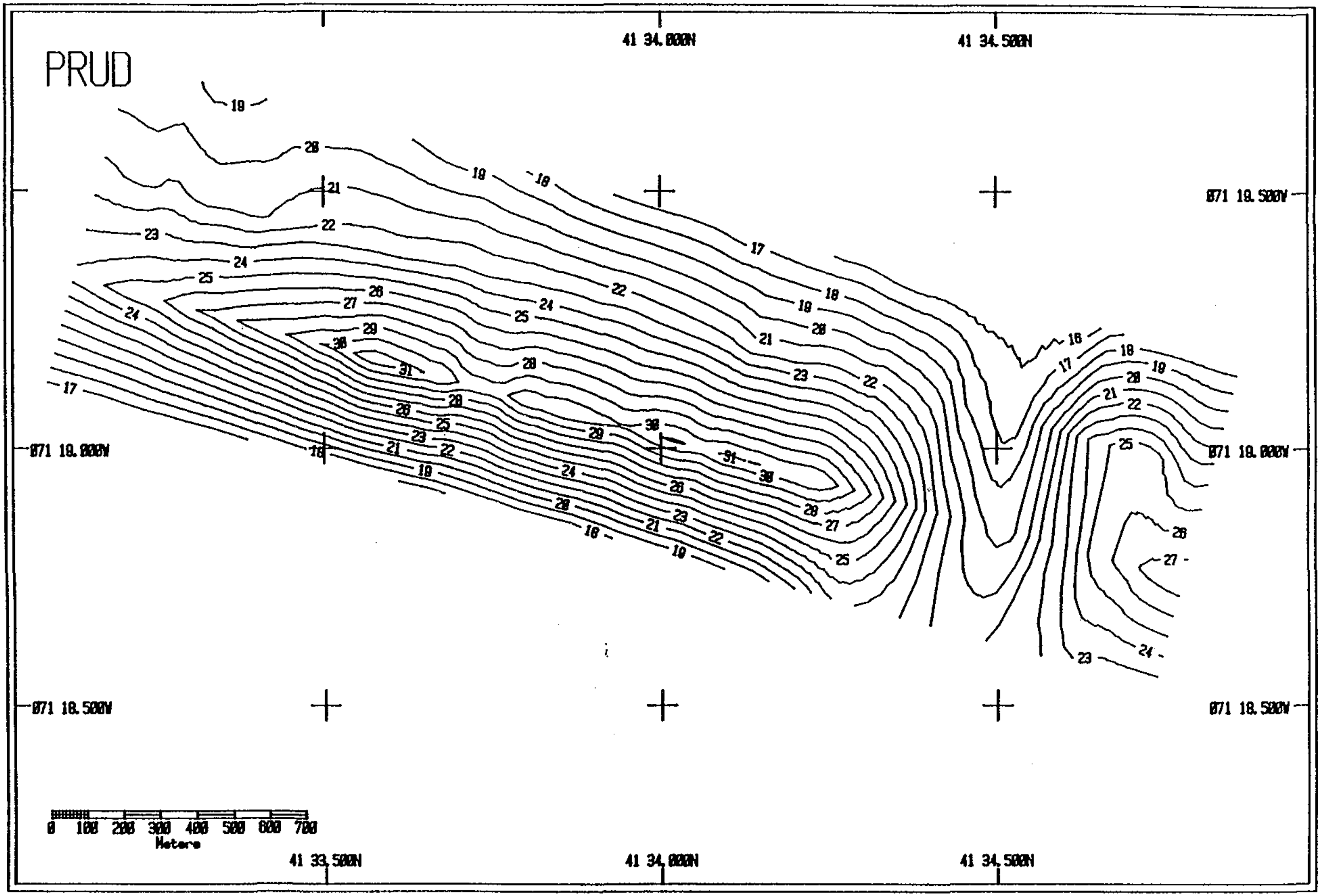


Figure 3-25. Contoured bathymetric chart of the Prudence study area, October 1987. Depths are in meters.

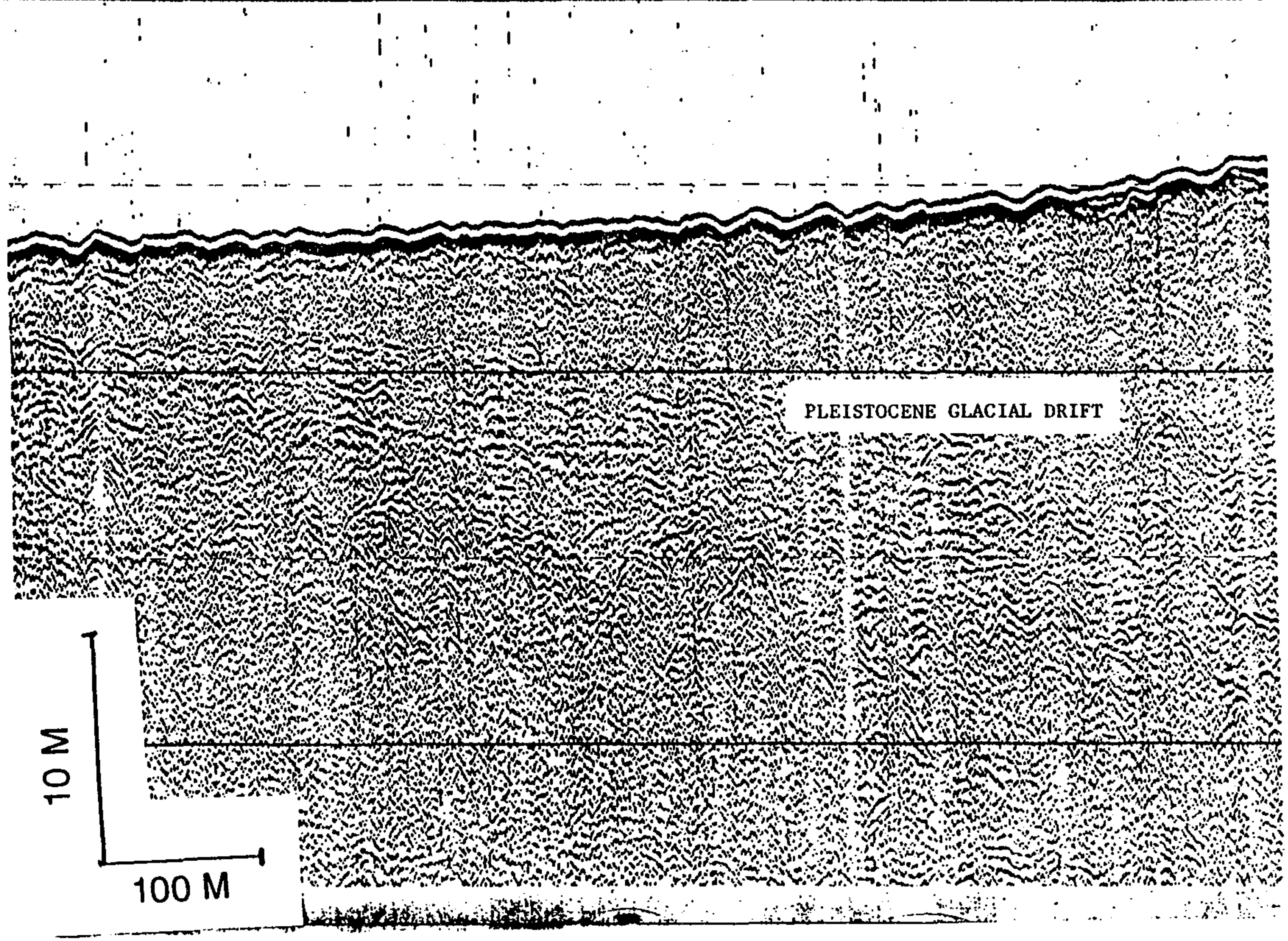


Figure 3-26. Seismic profile illustrating the diversity of acoustic reflector patterns in inferred glacial deposits, characteristic of sites Brenton A and Brenton B in Rhode Island Sound.

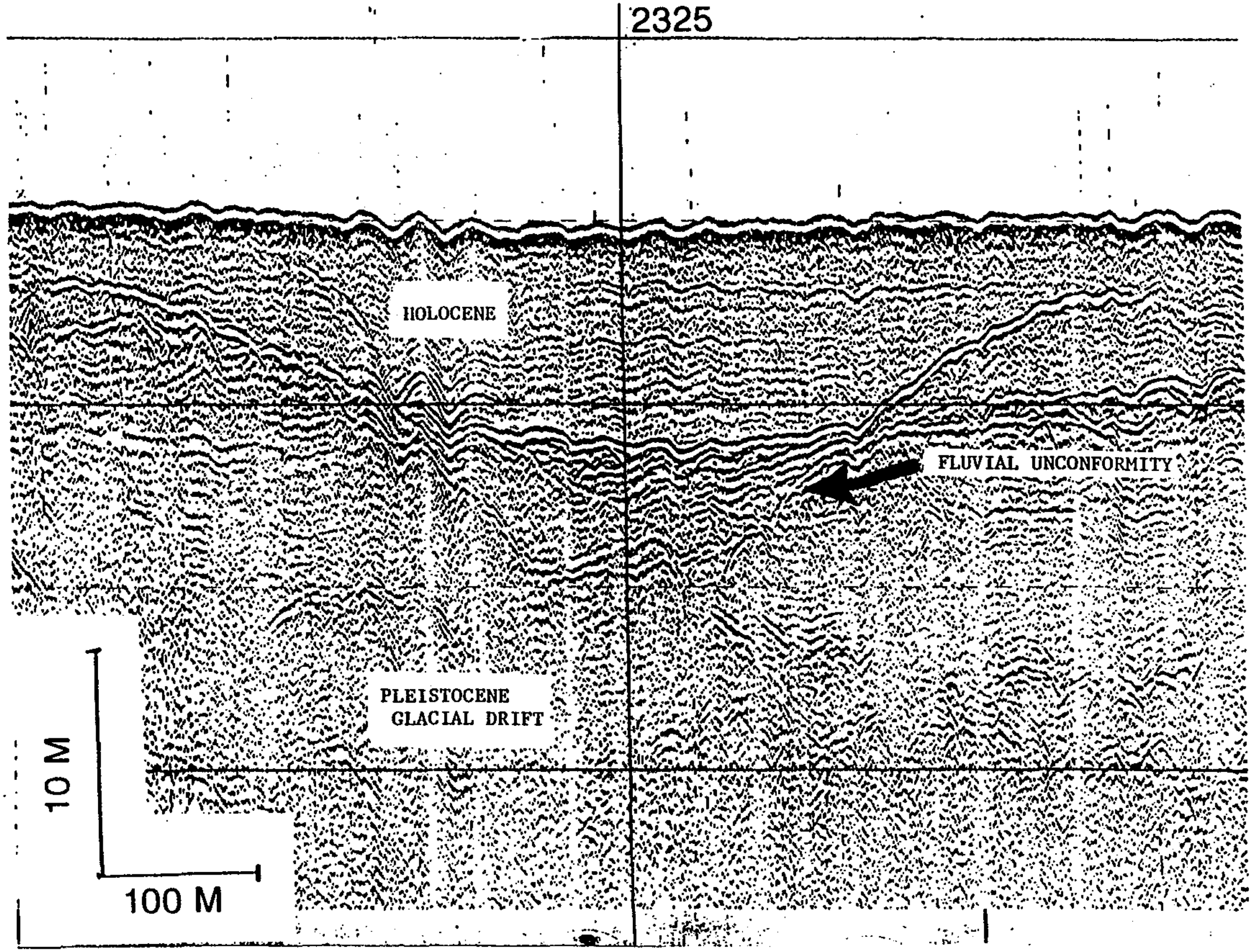


Figure 3-27. Seismic profile illustrating the fluvial unconformity (the prominent reflector indicated by the arrow) found to separate inferred glacial drift deposits (lower unit) from Holocene deposits (upper unit). This unconformity defines a relict drainage surface which is expressed surficially in sites

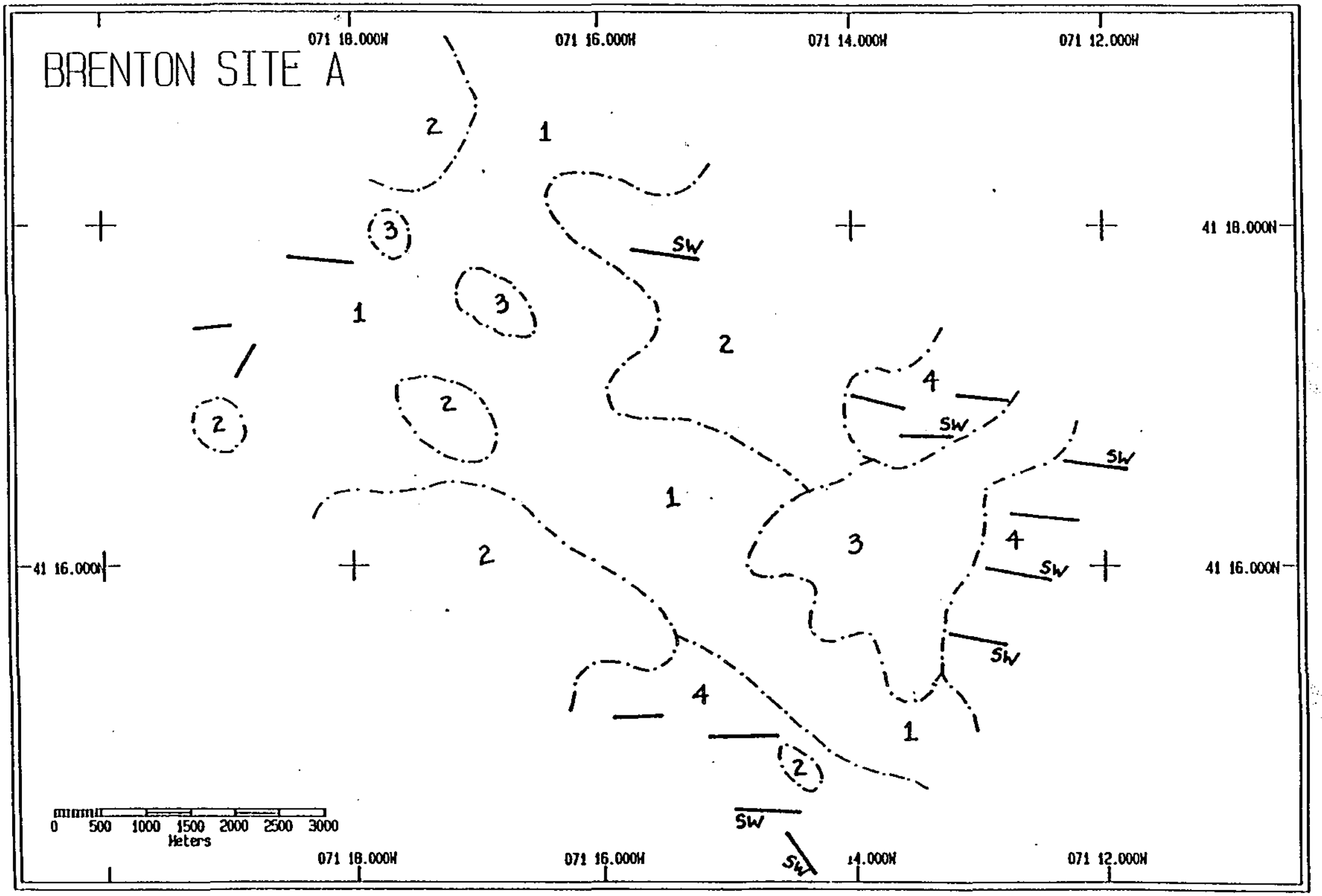


Figure 3-28. Map showing surficial textural characteristics at the Brenton A study area. Textural units, indicated by numbers 1 thru 4, are described in Table 3-5. The short "bars" represent the location and orientation of observed bedforms. Bedforms are megaripples unless otherwise noted as sandwaves (SW).

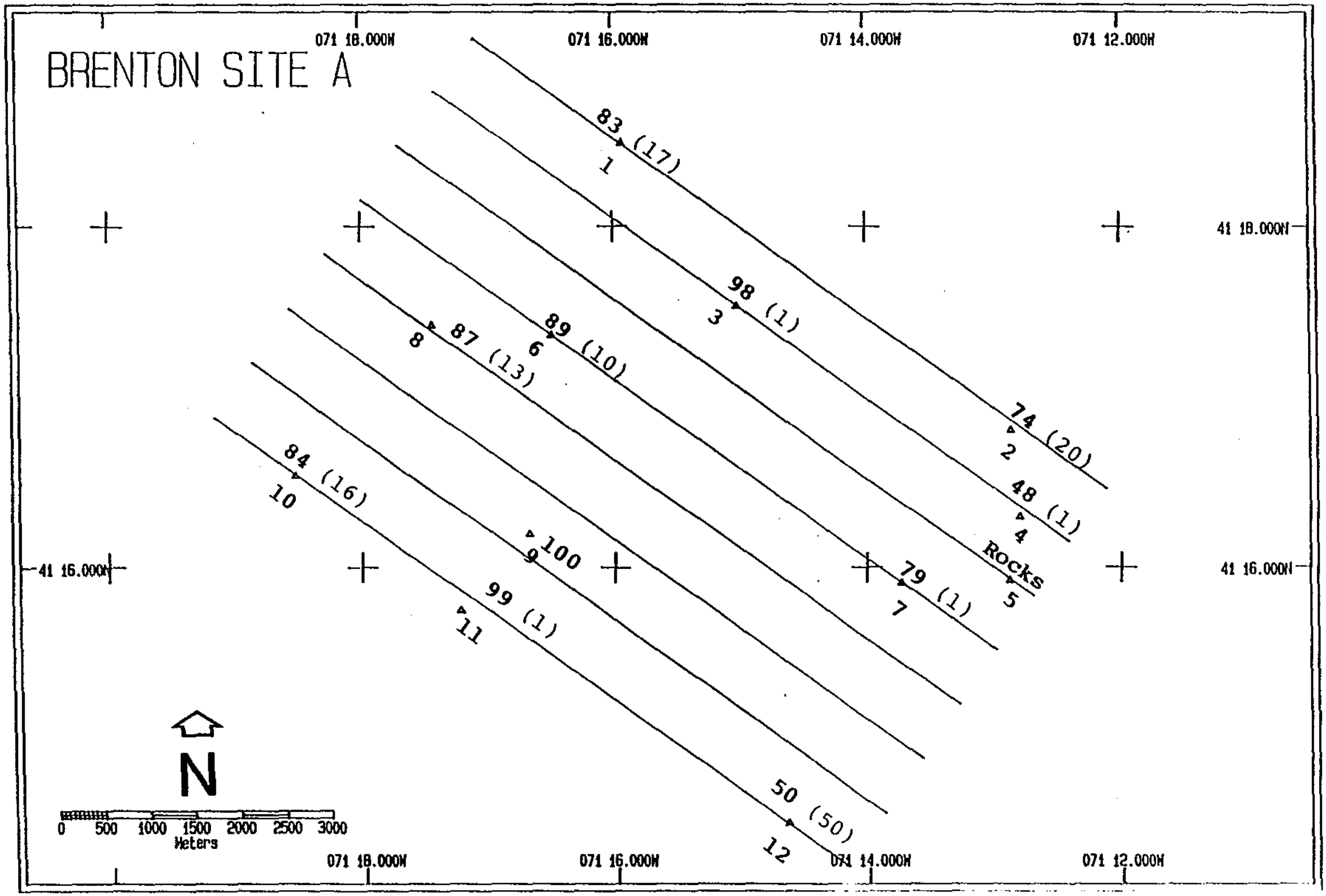


Figure 3-29. Results of grain size analysis on sediment grab samples obtained at stations 1 thru 12 (triangles) at the Brenton-A study area. The number above the triangle and outside the parentheses indicates the percent sand at each station; the number inside the parentheses is the percent silt-clay (i.e., mud). This information is also given in Table 3-6.

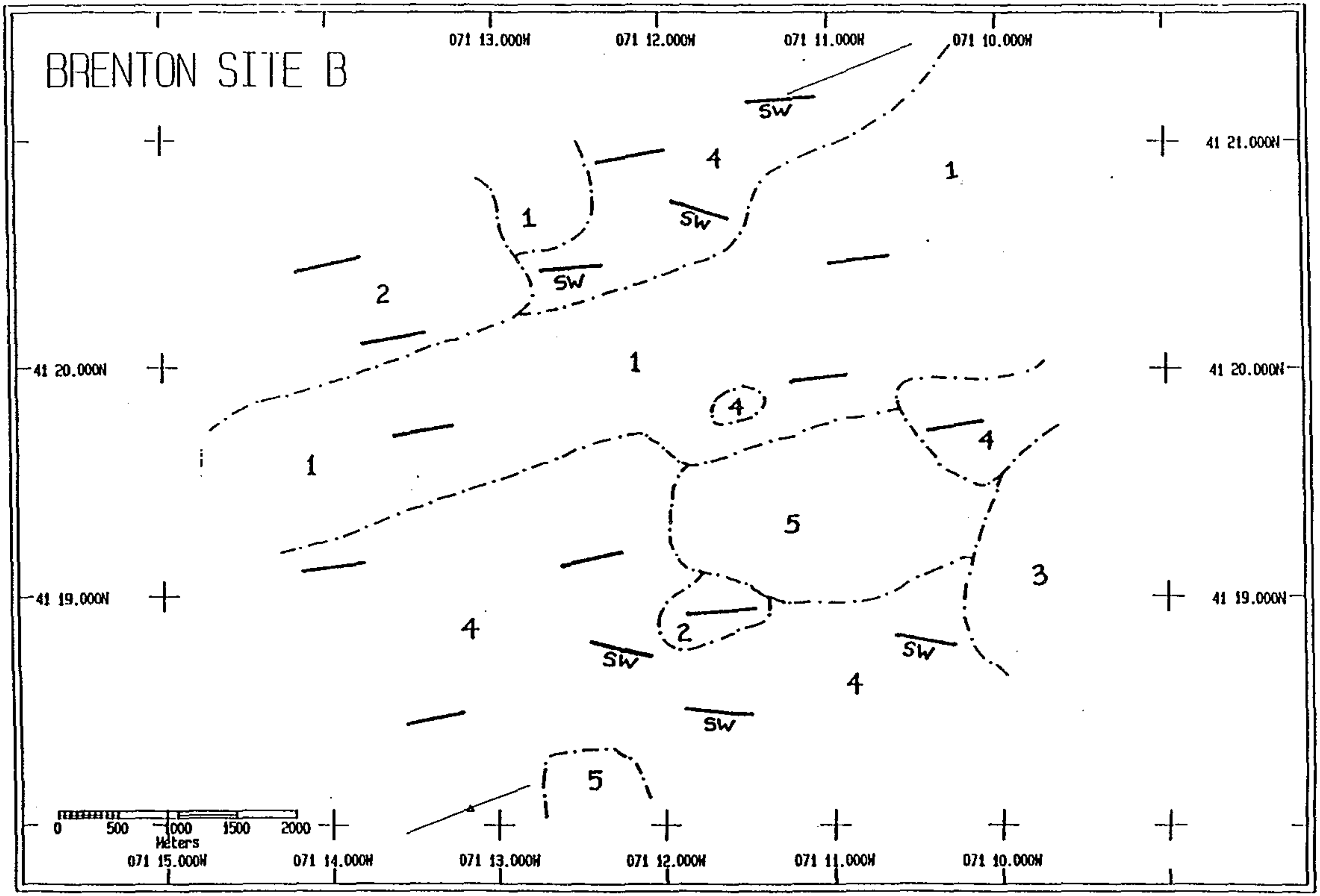


Figure 3-30. Map showing surficial textural characteristics at the Brenton B study area. Textural units, indicated by numbers 1 thru 5, are described in Table 3-5. The short "bars" represent the location and orientation of observed bedforms. Bedforms were widespread throughout units 1, 2 and 4. These bedforms are megaripples unless otherwise noted as sandwaves (SW).

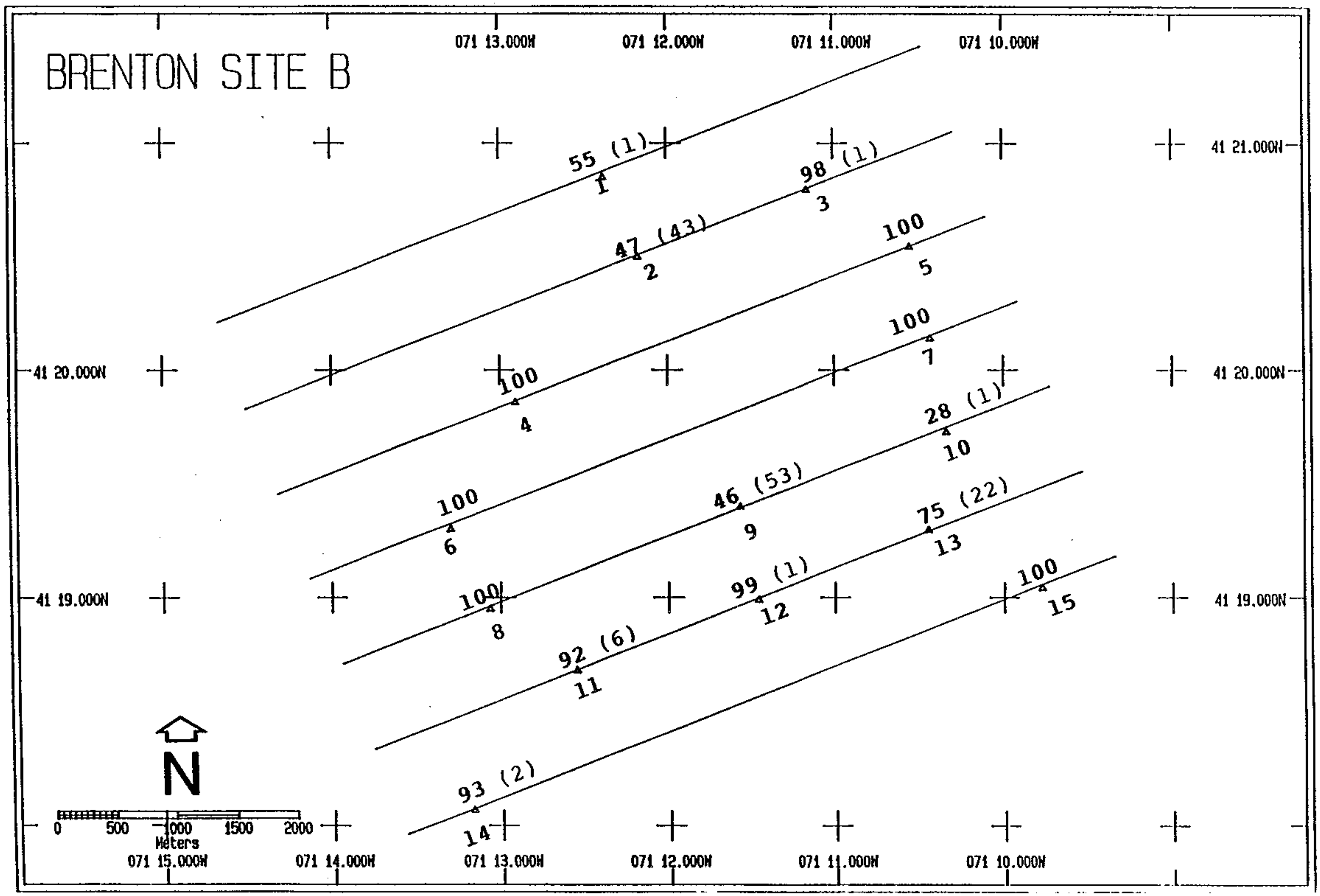


Figure 3-31. Results of grain size analysis on sediment grab samples obtained at stations 1 thru 15 (triangles) at the Brenton-B study area. The number above the triangle and outside the parentheses indicates the percent sand at each station; the number inside the parentheses is the percent silt-clay (i.e., mud). This information is also given in Table 3-7.

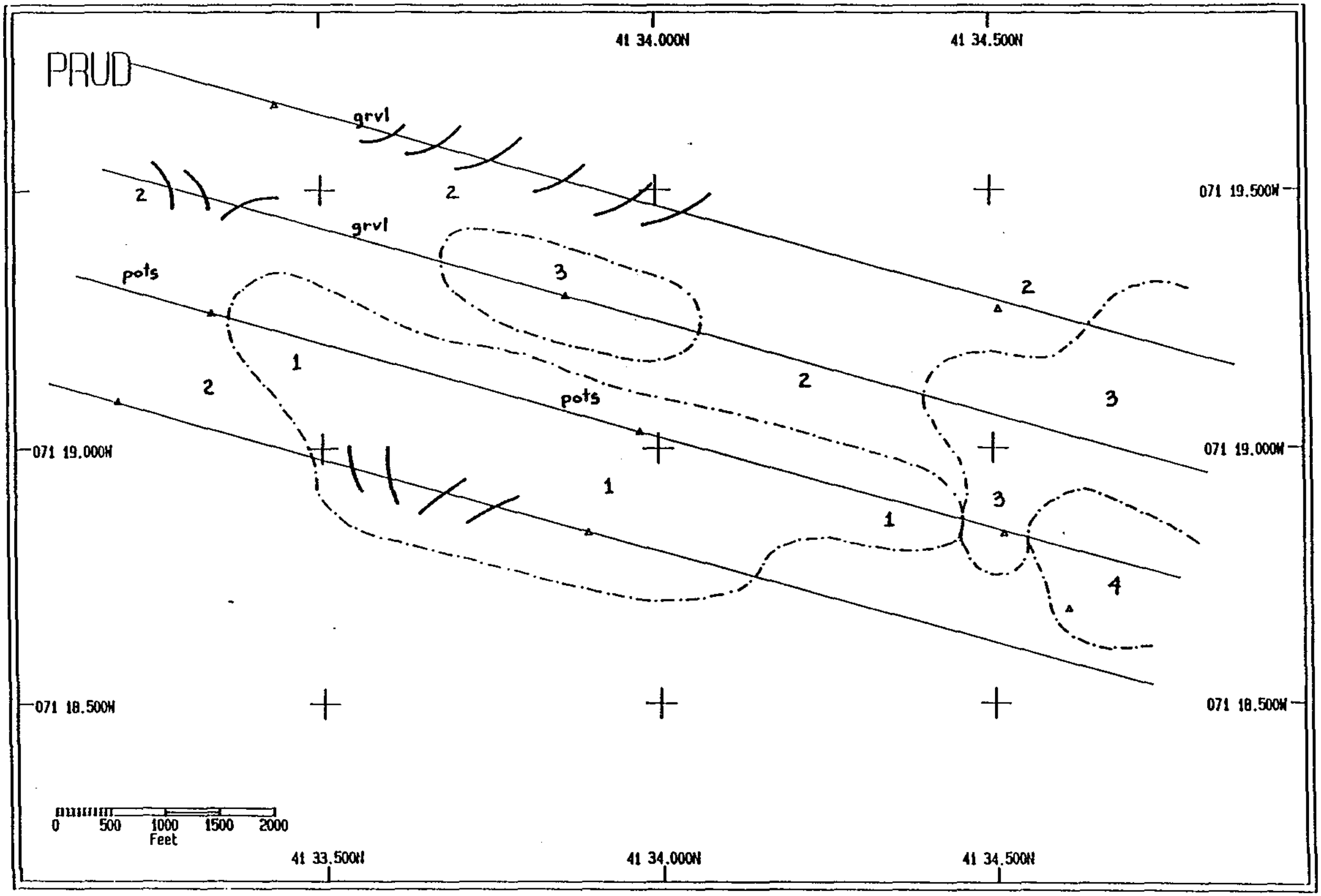


Figure 3-32. Map showing surficial textural characteristics at the Prudence Island historic disposal site in the East Passage of Narragansett Bay. Textural units, indicated by numbers 1 thru 4, are described in Table 3-5. The "whisker" marks represent trawl marks.

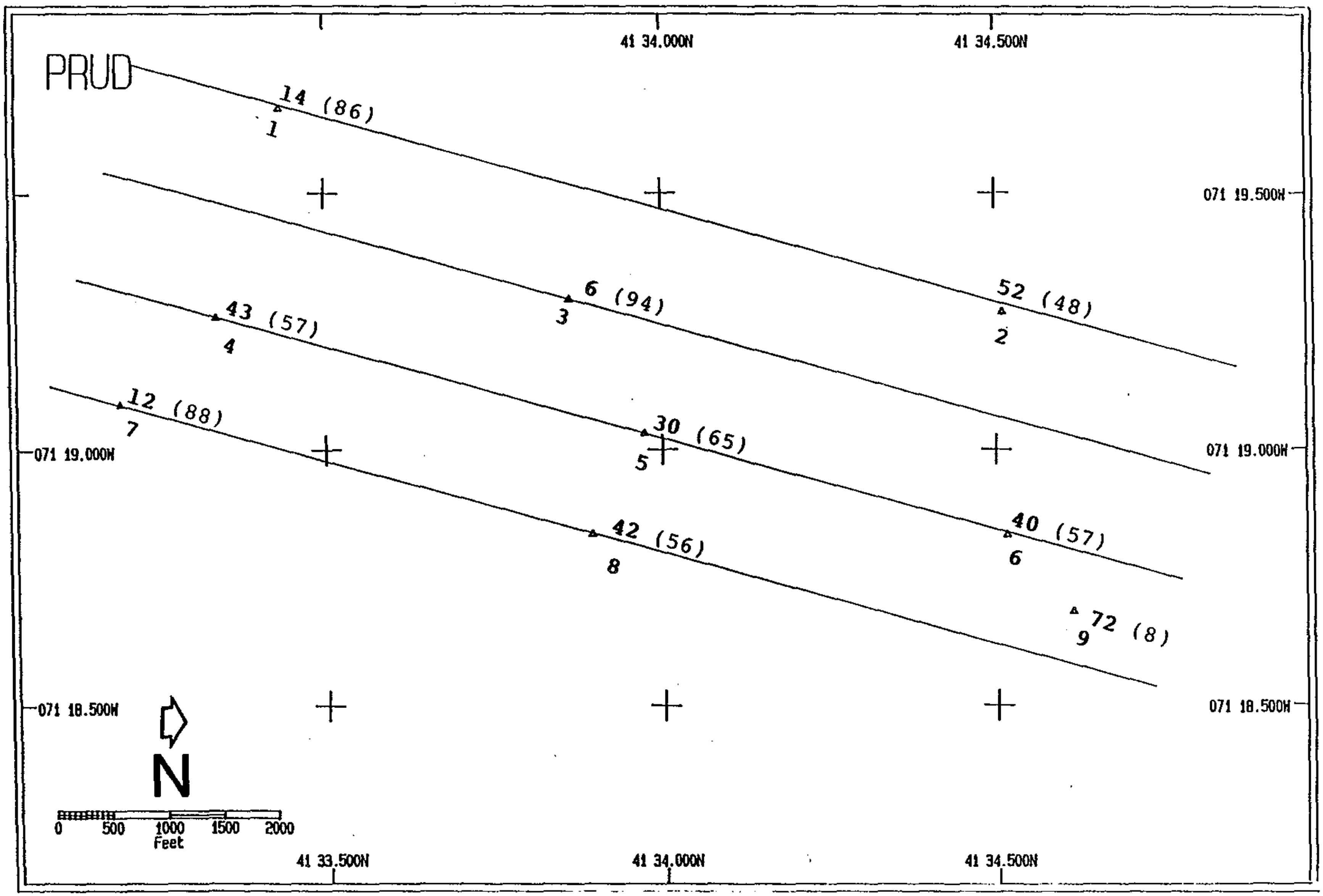


Figure 3-33. Results of grain size analysis on sediment grab samples obtained at stations 1 thru 9 (triangles) at the Prudence Island historic disposal site. The number above the triangle and outside the parentheses indicates the percent sand at each station; the number inside the parentheses is the percent silt-clay (i.e., mud). This information is also given in Table 3-8.

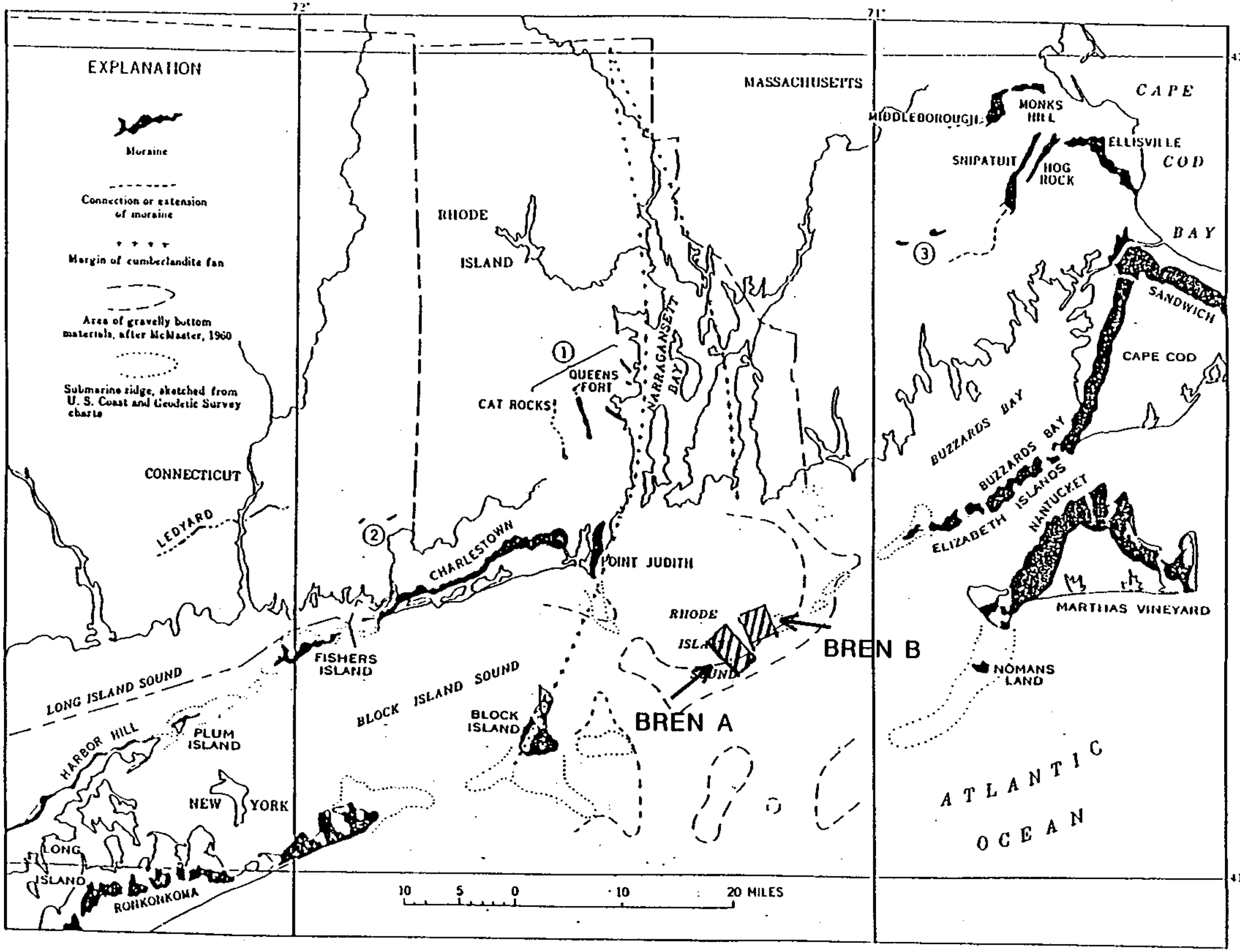


Figure 4-1. End moraines in part of southern New England (from Schafer, 1961).

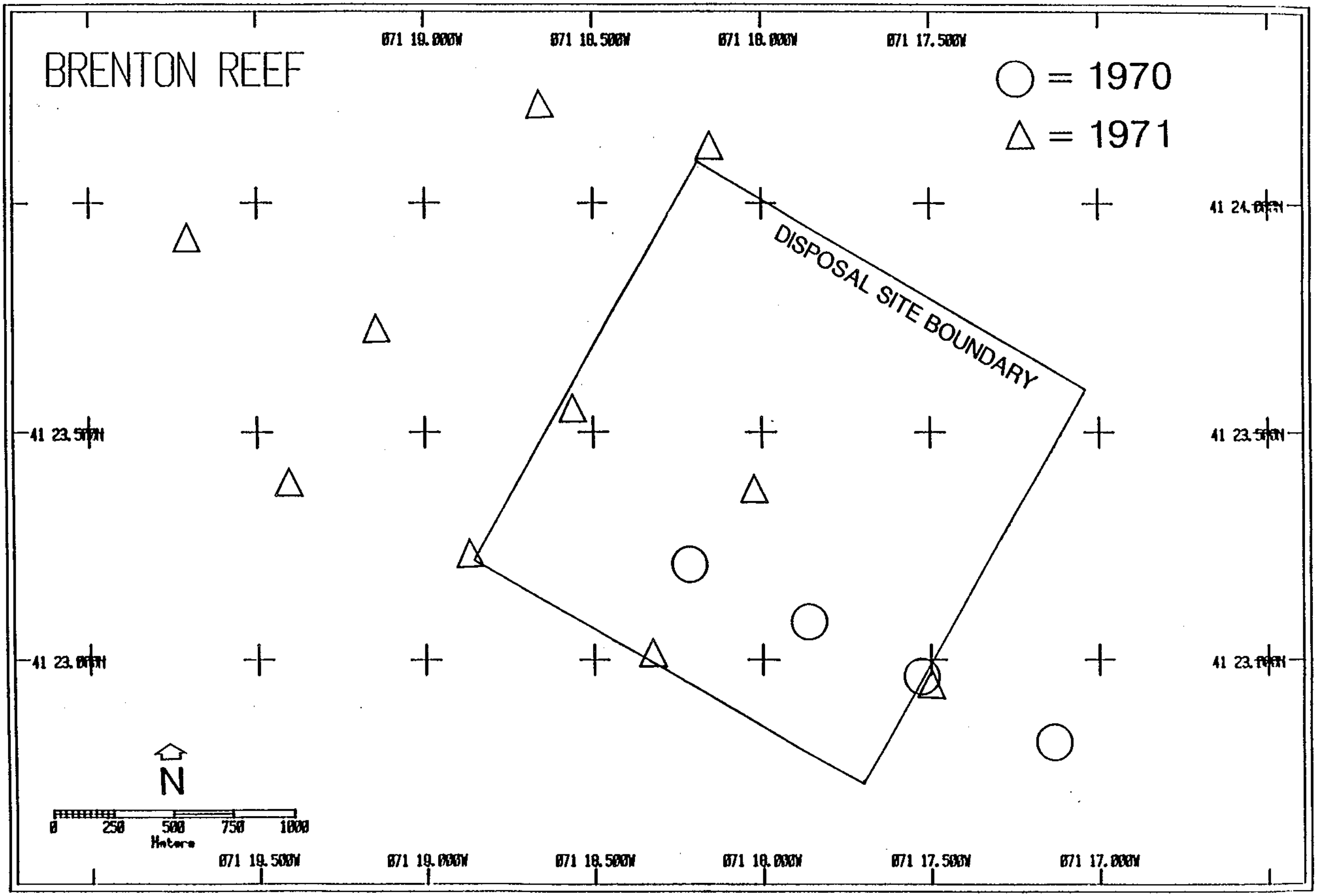


Figure 4-2. Locations of past benthic sampling stations at the Brenton Reef disposal site, 1970-71 (see text for study descriptions).

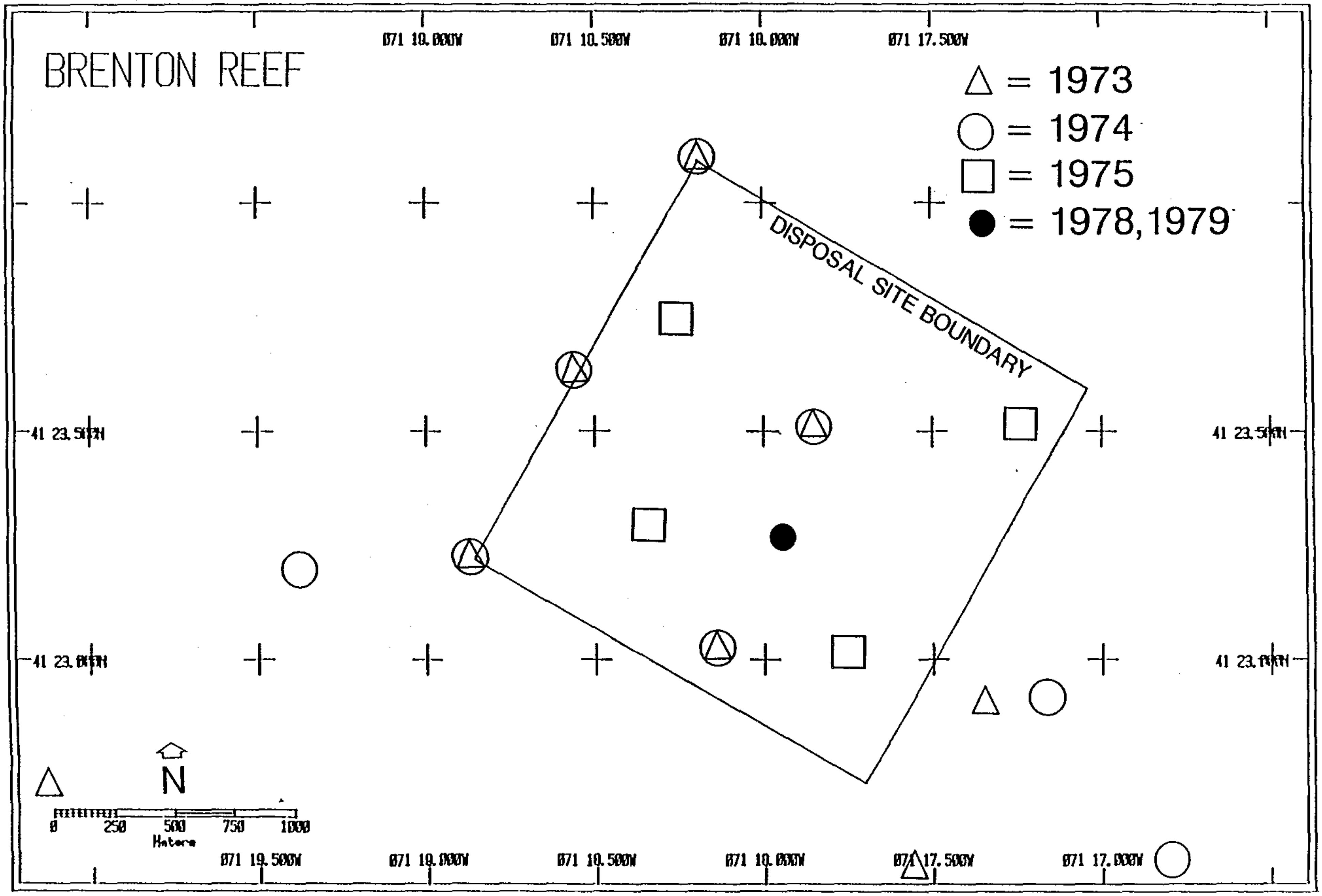


Figure 4-3. Locations of past benthic sampling stations at the Brenton Reef disposal site, 1973-79 (see text for study descriptions).