Monitoring Cruise at the Central Long Island Sound Disposal Site, July 1988

Disposal Area Monitoring System DAMOS

Contribution 72
April 1990

US Army Corps of Engineers
New England Division

MONITORING CRUISE AT THE CENTRAL LONG ISLAND SOUND DISPOSAL SITE JULY 1988

CONTRIBUTION #72

April 1990

Report No.
SAIC- 88/7548&C72

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1.0 INTRODUCTION

The Central Long Island Sound Disposal Site (CLIS) is located approximately 6 nautical miles south of New Haven Harbor, CT. Environmental monitoring by the U.S. Army Corps of Engineers New England Division (NED) has occurred at this site since 1977. A primary objective of past investigations has been to assess the environmental impacts of dredged material disposal, particularly in terms of the post-disposal recovery of benthic ecosystems. Several disposal points or mounds currently exist at CLIS as a result of past and recent disposal operations (Figure 1-1).

Field operations were conducted at CLIS from 25 to 27 July 1988. The field operations consisted of precision bathymetric and REMOTS® sediment-profile photographic surveys around the point where the disposal buoy was located during the 1987-88 disposal season (Figure 1-1). The objective of these surveys was to delineate the extent and topography of the recently-deposited dredged material resulting from the past year's disposal activities at the buoy. In addition, near-bottom and near-surface dissolved oxygen concentrations and vertical profiles of temperature and salinity were determined at selected disposal site and reference stations. The objective of this sampling was to characterize depth gradients and assess near-bottom dissolved oxygen concentrations relative to REMOTS® benthic analyses at and near the disposal site.
The 1988 monitoring scheme at CLIS was designed to verify the following predictions:

- sediment disposed during the 1987-88 season would result in the formation of a mound having a radius of approximately 250 to 300 meters, and

- near-bottom dissolved oxygen concentrations would be similar within the disposal site and the reference stations.

2.0 METHODS

2.1 Bathymetry and Navigation

The precision navigation required for all field operations was provided by the SAIC Integrated Navigation and Data Acquisition System (INDAS). This system uses a Hewlett-Packard 9920 series computer to collect position, depth, and time data for subsequent analysis as well as providing real-time navigation.

Positions were determined to an accuracy of 3 meters from ranges provided by a Del Norte Trisponder System. For the present survey, shore stations were established in Connecticut at known benchmarks at Stratford Point and Lighthouse Point. A detailed description of the navigation system and its operation can be found in DAMOS Contribution #60 (SAIC, 1989).

The depth was determined to a resolution of 3.0 cm (0.1 feet) using an Odom DF3200 Echotrac Survey Recorder with a narrow-beam 208 kHz transducer. The speed of sound was determined from the water temperature and salinity data measured by an Applied Microsystems CTD/DO probe (see Section 2.3 below). The speed of sound and the transducer depth were entered into the fathometer to adjust the depth values being transmitted to the computer. During analysis, raw bathymetric data were standardized to Mean Low Water by correcting for changes in tidal height during the survey. A detailed discussion of the bathymetric analysis technique is given in DAMOS Contribution #60 (SAIC, 1989).

The bathymetric survey conducted at CLIS on 26 July 1988 encompassed a 1200 X 1200 m grid with 25 m lane spacing, centered at coordinates 41 09.250 N and 72 53.950 W near the disposal buoy (Figure 1-1). This same grid was used in the previous bathymetric survey of the site in August 1987. It should be noted that the coordinates of the disposal buoy during the 1987-88 disposal season were 41 09.18 N and 72 53.650 W, placing it approximately 200 m southeast of its location during the 1986-87 season.

2.2 REMOTS® Sediment-Profile Photography

REMOTS® photography was used to detect the distribution of thin (1 to 20 cm) dredged material layers, map benthic disturbance gradients, and monitor the process of infaunal recolonization on and adjacent to the disposal mound. A detailed description of REMOTS® photograph acquisition, analysis, and interpretative rationale is given in DAMOS Contribution #60 (SAIC, 1989).

The REMOTS® stations occupied on 25 and 27 July 1988 were the same ones occupied during the last survey at the CLIS-86 mound in August and September 1987. Three replicate photographs were obtained at each of 37 stations situated around the disposal buoy and extending north and west of the buoy (Figure 2-1). In addition, thirteen REMOTS® stations, arranged in a cross-shaped pattern and spaced 100 m apart, were occupied at each of three reference locations to allow comparisons between ambient and on-site conditions. These reference stations were located 2500 m west (2500W), 4500 m east (4500E), and 5094 m southeast (CLIS-REF) of station CTR (Figure 2-1).

2.3 CTD and Dissolved Oxygen Sampling

The depth gradients in temperature and salinity were characterized at selected REMOTS® stations using a CTD probe (Applied Microsystems, Ltd. Model STD-12). A complete description of this instrument is given in DAMOS Contribution #66 (SAIC, 1990c). The CTD was mounted vertically on the REMOTS® camera frame such that its sensors were located approximately 42 cm from the camera base. In this configuration, vertical hydrographic profiles were obtained with each deployment of the camera.

At selected REMOTS® stations, a Niskin bottle was used to obtain water samples approximately one meter above the bottom and one meter below the surface. At some of these stations, an additional sample was obtained at an intermediate depth. A 300-ml subsample was drawn from the Niskin bottle following retrieval and the dissolved oxygen concentration was determined immediately using a modification of the standard Winkler titration method (Strickland and Parsons, 1972; Parsons et al., 1984).

3.0 RESULTS

3.1 Bathymetry

Both the 1987 and 1988 precision bathymetric surveys revealed the presence of the CS-1, CS-2, and CLIS-86 disposal mounds in the northwest corner of the CLIS disposal site (Figures 3-1 and 3-2). During the 1987-88 disposal season, a new disposal mound was formed at the buoy location approximately 200 meters southeast of the CLIS-86 mound (Figure 3-2). The minimum depths of the CS-1 (17.6 m), CS-2 (17.2 m), and CLIS-86 (16.4 m) mounds had not changed since the August 1987 survey. The minimum depth at the new mound was approximately 15.0 meters (Figure 3-3), compared to an ambient depth before disposal of 18.6 meters (Figure 3-4). The new mound had relatively steep sides; there were rapid changes in depth on the mound slopes of up to 3.0 meters over a 50 meter distance.

The depth matrices from the 1987 and 1988 bathymetric surveys were compared for the 500 X 500 meter area encompassing the new disposal mound (Figures 3-3 and 3-4). This resulted in a calculation of 114,000 m^3 of material deposited since the August 1987 survey. Examination of the scow logs indicated that an uncorrected estimate of 310,500 m^3 of material was disposed at this location during the 1987-88 disposal season.

3.2 REMOTS® Sediment-Profile Photography

Dredged material layers presumed to be recently deposited (i.e., during the 1987-88 disposal season) were evident in the REMOTS® photographs from stations in the area surrounding the disposal buoy (Figure 3-5). It was difficult to determine the precise boundaries of the new mound due to the presence of relict dredged material at stations to the south, west, and north of the buoy (Figures 3-5 and 3-6). This relict material resulted from past disposal (i.e., prior to the 1987-88 season) both at the CLIS-86 mound and at the CS-1 and CS-2 mounds located at the western boundary of the disposal site. The relict material generally occurred at the same stations where either relict or fresh dredged material was noted in the August 1987 REMOTS® survey of the site.

The apparent "fresh" dredged material exhibited varying stratigraphy, grain-size, and optical reflectance at different stations. For example, the material had a "streaky" appearance and was predominantly fine-grained at stations 200W, 2-400NE, and 600E (Figure 3-7). At other stations, both fine-grained and coarse- grained (i.e., sandy) material was noted in the replicate photographs (Figure 3-8). This reflected heterogeneity in the grain size of the disposed material. Such heterogeneity also resulted in the sediments at some stations exhibiting a distinct stratigraphy in which silt-clay layers alternated with layers of fine-to-medium sand (Figure 3-9). This type of stratigraphic pattern, reflecting temporally-varying depositional events, also was noted at several dredged material stations in the August 1987 survey. Again, the thickness of the recently-deposited layers often could not be measured accurately because of a lack of distinction between the "fresh" dredged material and underlying relict material.

The majority of REMOTS® grid and reference stations consisted of silt-clay sediments (> 4 phi, Figure 3-10). Many of the disposal site stations having either relict or fresh dredged material exhibited grain size major modes ranging from fine sand (4-3 phi) to silt-clay (>4 phi), reflecting past and recent inputs of fine sand and/or mud having a significant sand component. The majority of small-scale surface boundary roughness values at the disposal site stations (i.e., those grid stations within the disposal site boundary) fell in the range 0 to 1.4 cm, while those at the reference stations were in the range 0.6 to 1.0 cm (Figure 3-11). Boundary roughness values at the disposal site stations were not significantly different from those at the reference stations (Mann-Whitney U-test, $p = 0.1243$), although more values at the disposal site fell within the higher class intervals (Figure 3-11). This reflected physical bottom disturbance related to past and recent dredged material disposal (e.g., Figure 3-8a).

The frequency distribution of apparent RPD depths for the REMOTS® stations within the disposal site boundary had a major mode at the 3.0 cm class interval, while the distribution of RPD depths for the reference stations had a major mode at the 4.0 cm class interval (Figure 3-12). The reference station RPD depths were significantly deeper (Mann-Whitney U-test, $p = 0.005$). The RPD depths at the disposal site were not significantly different from those measured in the August 1987 survey (Mann-Whitney U-test, $p = 0.6555$). RPD depths less than 3.0 cm occurred at stations around and northwest of the buoy, generally corresponding to that area of the disposal site having recently-deposited dredged material (Figure 3-13). With a few exceptions, the RPD depths at the reference stations exceeded 3.0 cm.

Only Stage I organisms were present at two stations within the disposal site boundaries and at several reference stations (Figure 3-14). At the remainder of the disposal site stations, there was evidence of Stage III taxa (i.e., head-down deposit-feeding infauna) in at least one of the replicate photographs (Figure 3-14). Most of these stations were designated as having either a Stage III or Stage I on III successional stage (Figures 3-6 and 3-15). In August 1987, 51% of the replicate photographs at the stations within the disposal site boundaries showed evidence of Stage III taxa, compared to 61% in July 1988. At the reference stations, 59% of the 1988 replicates showed Stage III taxa, compared to 75% in August 1987.

Based on the results of past REMOTS® surveys, Organism-Sediment Index (OSI) values of +6 or less are considered indicative of chronically-stressed benthic habitats and/or those which have experienced recent disturbance (e.g., erosion, dredged material disposal, hypoxia, demersal predator foraging, etc.). Only three disposal site stations (200W, CTR, 400E) had mean OSI values +6 (Figure 3-16). These low values reflected relatively shallow RPD depths and an absence of Stage III infauna, probably related to the recent inputs of dredged material at the buoy. Small-scale (i.e., within-station) patchiness in the distribution of Stage III infauna primarily accounted for OSI values +6 at several reference stations. Generally, mean OSI values exceeded +6 at the majority of disposal site and reference stations.

The frequency distribution of reference station OSI values had a major mode at +11, while the distribution of OSI's at stations within the disposal site boundaries has major modes at +9 and +11 (Figure 3-17). There was no significant difference in OSI values at these disposal site stations versus the pooled reference stations (Mann-Whitney U-test, $p = 0.2920$). The overall average OSI value was 8.6 at the reference stations and 7.9 at the disposal site stations. The OSI values at both the disposal site and reference stations were not significantly different from those calculated in the August 1987 REMOTS® survey (Mann-Whitney U-test, p = 0.3357 for the disposal site and p = 0.6383 for the reference stations).

3.3 CTD and Dissolved Oxygen Sampling

Near-bottom dissolved oxygen concentrations at the disposal site stations ranged between 4.6 to 5.3 mg/, while those measured at the three reference stations ranged between 3.9 to 5.4 mg/ (Table 3-1). Dissolved oxygen concentrations one meter below the surface were significantly higher at all stations, ranging between 7.2 to 8.6 mg/ at the disposal site and having a value of 8.3 mg/ at each of the reference stations. Dissolved oxygen levels in mid-depth water samples taken at random stations were intermediate between the surface and near-bottom concentrations. This suggests a steady decrease in dissolved oxygen levels from surface to bottom on the day of sampling.

Plots of the depth gradients in temperature, salinity, and density (as sigma-t) at selected disposal site and reference REMOTS® stations are given in the Appendix. The depth gradients were similar at all the stations sampled; the plot from disposal site station 4-400SE is representative (Figure 3-18). This plot indicates that at the time of sampling, the water column was well-stratified, as evidenced by the distinct thermocline at a depth of about 5 m. Temperatures ranged between 22.4C at the surface to 19.0C at depth. Concomitant increases in salinity and density (as sigma-t) with depth suggested a relatively stable stratification of the water column, making it resistant to large-scale vertical mixing.

4.0 DISCUSSION

The objective of the combined REMOTS® and precision bathymetric surveys was to delineate the extent and topography of the deposit resulting from the past year's disposal at CLIS. The bathymetric survey showed a significant accumulation of dredged material approximately 250 meters southeast of the CLIS-86 mound, in the vicinity of the disposal buoy's location during the 1987-88 disposal season. The circular, relatively steep-sided new mound had a maximum thickness of 3.6 meters at its apex, centered slightly east-southeast of the buoy. Based on changes in bathymetry, the radius of the mound to the north, west and south was determined to be between 200 to 250 meters.

Changes in depth of up to 40 centimeters occurred 200 meters east of the center of the new mound, indicating fresh material extended beyond the limits of the bathymetric survey in this direction (Figure 3-3). The REMOTS® photos confirmed this, showing dredged material layers greater than 19.5 centimeters at station 600E, which was located about 400 meters east-northeast of the new mound's center. Fresh dredged material probably occurred beyond this eastern-most REMOTS® station, making the location of the eastern boundary of the mound indeterminate. However, the combined bathymetry and REMOTS® results indicate that the new mound was situated well within the disposal site boundaries.

REMOTS® photography indicated that the roughly circular area around the buoy covered by recently-deposited dredged material had an approximate radius of 350 to 400 meters (Figure 3-5). This exceeds the predicted radius of 250 to 300 meters for the new mound; however, this prediction was based on an estimated volume of 65,000 m^3 of disposed material. The final scow log volume estimate of 310,500 m^3 of disposed material far exceeds the earlier estimate and accounts for the wider "footprint" of the new mound as observed in the REMOTS® photographs. The REMOTS® mapping probably tended to overestimate the extent of the recent deposit because the contouring was between relatively widely-spaced stations and because of the aforementioned difficulties in distinguishing between fresh and "relict" dredged material layers at several of the stations on the mound flanks. This latter difficulty also was noted in the August 1987 survey; this situation is difficult to avoid when the same disposal point is used for several successive seasons.

Despite these considerations, the REMOTS® results show the new mound had a larger radius than indicated by the bathymetry results (Figure 4-1). This is mainly because of the camera's ability to detect thin layers on the flanks of the deposit. Such layers were below the limits of detection by precision bathymetry and were therefore unaccounted for in the volume difference calculation. When the area representing the flanks of the mound was *digitized and measured (Figure 4-2), it was found to occupy* 334,912 m^2. It might be assumed that the average thickness of the fresh dredged material layers in this area was 15 cm, an estimate based on the actual thickness of such layers at several flank stations (Figure 3-5). This results in a estimated total volume of 50,237 m^3 of material on the mound flanks not accounted for in the bathymetric depth difference calculation. Adding this to the depth difference volume estimate of 114,000 m^3 results in a final total of approximately 164,000 m^3 of dredged material detected on the bottom using these two techniques.

The final total volume estimate of 164,000 m^3 is less than the scow log volume estimate of 310,500 m^3 of disposed material. Tavolaro (1984) showed that volume estimates based on scow log records considerably overestimate the amount of dredged material because of the significant amount of interstitial water associated with the dredged material in the barges. He calculated that "depth difference" volume estimates based on successive bathymetric surveys will be as much as 41% less than the scow log volume estimates. The discrepancy was attributed not only to the scow log inaccuracies, but also to the compaction of dredged material on the bottom following disposal and the significant volume of material deposited at the flanks of the mounds in layers too thin to be detected acoustically. Applying the 41% factor to the scow log estimates in the present study results in a corrected volume of 184,130 m^3 of material, compared to the depth difference volume estimate of 114,000 m^3. At CLIS as well as at the Western Long Island Sound and New London Disposal Sites, dredged material volumes calculated from bathymetric data have consistently been less than the scow log volumes. Until a comprehensive mass balance study is performed and methods are developed to easily and accurately measure scow volumes, attempts to reconcile the two volume estimates almost certainly will result in such a discrepancy.

The significantly shallower RPD depths at the disposal site stations versus the reference stations probably were due to the higher content of labile organic matter and, therefore, increased sediment oxygen demand of the recently disposed material compared to ambient sediments. However, Stage III taxa were present in a relatively high percentage of the replicate REMOTS® photographs at the disposal site stations, such that only stations 200W, CTR, and 600E in the area affected by recent disposal exhibited OSI values +6. Moreover, OSI values at stations within the disposal site did not differ significantly from those at the reference stations. It appears there was a relatively rapid recovery by the ambient benthic community following the seafloor disturbance caused by dredged material disposal. The continued presence of Stage III organisms in the area affected by disposal suggests that the disturbance was transient as detected at the benthic population level.

Because of within-station patchiness in their distribution, Stage III taxa could have been missed in the single REMOTS® photograph obtained at individual reference stations. This may account for the decrease between 1987 and 1988 in the percentage of photographs showing evidence of Stage III organisms at the reference stations. Likewise, there was no way to determine the small-scale (i.e., within-station) variability in RPD depths at these stations. Because of the patchy distribution of Stage III benthic organisms, it is recommended that additional replicate photographs be obtained at each individual reference station in future studies so that any apparent variability or sampling artifact caused by using the cross-shaped station pattern at the reference stations can be better assessed. Additional rationale for this recommendation is presented in the following discussion.

Over the past three years there has been a change in sampling procedures at CLIS-REF in order to better characterize regional ambient bottom conditions for comparison with conditions at the disposal site. In 1986, twenty replicate shots were taken at the CLIS-REF site, and Stage III taxa were observed in 90% of these replicates (SAIC, 1990a). However, despite the large number of replicates acquired, all the data were obtained from one location and intended to represent ambient bottom for the larger region. In order to eliminate this error of "pseudoreplication" (Hurlbert, 1984), triplicate photographs were taken in 1987 at four reference areas throughout the region concerned. In the 1987 study, Stage III taxa were reported in 75% of the reference photographs (SAIC, 1990b).

In the present study, the sampling design utilizing several different reference areas was maintained, providing adequate spatial coverage in order to characterize ambient bottom in the region. However, only one photograph was taken at each of the thirteen stations in the cross-shaped grid in each area. This allowed some assessment of Stage III patchiness on the order of the 100 meters between stations, but did not allow assessment of within-station patchiness (i.e., on the order of several meters between camera drops). In reality, without a priori knowledge of the patchiness in Stage III distributions in an area, it is virtually impossible to know whether the spacing of samples will allow adequate detection of the variation in the patch size. In addition, because benthic assemblages are not static in space or time, calculating the required number of replicate samples needed to obtain a specified level of precision at a specific location will yield a result which may not be valid at future monitoring times or in other locations. However, taking three photos at each of the reference grid stations in the present study would at least have matched the level of replication performed at the disposal site grid stations. It is therefore recommended that such replication be performed at the cross-shaped reference grids in the future, or substituted with a series of random camera drops within a given radius of operation at each reference location.

In the August 1987 survey, the CLIS-86 mound had shown a noteworthy increase in colonization by Stage III taxa compared to July 1986, suggesting an overall improvement in benthic conditions. The OSI values and RPD depths in July 1988 were unchanged from August 1987, while the percentage of replicates showing Stage III infauna increased from 51% to 61% at stations within the disposal site. This increase, along with an overall average RPD depth of 3.1 cm and an average OSI value of 7.9, suggests an absence of adverse impacts related to dredged material disposal during the 1987-88 season.

The objective of the CTD/DO sampling was to assess near-bottom dissolved oxygen concentrations in relation to benthic habitat conditions at and in the vicinity of the disposal site. Although the near-bottom waters had less dissolved oxygen than those near the surface, the lowest near-bottom concentration measured at the time of sampling (3.9 mg/) was still within the "aerobic" range (Table 4-1). The lack of vertical mixing of the water column associated with the strong stratification apparent in the CTD profiles most likely contributed to the observed depletion of dissolved oxygen in the bottom waters. The absence of a significant difference in dissolved oxygen levels between the disposal site and reference stations suggests that this dissolved oxygen depletion was a region-wide phenomenon unrelated to disposal. Very similar water column structure and an identical pattern of near-bottom dissolved oxygen depletion was observed a few days prior to the CLIS survey at the WLIS Disposal Site and reference stations, located in Long Island Sound about 34 km (21 miles) west of CLIS. This strongly suggests that the "region" experiencing near-bottom dissolved oxygen depletion at the time of sampling included the entire western half of Long Island Sound. This verifies the prediction that dissolved oxygen concentrations would be similar within the disposal site and the reference stations.

The time-integrated sediment record represented in the cross-sectional REMOTS® photographs obtained at CLIS did not show any evidence of stress which might otherwise be attributed, as in past years, to region-wide near-bottom hypoxia occurring prior to or during the survey. This agrees well with earlier findings that seasonal hypoxia was not as severe or widespread in Long Island Sound in the summer of 1987 compared to the preceding year (SAIC, 1988). The apparent absence of severe hypoxic stress in 1987 and 1988 (up to and including the time of sampling) largely explains the continued healthy benthic conditions noted at the active disposal mound in both years. Likewise, improved benthic conditions were noted at the Western Long Island Sound Disposal Site in both years. It is possible that the near-bottom dissolved oxygen depletion observed in July 1988 still represented a "pre-hypoxic" condition, such that the most severe effects had not yet become fully manifested in the water column (and subsequently in the sediments). This could not be determined within the time frame of the 1988 DAMOS sampling. However, the 1988 results generally showed that in the absence of severe hypoxia, relatively healthy benthic conditions became re-established following dredged material disposal.

5.0 CONCLUSIONS

Dredged material deposited at CLIS during the 1987-88 disposal season occurred as a circular, relatively steep-sided mound with a maximum thickness of 3.6 meters, located at the buoy approximately 200 meters southeast of the CLIS-86 mound. Based on changes in bathymetry, the radius of the new mound to the north, west and south was estimated to be between 200 to 250 meters, while the REMOTS® results suggested a radius of 350 to 400 meters. This exceeded the predicted radius of 250 to 350 meters for the new deposit, because a greater volume of material was disposed than originally had been predicted. The new mound was situated well within the disposal site boundaries. Fresh dredged material apparently occurred beyond both the eastern limits of the bathymetric survey and the eastern-most REMOTS® station, making the extent of the deposit unknown in this direction.

Based on the combined results of bathymetric and REMOTS® surveys, an estimated 164,000 m^3 of dredged material accumulated at the CLIS buoy during the 1987-88 disposal season. This was less than the scow log volume estimate of 310,500 m^3 of disposed material, but such discrepancies are expected because of the inaccuracies of scow estimates, the compaction of the dredged material on the bottom following disposal, and the significant amount of interstitial water associated with the dredged material in the barges. A comprehensive study done in Long Island Sound or a similar physical environment would help to quantify the effects of such factors on mass balance calculations.

The recent inputs of dredged material resulted in significantly shallower RPD depths at the disposal site versus the reference stations. However, the lack of a significant difference in OSI values and an increased percentage of Stage III organisms at the disposal site stations suggested that any seafloor disturbance related to dredged material disposal was minimal. The generally healthy benthic conditions observed in the REMOTS® photographs further suggested an absence of stress related to near-bottom hypoxia in the weeks and months preceding the survey. At the time of sampling, dissolved oxygen levels in near-bottom waters were lower than in surface waters but still within the aerobic range. The prediction that near-bottom dissolved oxygen concentrations would be similar within the disposal site and the reference stations was confirmed.

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Table 3-1

Dissolved Oxygen Concentrations at Selected Disposal Site and Reference Stations at CLIS, July 1988. Concentrations are in mg/ℓ.

Station	One meter above bottom	Mid-depth	Two meters below surface
800N	5.1	-	7.9
6-400NW	4.9	-	8.6
6-400NE	4.7	-	8.3
4-800NW	5.1	-	7.4
2-400NW	4.9	-	8.1
2-200NE	5.3	-	8.3
800W	4.9	-	7.2
200W	5.3	-	7.9
CTR	5.1	6.1	7.7
200E	5.1	-	7.9
600E	4.7	-	7.7
200S	4.9	-	8.3
600S	4.6	-	8.4
2500W*	3.9	4.6	8.3
4500E*	5.1	6.1	8.3
CLIS REF*	5.4	5.8	8.3

* = reference station

Table 4-1

Ecologically Important Dissolved Oxygen Ranges as Determined from Permanently Stratified Low-Oxygen Marine Basins (from Rhoads And Morse, 1971)

Dissolved Oxygen Range (mg/ℓ)	Facies
> 3.0	Aerobic
3.0 to 0.41	Hypoxic*
0.4 to 0.14	Dysaerobic
< 0.14	Anaerobic

* The hypoxic facies has been added to the Rhoads and Morse (1971) basin model by Dr. Barbara Welsh, University of Connecticut, to include responses of high metabolic rate demersal or benthic megafauna.

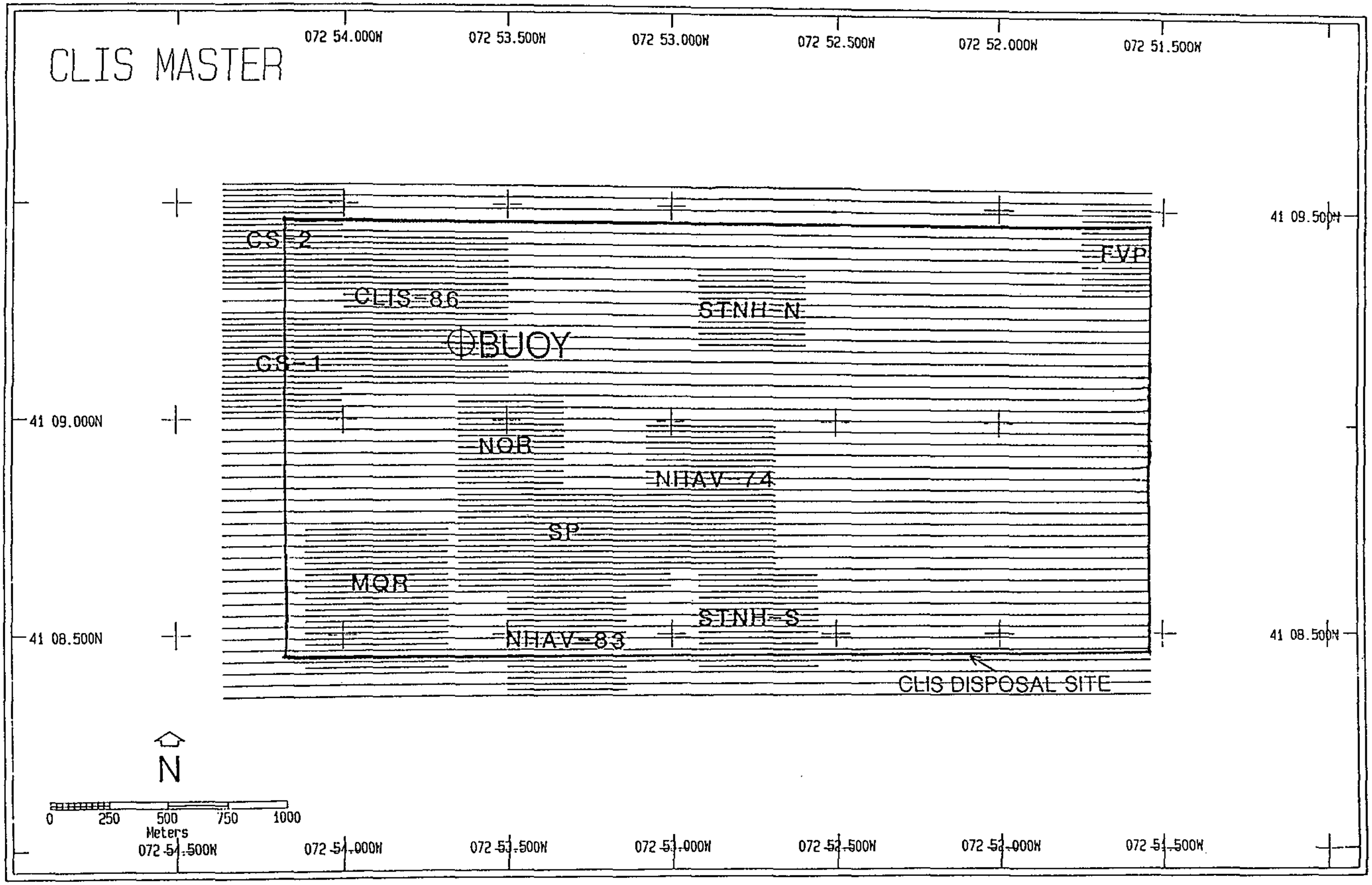


Figure 1-1. Map of bathymetric survey lanes used at CLIS, indicating the approximate locations of past and recent disposal mounds.

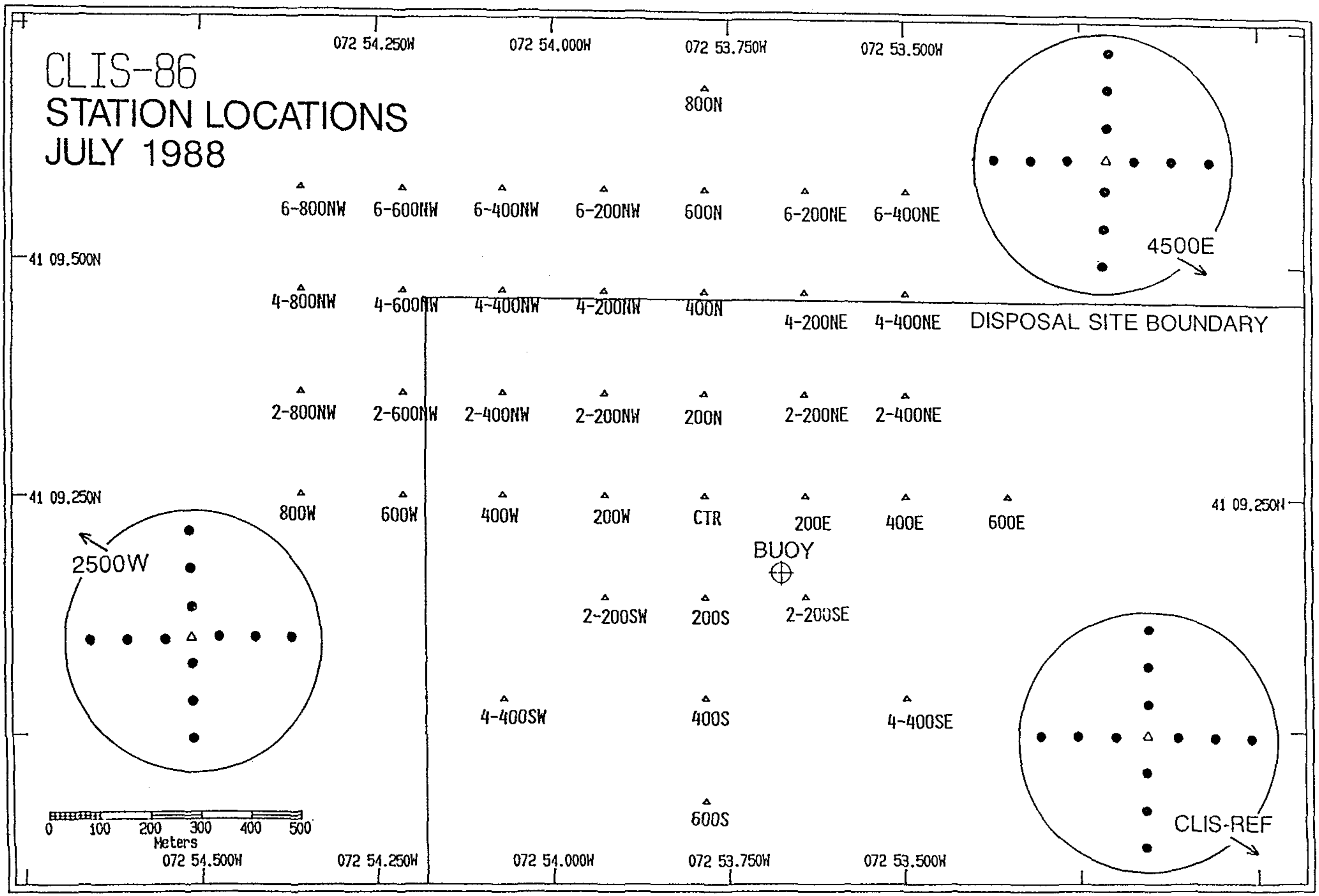


Figure 2-1. Locations and designations of REMOTS® stations (triangles) at CLIS, July 1988. Cross-shaped grids with 100 m station spacing were used at the three outlying reference sites (2500W, 4500E, and CLIS-REF).

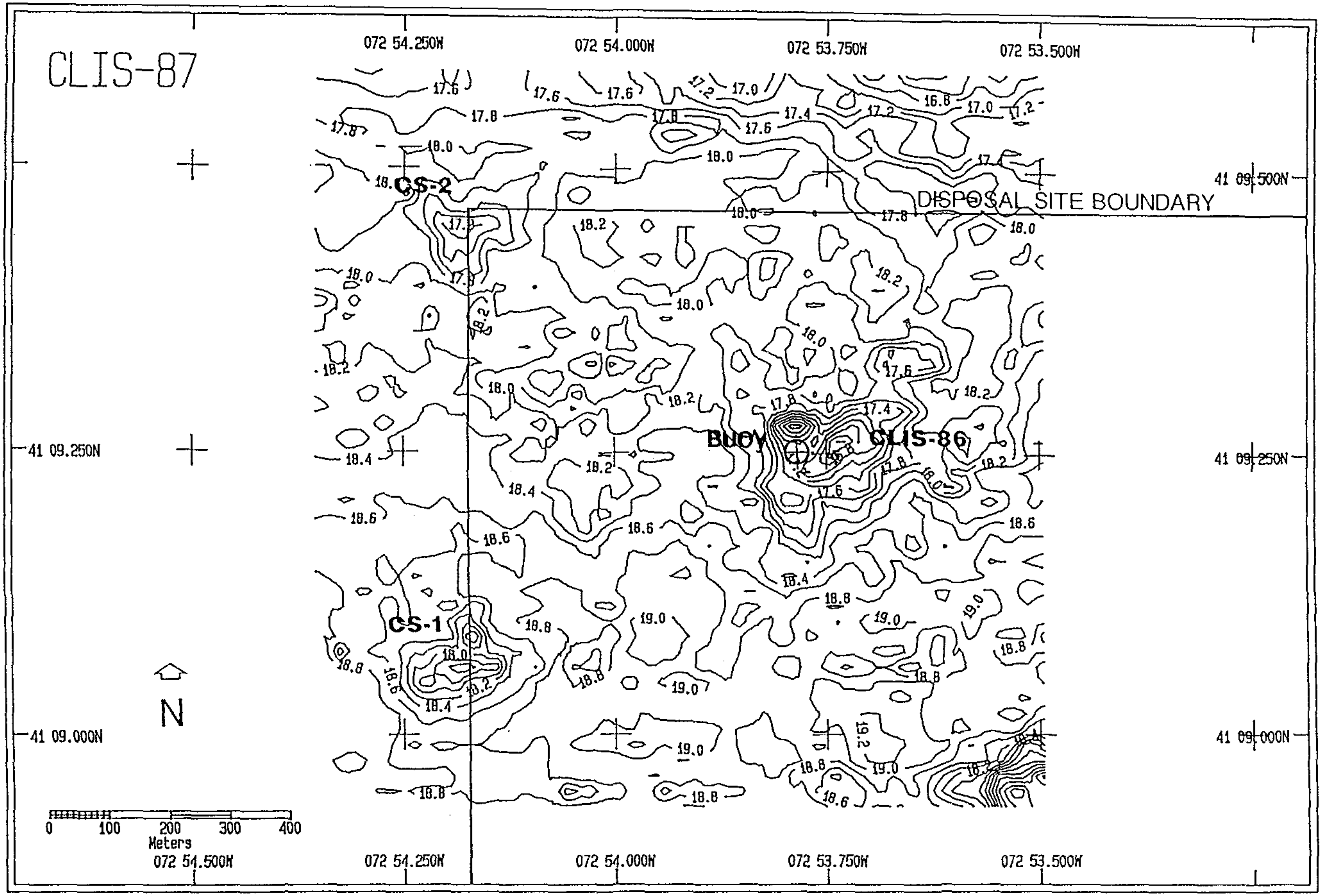


Figure 3-1. Bathymetric contour chart of the northwest corner of CLIS, August 1987. Depths are in meters.

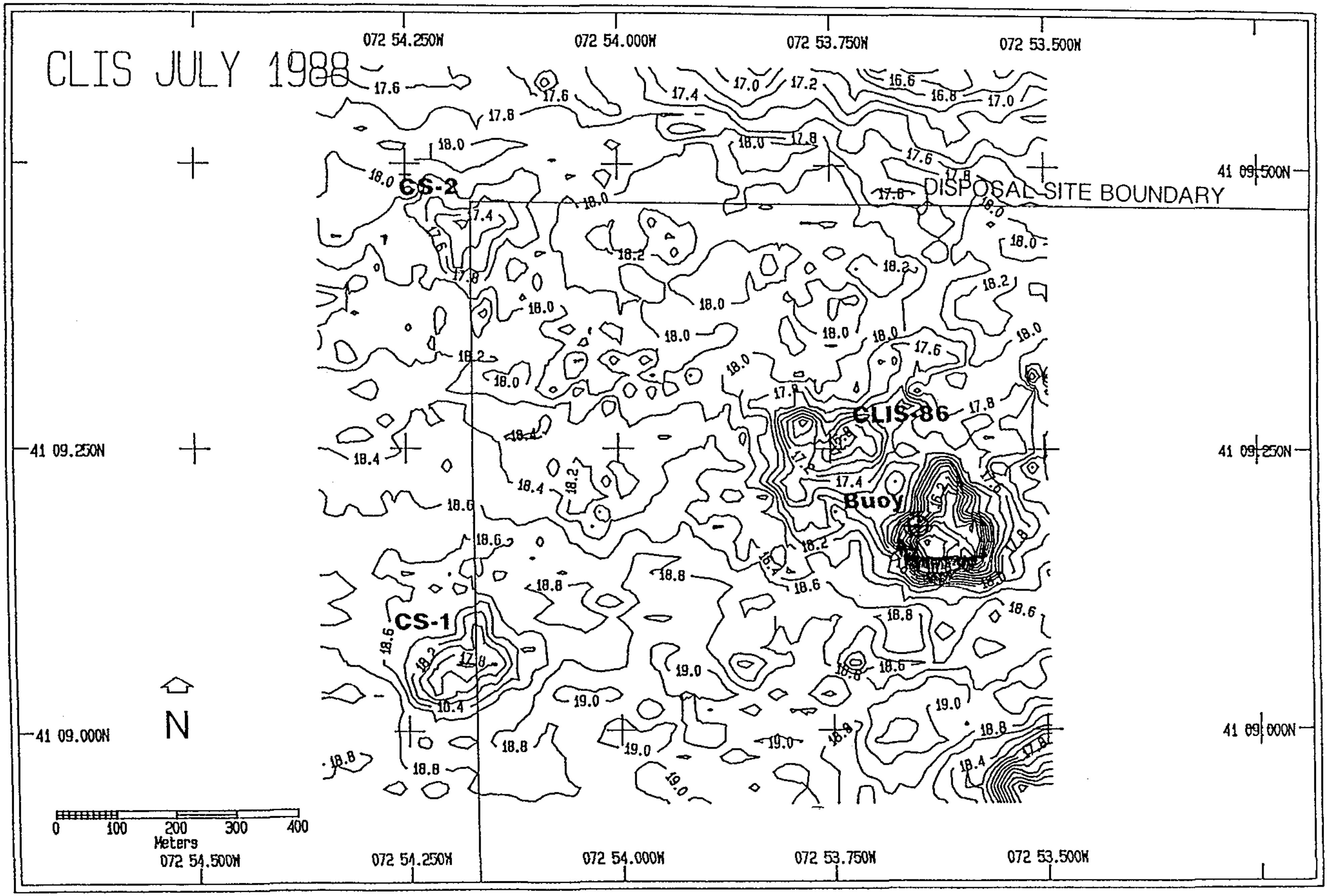


Figure 3-2. Bathymetric contour chart of the northwest corner of CLIS, July 1988. Depths are in meters.

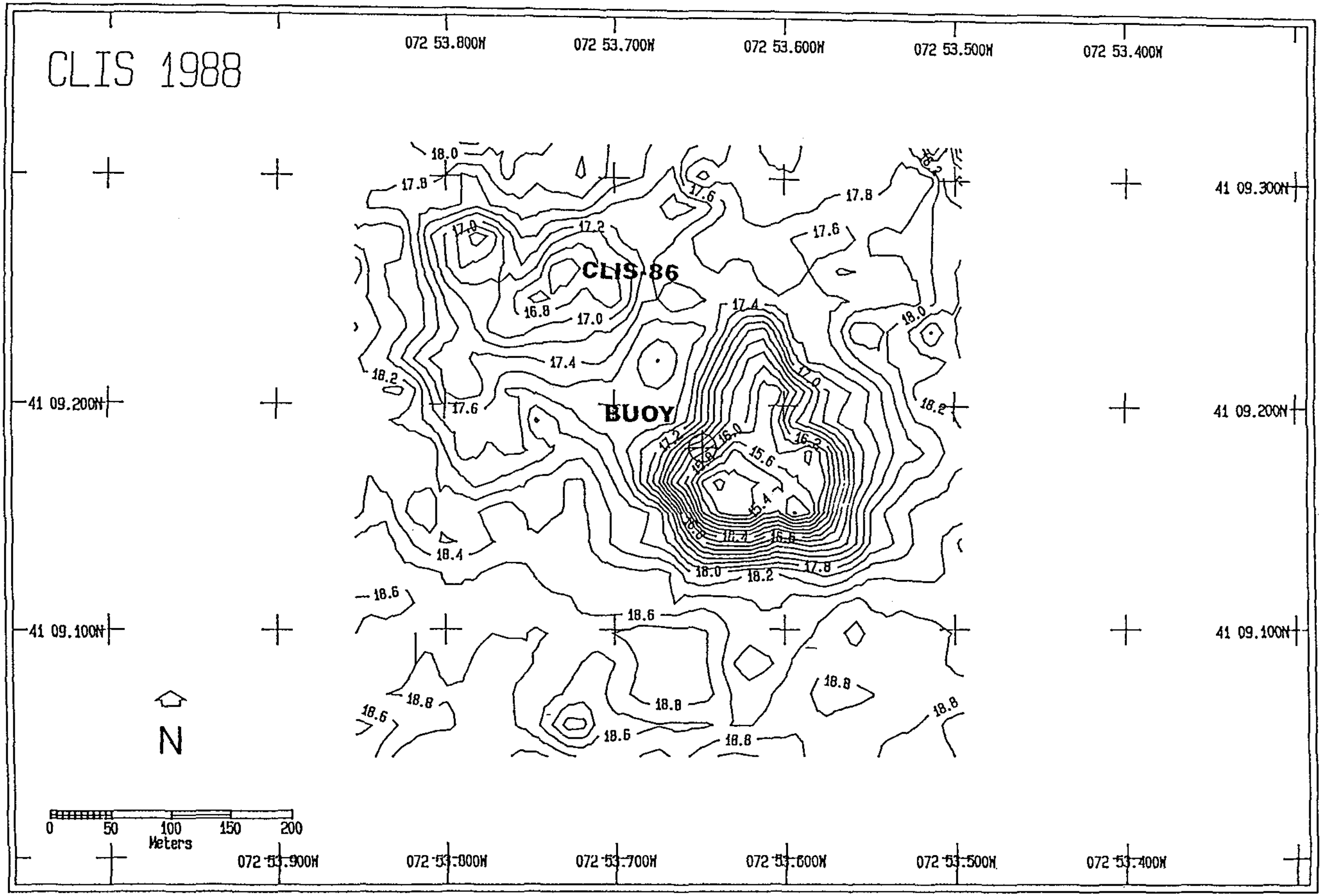


Figure 3-3. Bathymetric contour chart from July 1988 showing the 500 X 500 meter area encompassing the new disposal mound, which was formed southeast of the CLIS-86 mound. Depths are in meters.

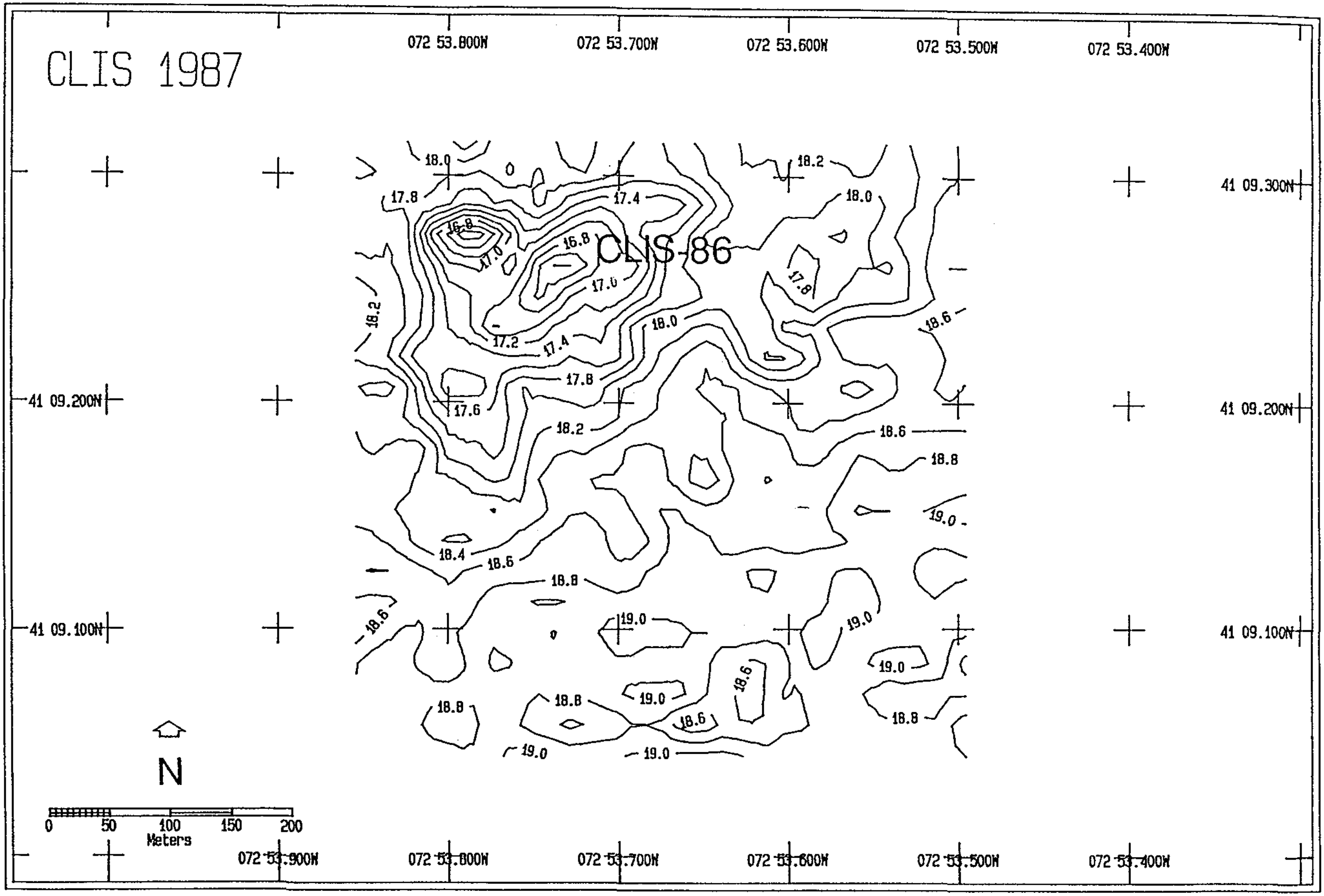


Figure 3-4. Bathymetric contour chart from August 1987 showing the 500 X 500 meter area where the new disposal mound was formed during the 1987-88 disposal season. Depths are in meters.

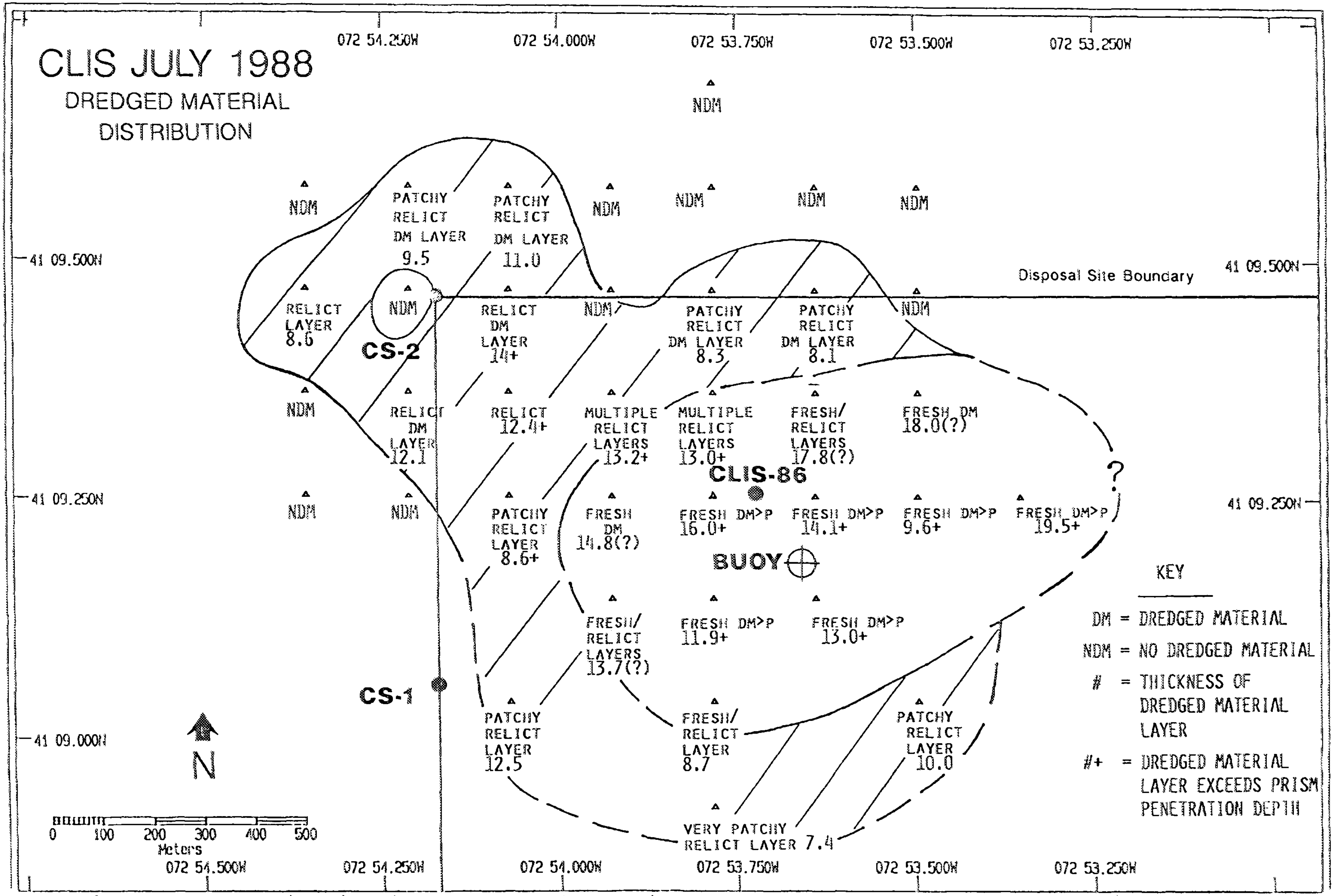


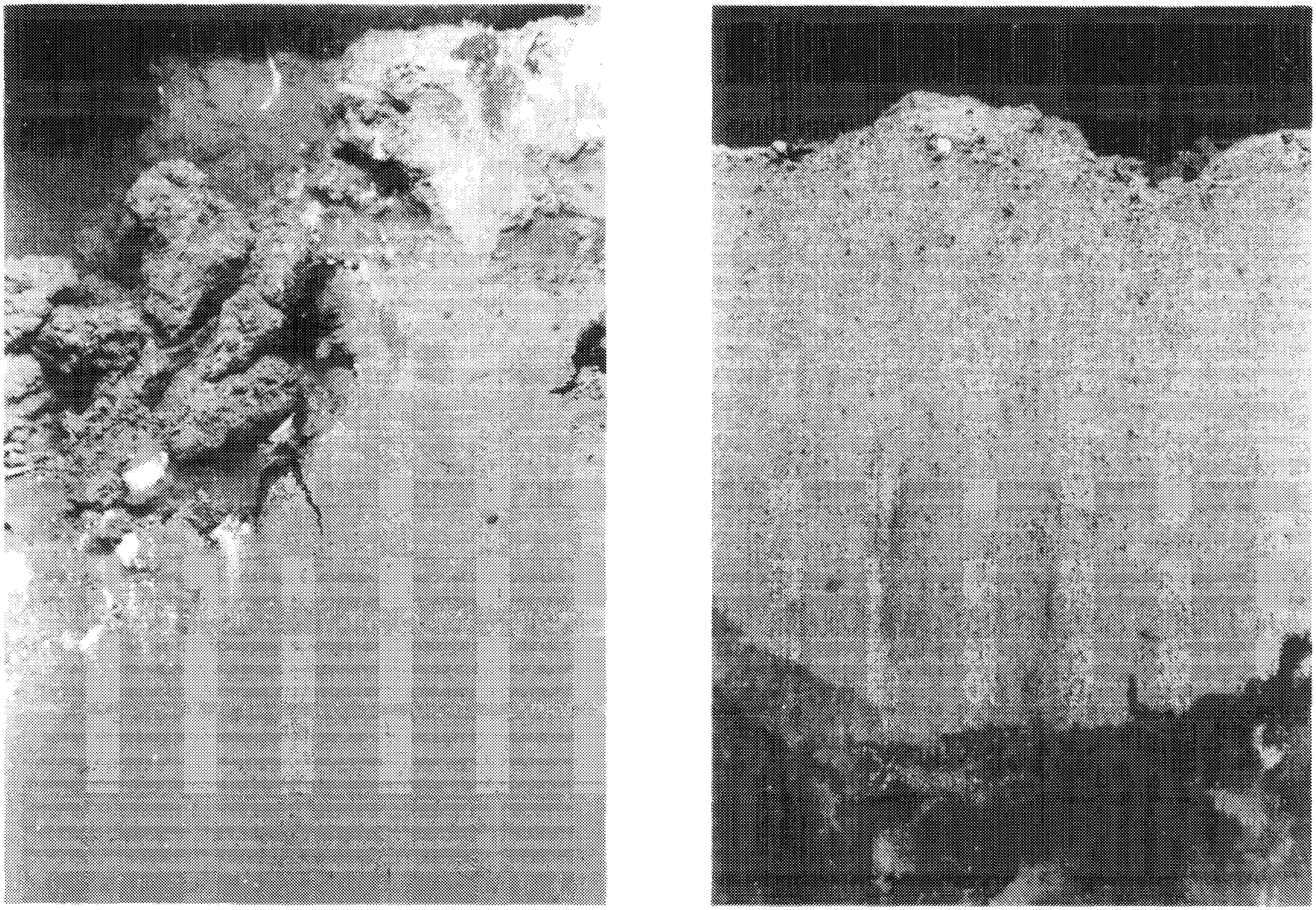
Figure 3-5. Distribution of dredged material at the northwest corner of CLIS in July 1988, as inferred from the REMOTS® photographs. The inner contour delimits stations having apparent "fresh" dredged material layers (i.e., deposited during the 1987-88 disposal season). Question marks reflect uncertainty in distinguishing between fresh dredged material layers and underlying relict layers at some stations.

A

B

Figure 3-6. REMOTS® photographs from station 4-800NW near the CS-2 mound (A) and from station 200N (B) showing bands of reduced sediment at depth representing relict dredged material layers. Arrows point to a burrow opening in photograph A and to a small feeding void in photograph B, giving both stations a Stage I on III successional designation. Scale of both images = 1X.

Figure 3-7. REMOTS® photograph from station 600E showing "fresh" dredged material exceeding the depth of penetration of the camera prism. The streaky appearance is due to smearing by the camera prism and the high water content of this fine-grained material. Scale = 1X.



A   B

Figure 3-8.   Two replicate REMOTS® photographs from station CTR illustrating heterogeneity in the freshly-disposed material. Photograph A shows clumps of consolidated silt-clay contributing to surface boundary roughness at this station. Photograph B shows a layer of well-sorted fine sand over reduced mud. Scale of images = 1X.

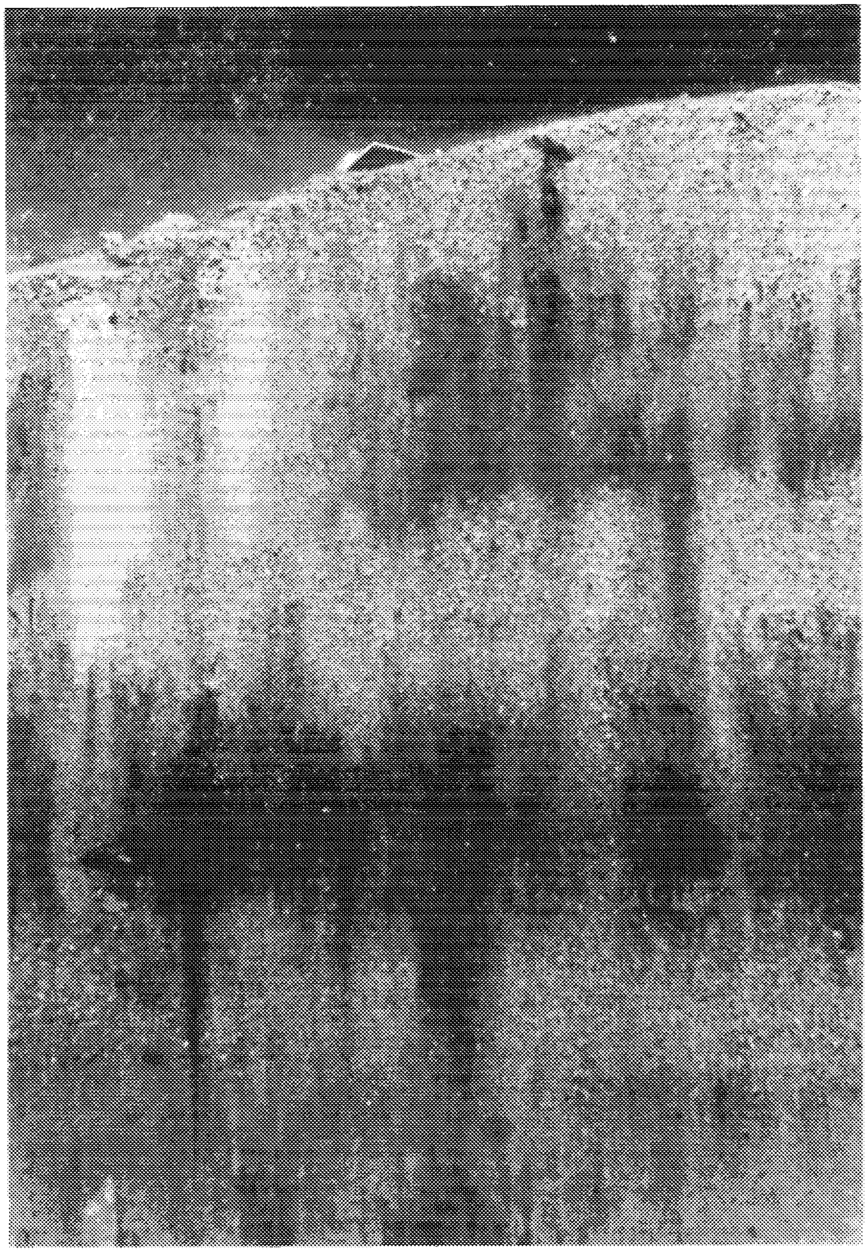


Figure 3-9. Alternating layers of fine sand and low-reflectance silt-clay at station 2-200NW. Scale of image = 1X.

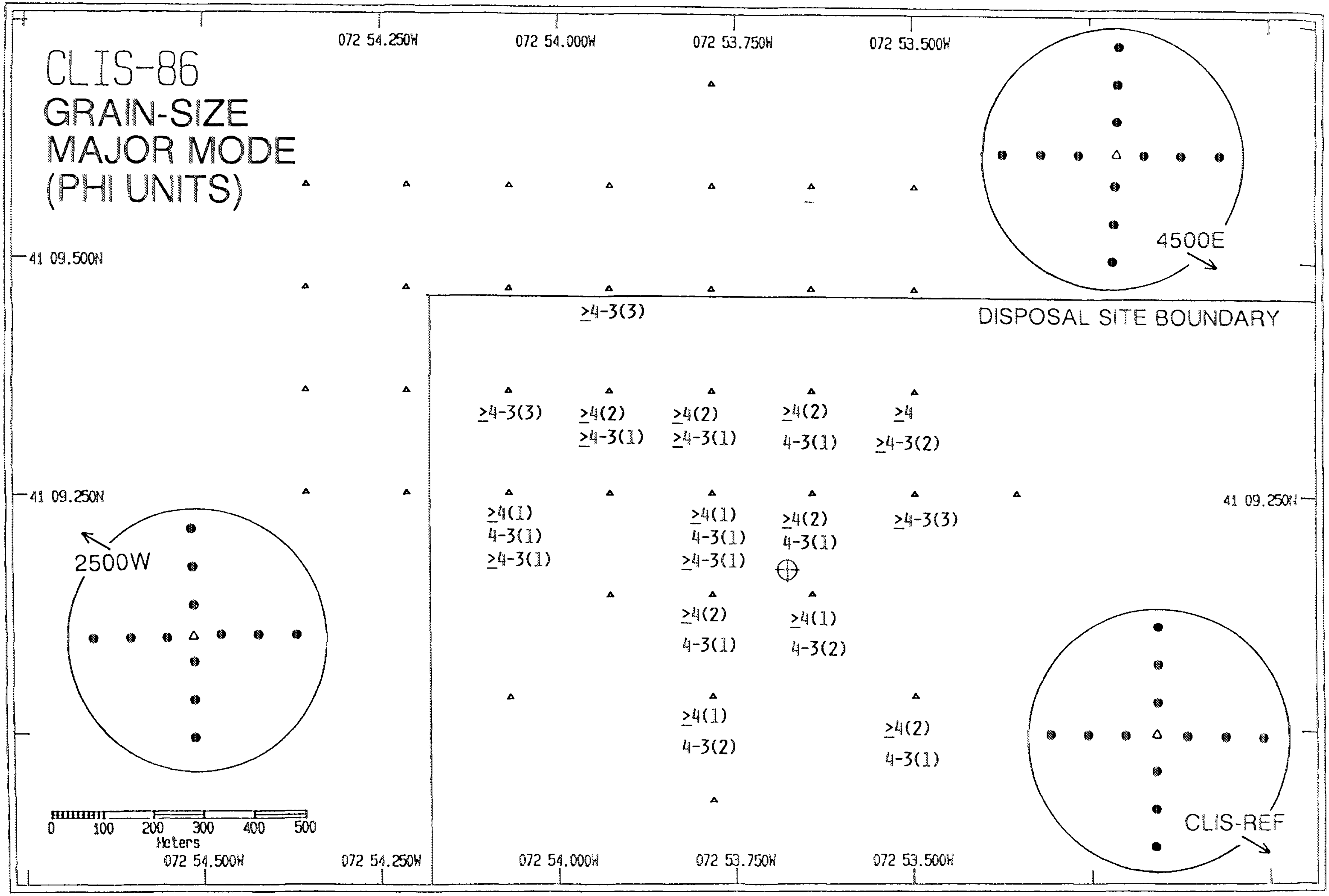
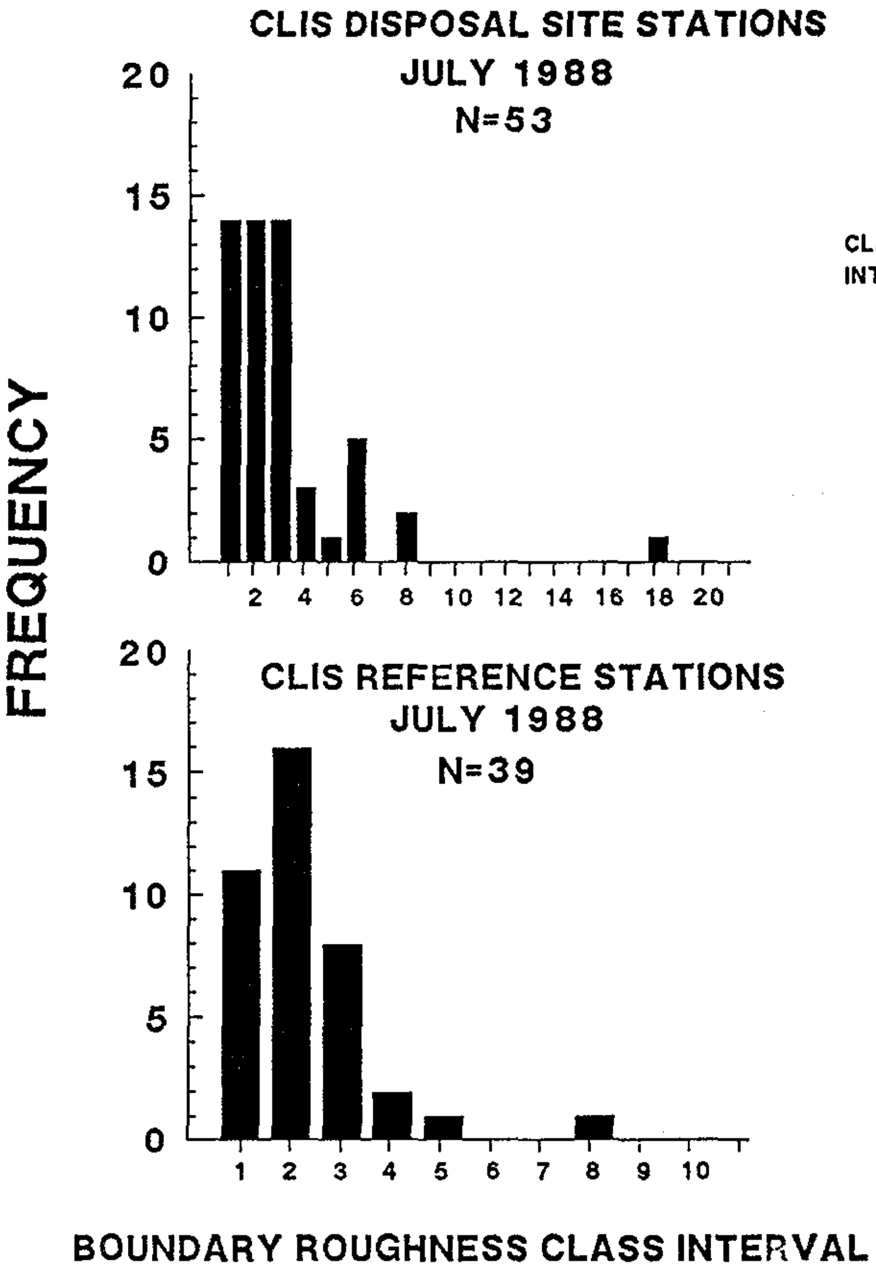


Figure 3-10. Map of sediment grain size major mode (in phi units) at the northwest corner of CLIS, July 1988. Only stations having major modes other than >4 phi (silt/clay) are indicated; the number in parenthesis is the number of replicate REMOTS® photographs showing a particular grain size.



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
15	5.8-6.2
16	6.2-6.6
17	6.6-7.0
18	7.0-7.4
19	7.4-7.8
20	7.8-8.2
21	8.2-8.6
22	8.6-9.0

Figure 3-11. Frequency distributions of small-scale surface boundary roughness values for all replicates at both the reference and disposal site stations (i.e., within the disposal site boundary) at CLIS, July 1988 (n = number of replicates).

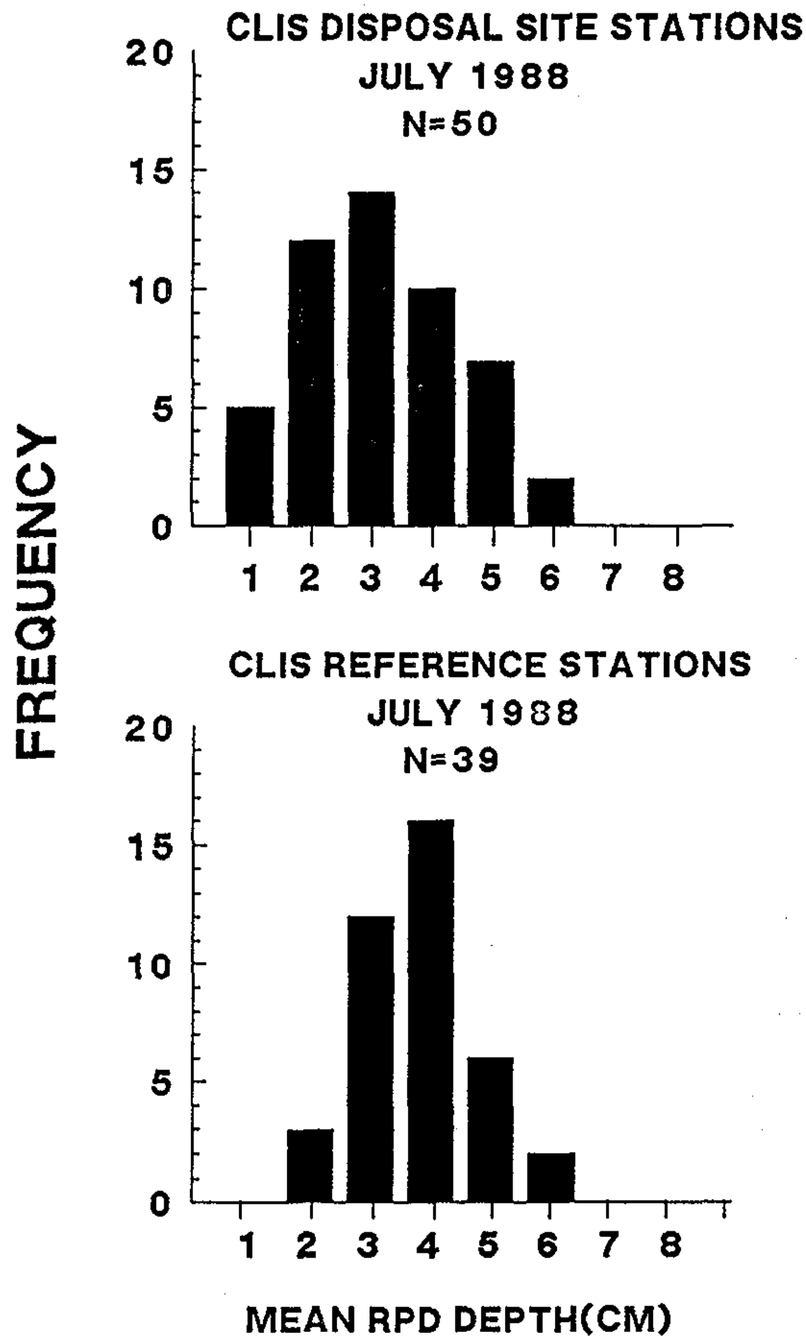


Figure 3-12. Frequency distributions of apparent RPD depths for all replicates at both the reference and disposal site stations at CLIS, July 1988 (n = number of replicates).

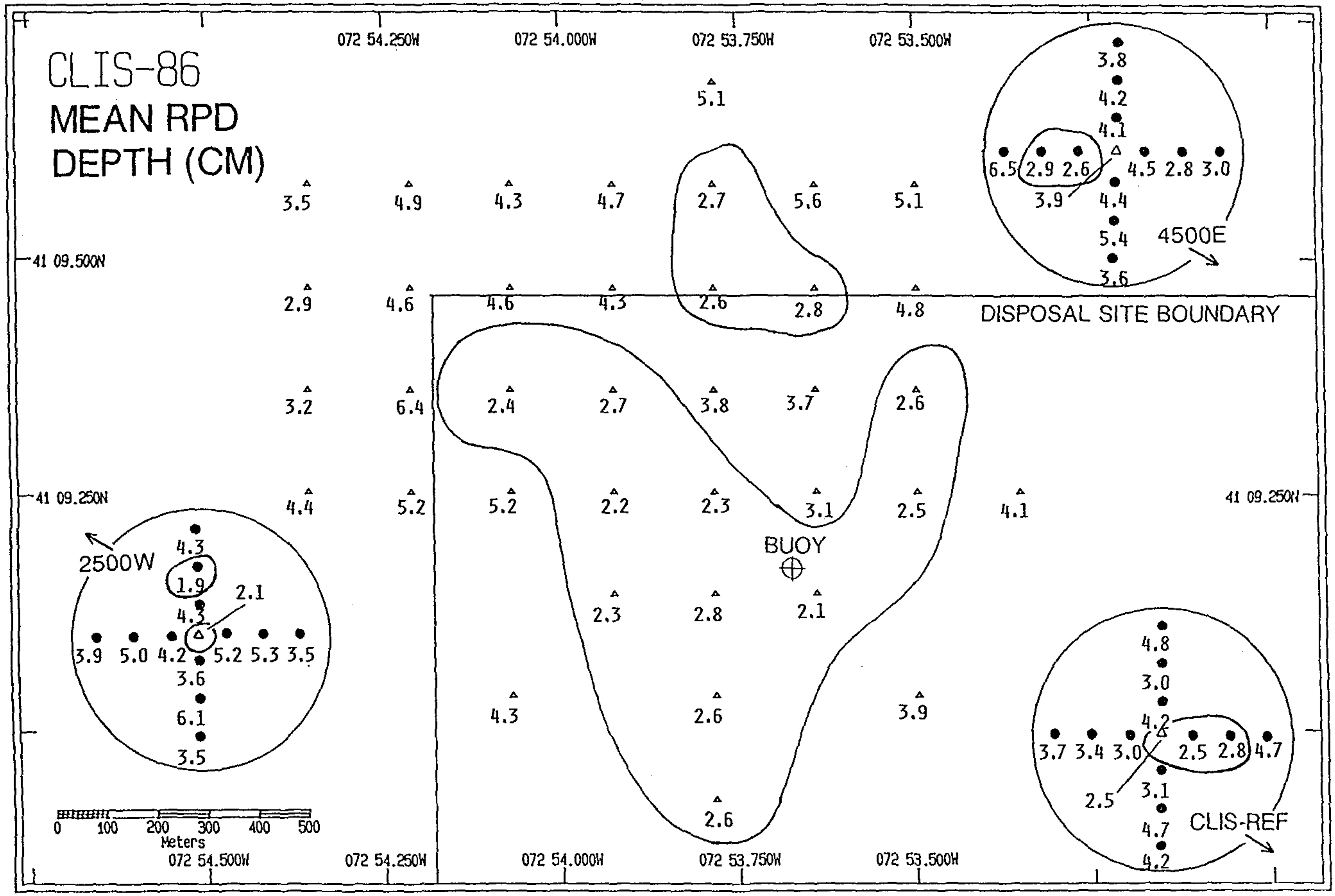


Figure 3-13. The mapped distribution of apparent RPD depths (cm), averaged by station, at CLIS in July 1988. The contours delimit stations having mean apparent RPD depths < 3 cm. At the reference stations, the mapped RPD value was based on a single REMOTS® photograph.

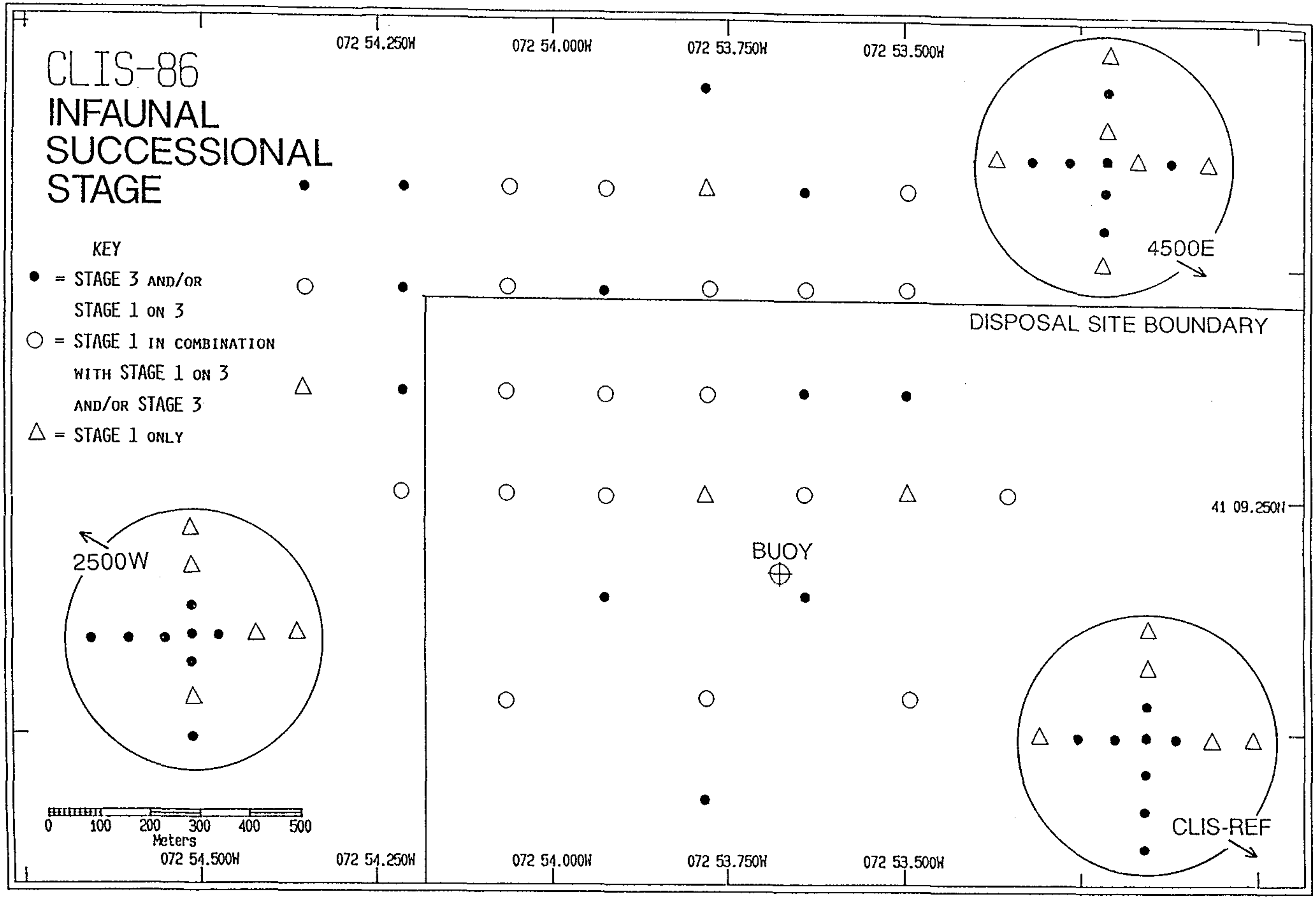


Figure 3-14. The mapped distribution of infaunal successional stages at CLIS, July 1988. Successional stages mapped at the reference stations were based on a single REMOTS® photograph.

Figure 3-15. The large feeding void at depth indicates the presence of Stage III organisms in this REMOTS® photograph from the disposal site. A shrimp also is visible at the sediment surface. Scale = 1X.

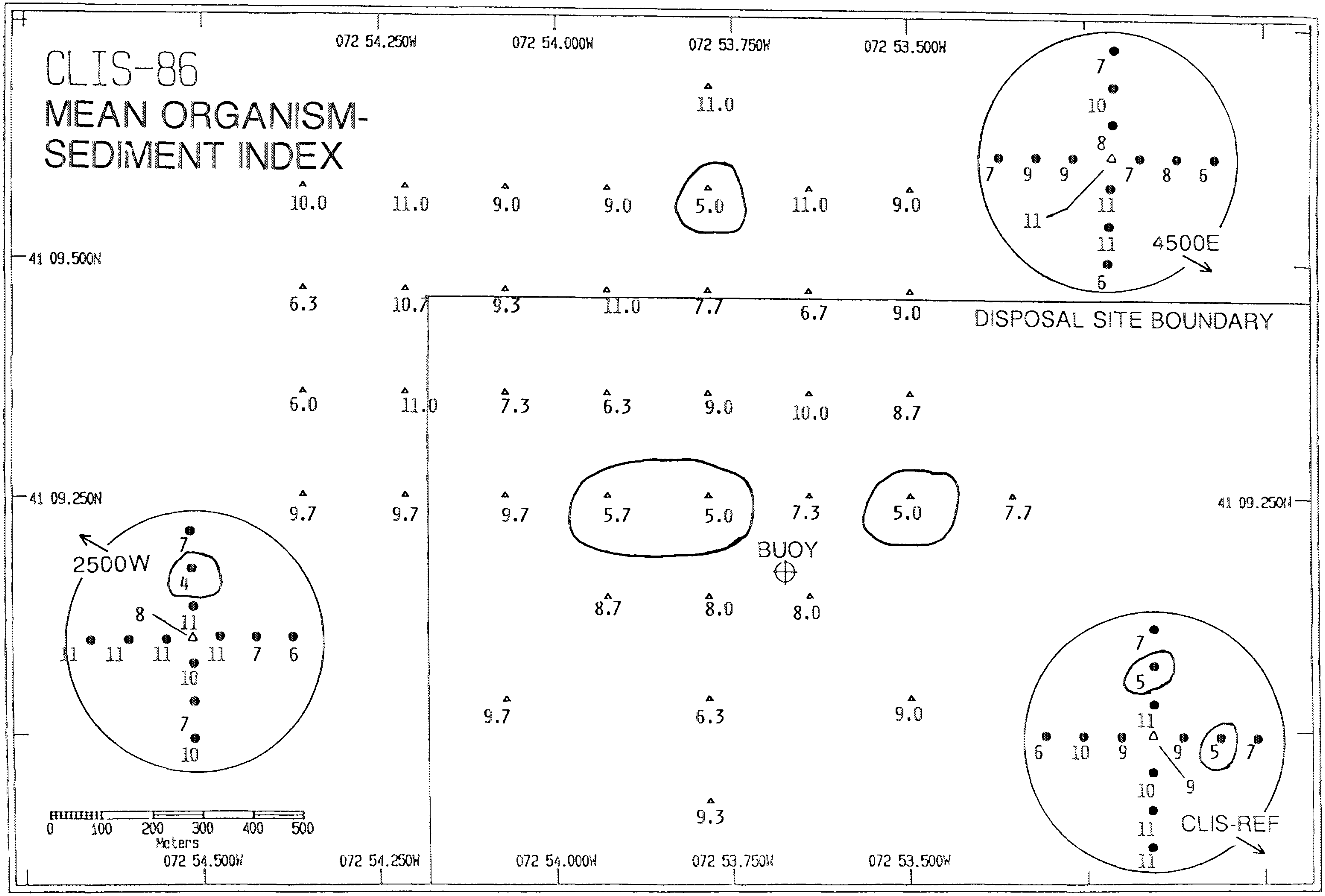


Figure 3-16. The distribution of Organism-Sediment Indices, averaged by station, at CLIS in July 1988. OSI values at the reference stations were calculated based on a single REMOTS® photograph. Contours delimit OSI values < +6.

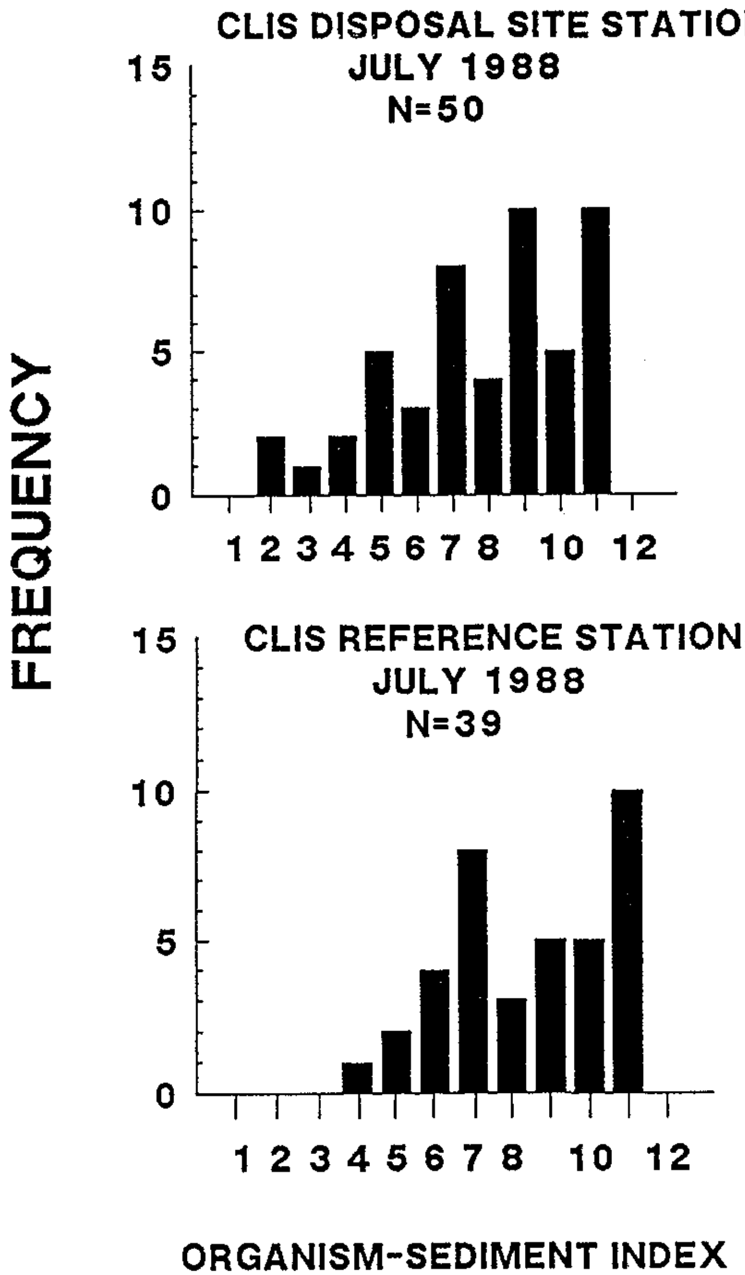


Figure 3-17. Frequency distributions of Organism-Sediment Indices for all replicates at both the reference and disposal site stations at CLIS, July 1988 (n = number of replicates).

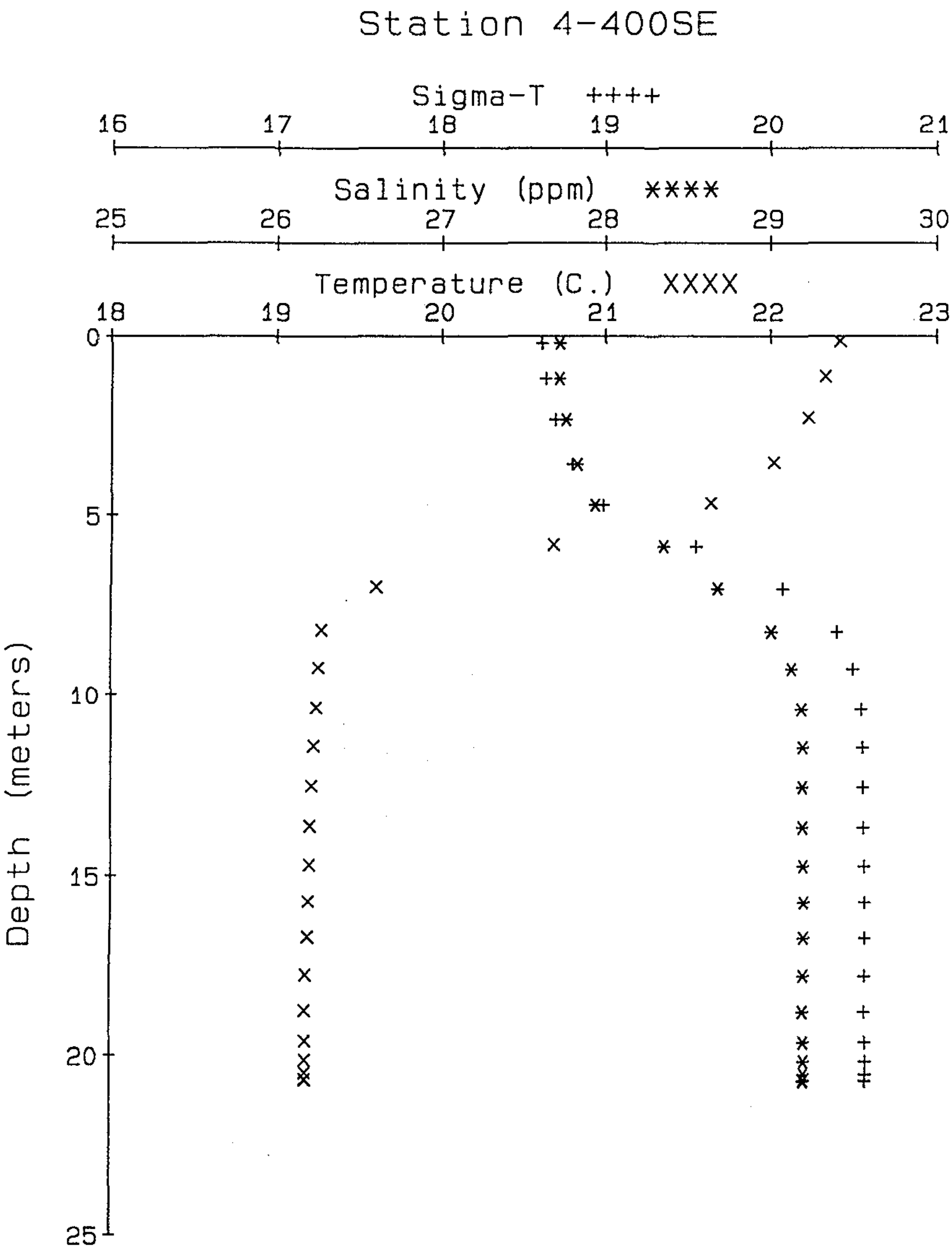


Figure 3-18. **Representative CTD plot obtained at CLIS station 4-400SE on 27 July 1988.**

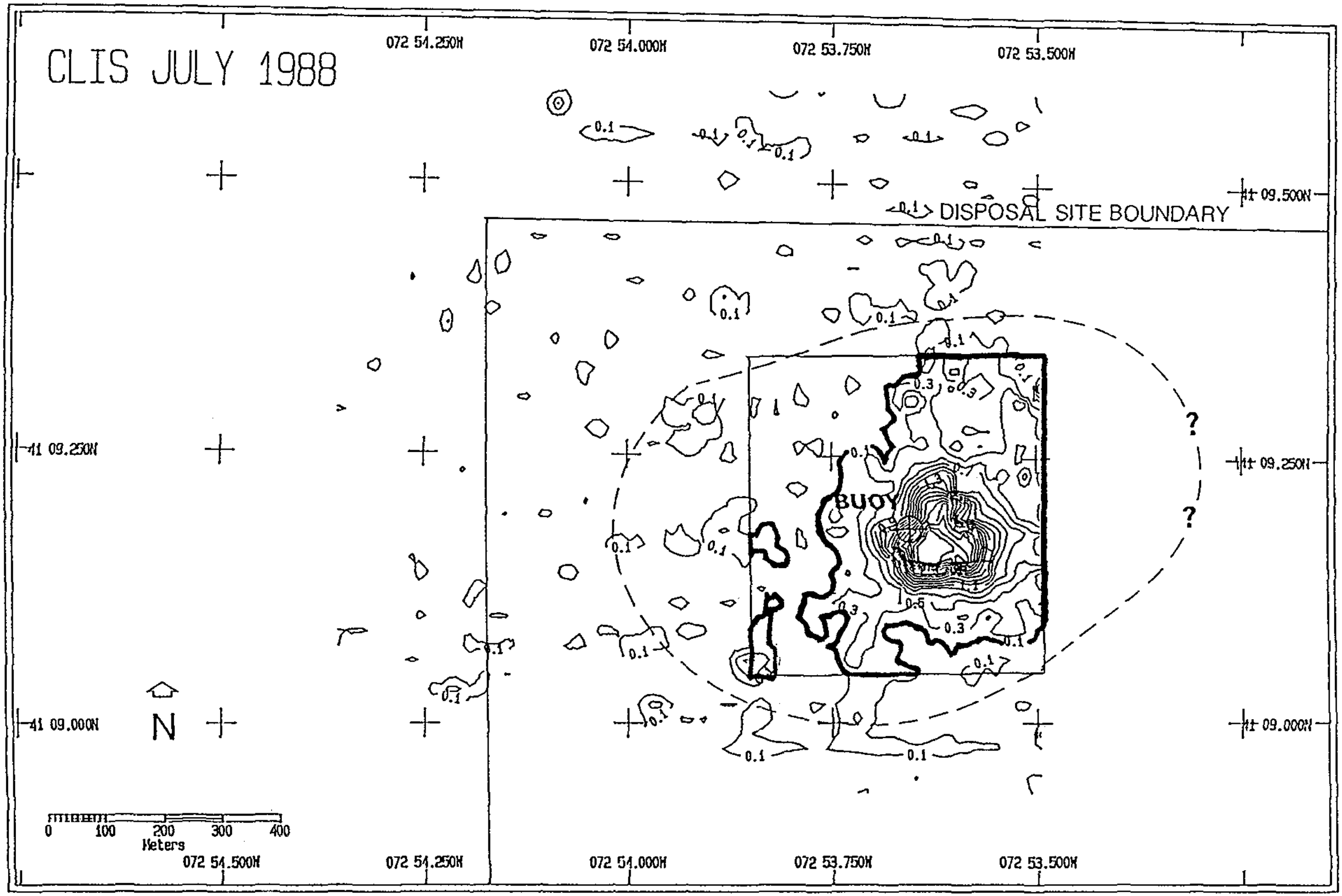


Figure 4-1. Depth difference (in meters) contour map based on comparision of the August 1987 and July 1988 precision bathymetric surveys in the northwest corner of CLIS. The 500 X 500 meter square area encompassing the new mound is outlined (see Figure 3-3). Changes in depth inside the area outlined by the heavy black line resulted in the "depth difference" estimate of dredged material volume. The broken line indicates the extent of the new mound as determined by REMOTS® (see Figure 3-5). Question marks indicate that the extent of the new deposit to the east was indeterminate.

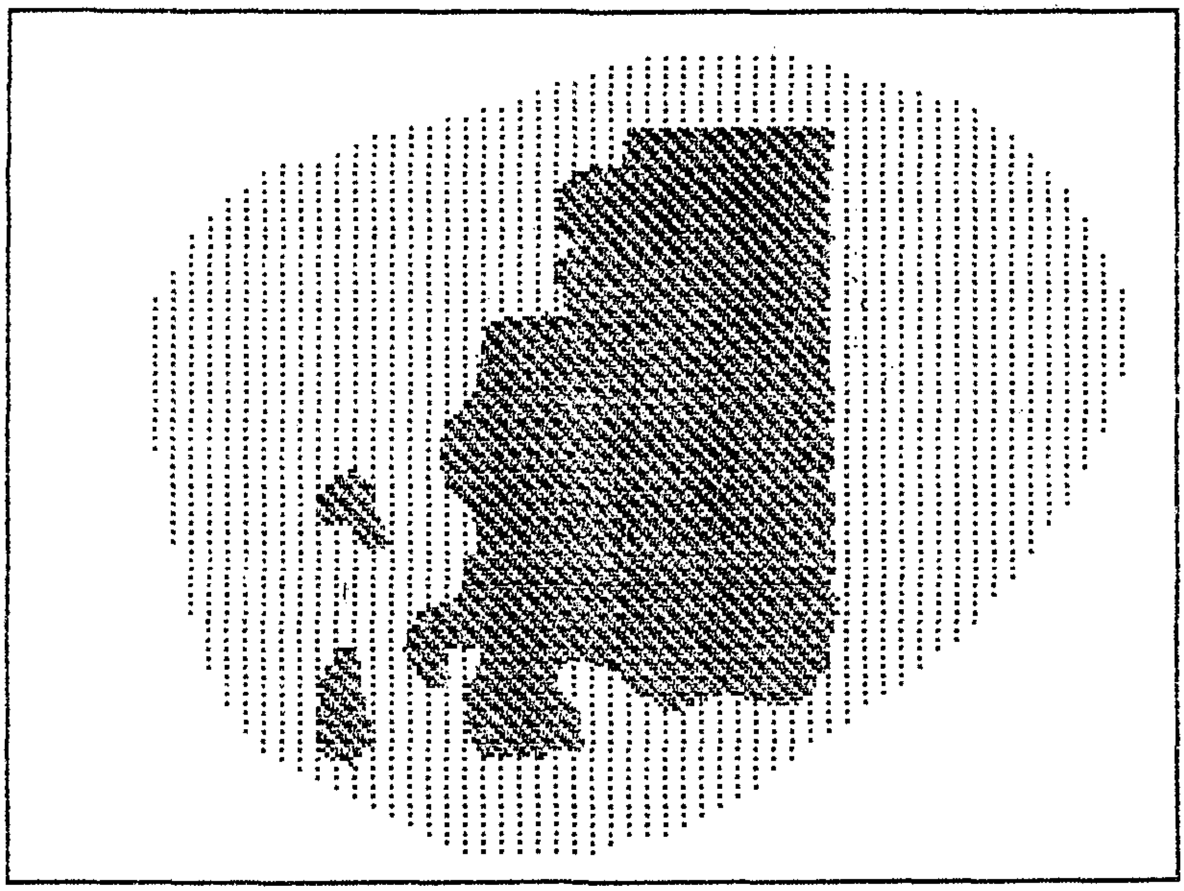
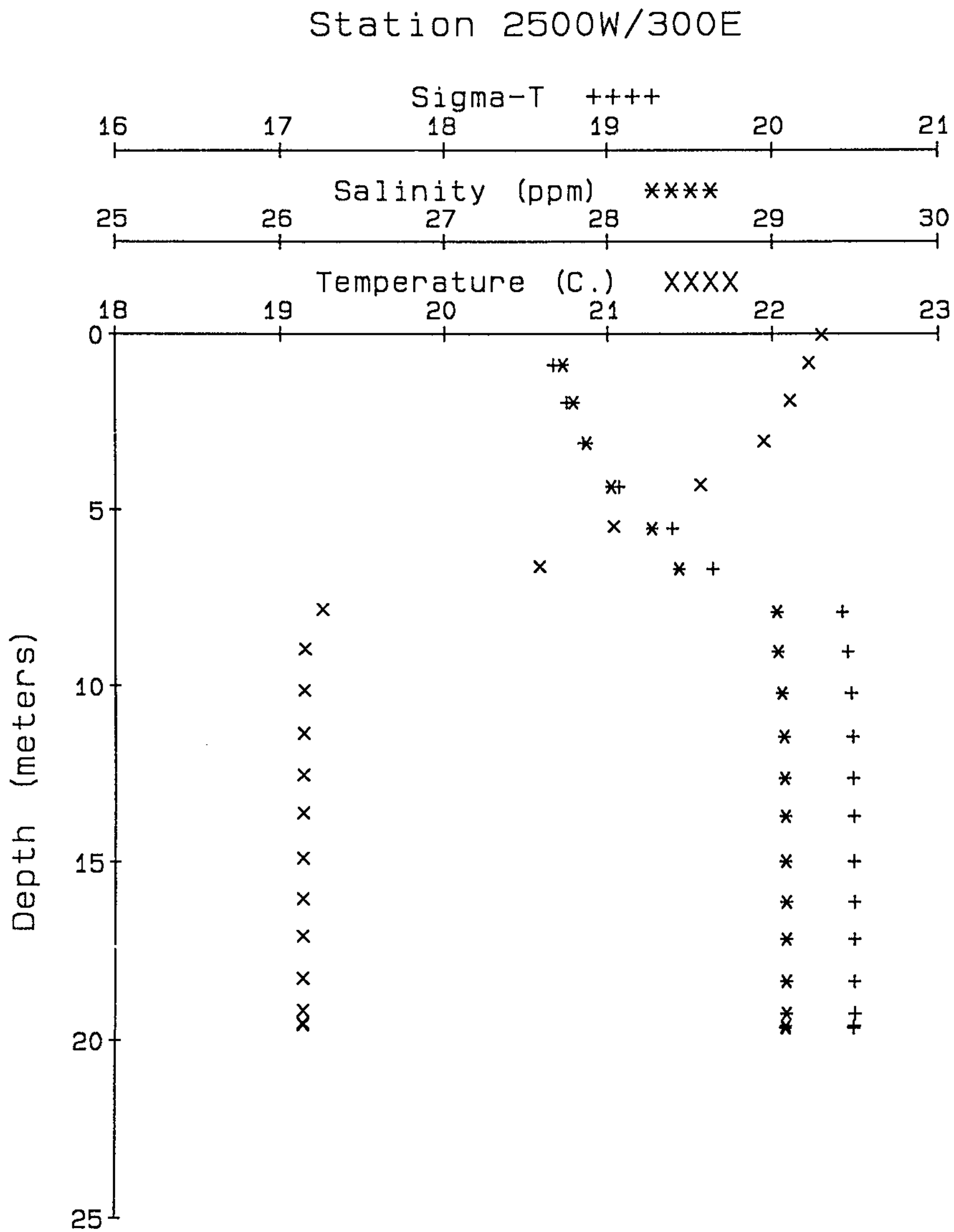
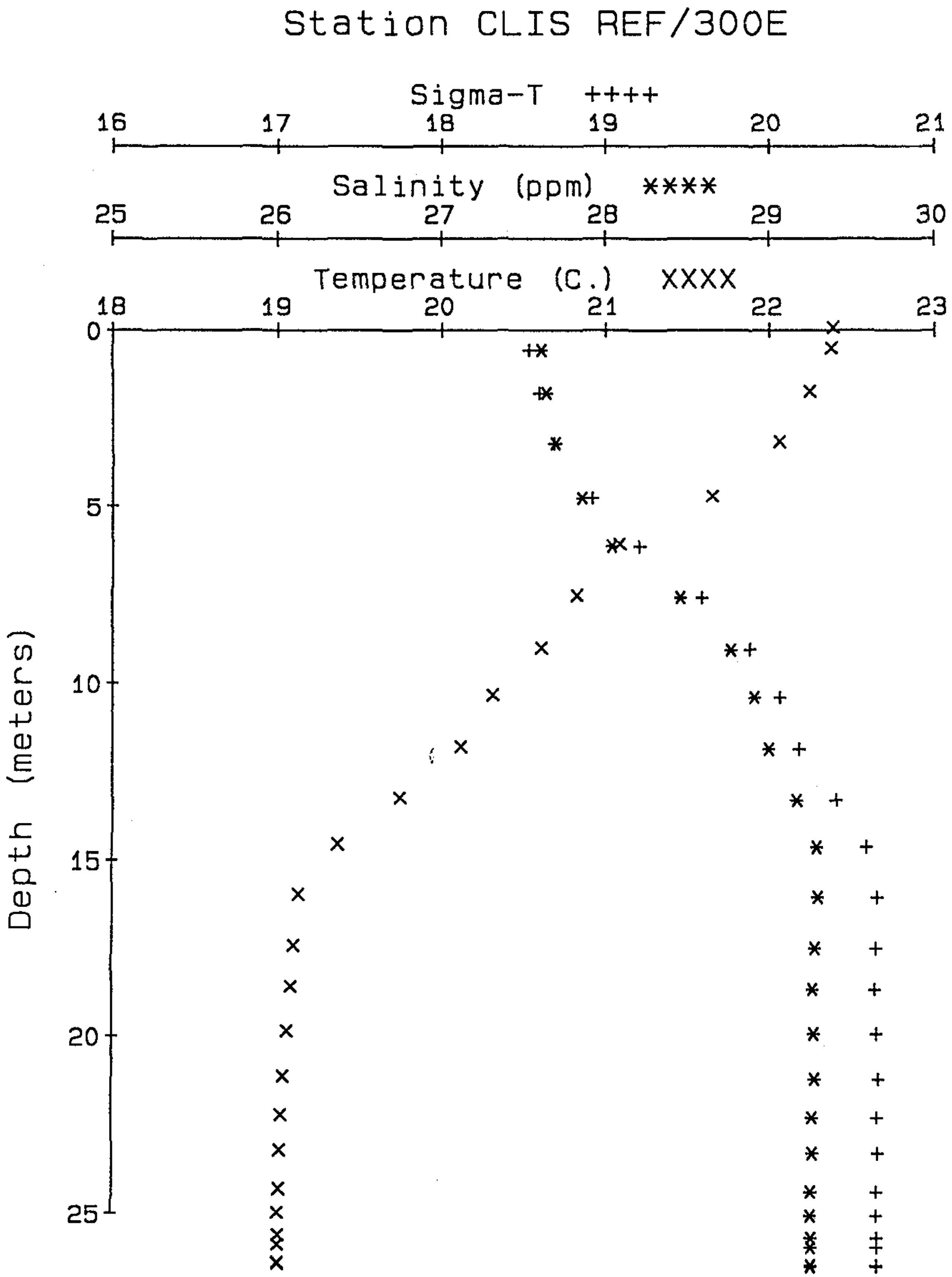


Figure 4-2. Computer digitized representation of the new mound based on Figure 4-1. The dark-shaded area measured 176,861 m^2; changes in depth determined by acoustic methods within this area were used to calculate the "depth difference" estimate of dredged material volume. The lighter-shaded area measured 334,912 m^2; this is the mound flank as determined by REMOTS®.

APPENDIX



Station 2500W/300E
Sigma-T ++++
16 17 18 19 20 21
Salinity (ppm) ****
25 26 27 28 29 30
Temperature (C.) XXXX
18 19 20 21 22 23
Depth (meters)
0 5 10 15 20 25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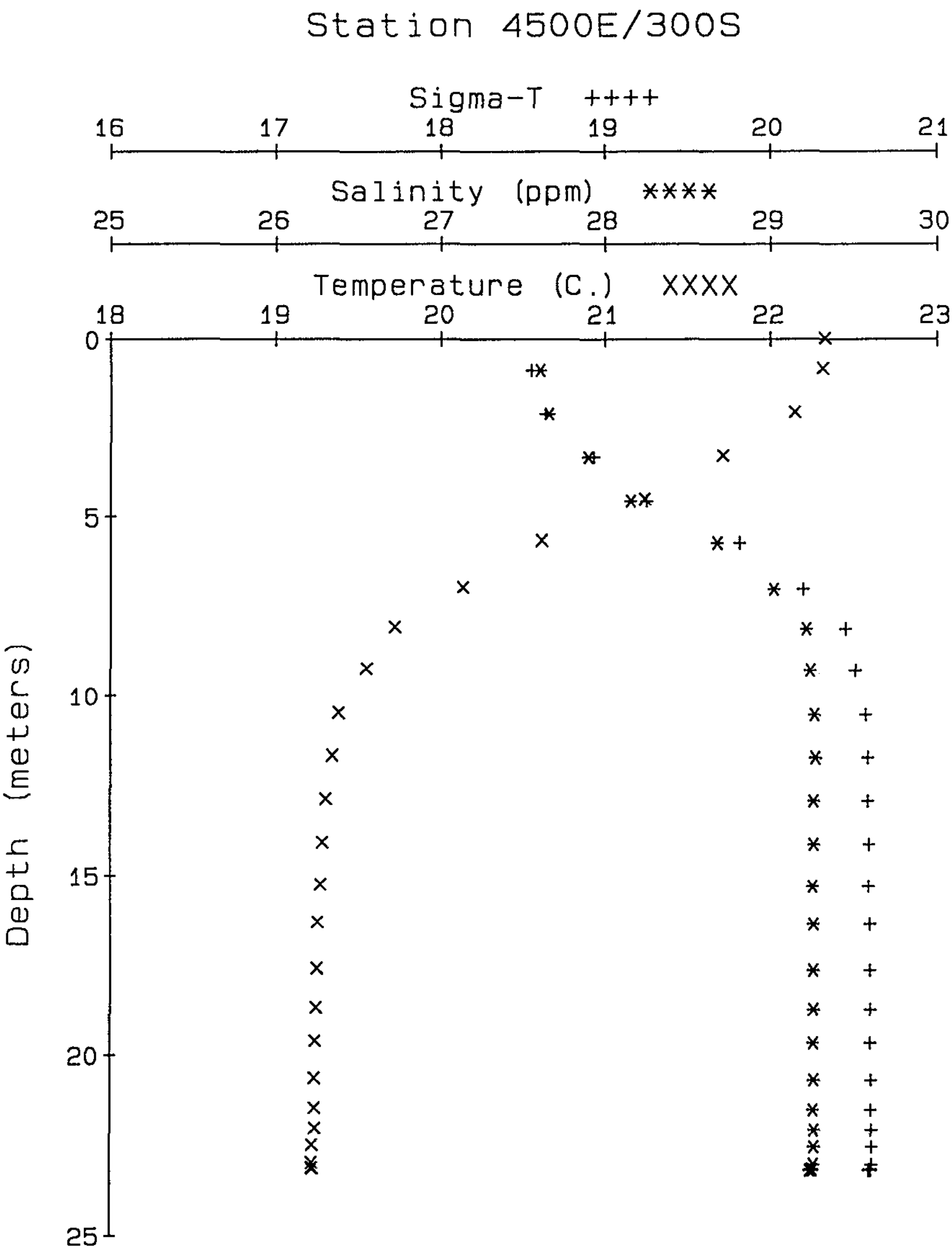
Sigma-T ++++
16
17
18
19
20
21
Salinity (ppm) ****
25
26
27
28
29
30
Temperature (C.) XXXX
18
19
20
21
22
23
Depth (meters)
0
5
10
15
20
25



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Sigma-T ++++
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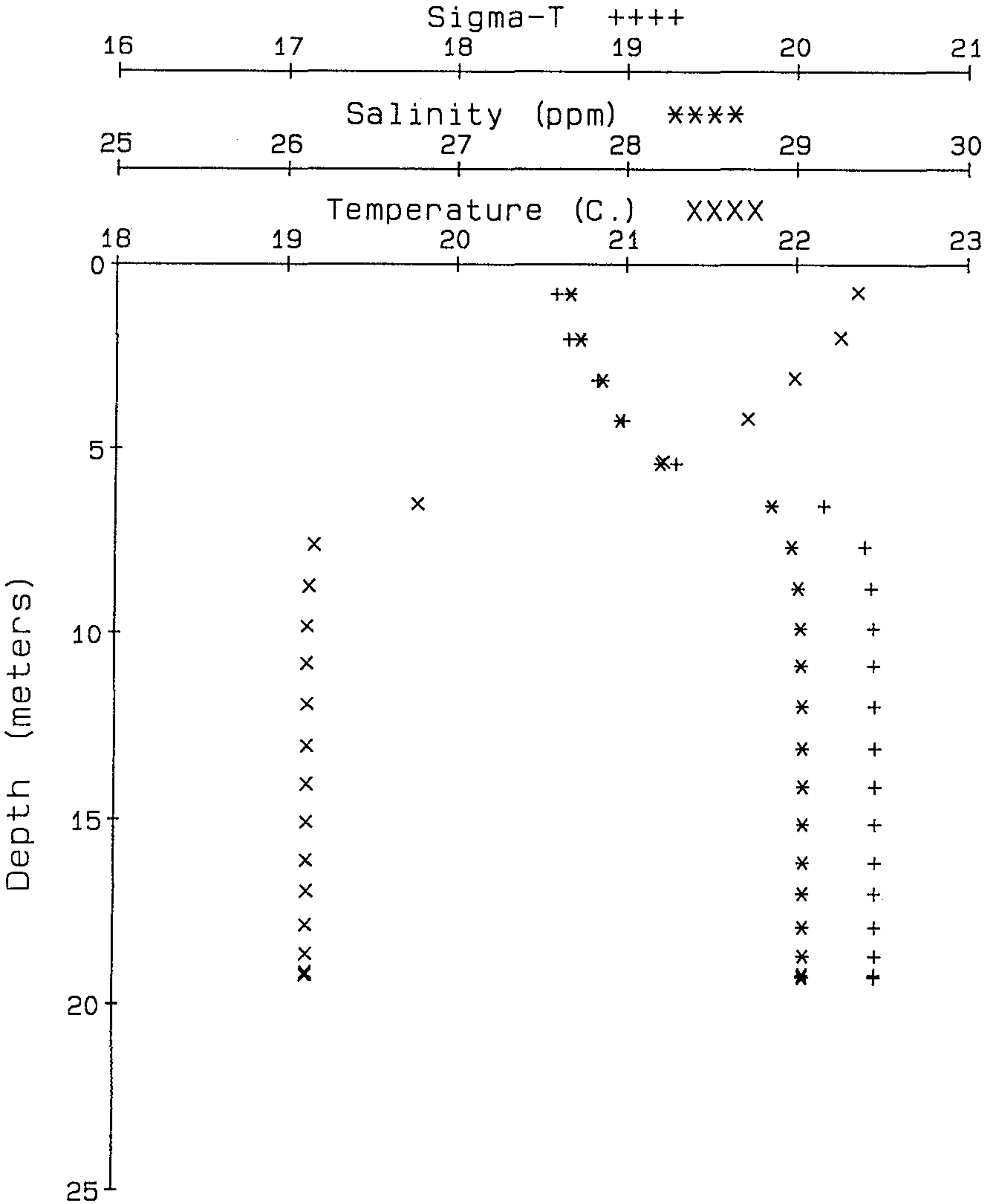
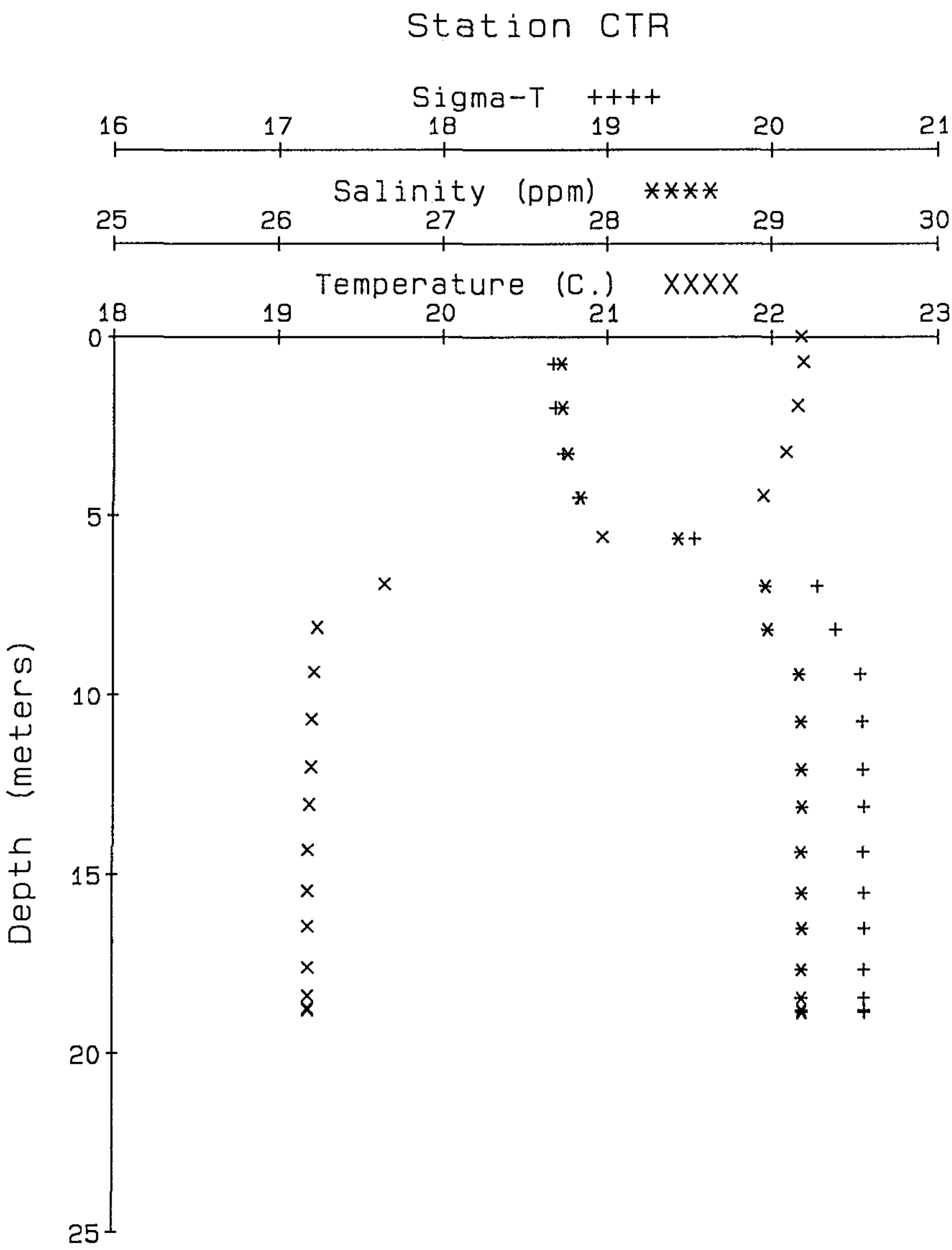
17
18
19
20
21
Salinity (ppm) ****
25
26
27
28
29
30
Temperature (C.) XXXX
18
19
20
21
22
23
0
5
10
15
20
25
Depth (meters)

Station 2500W/300N

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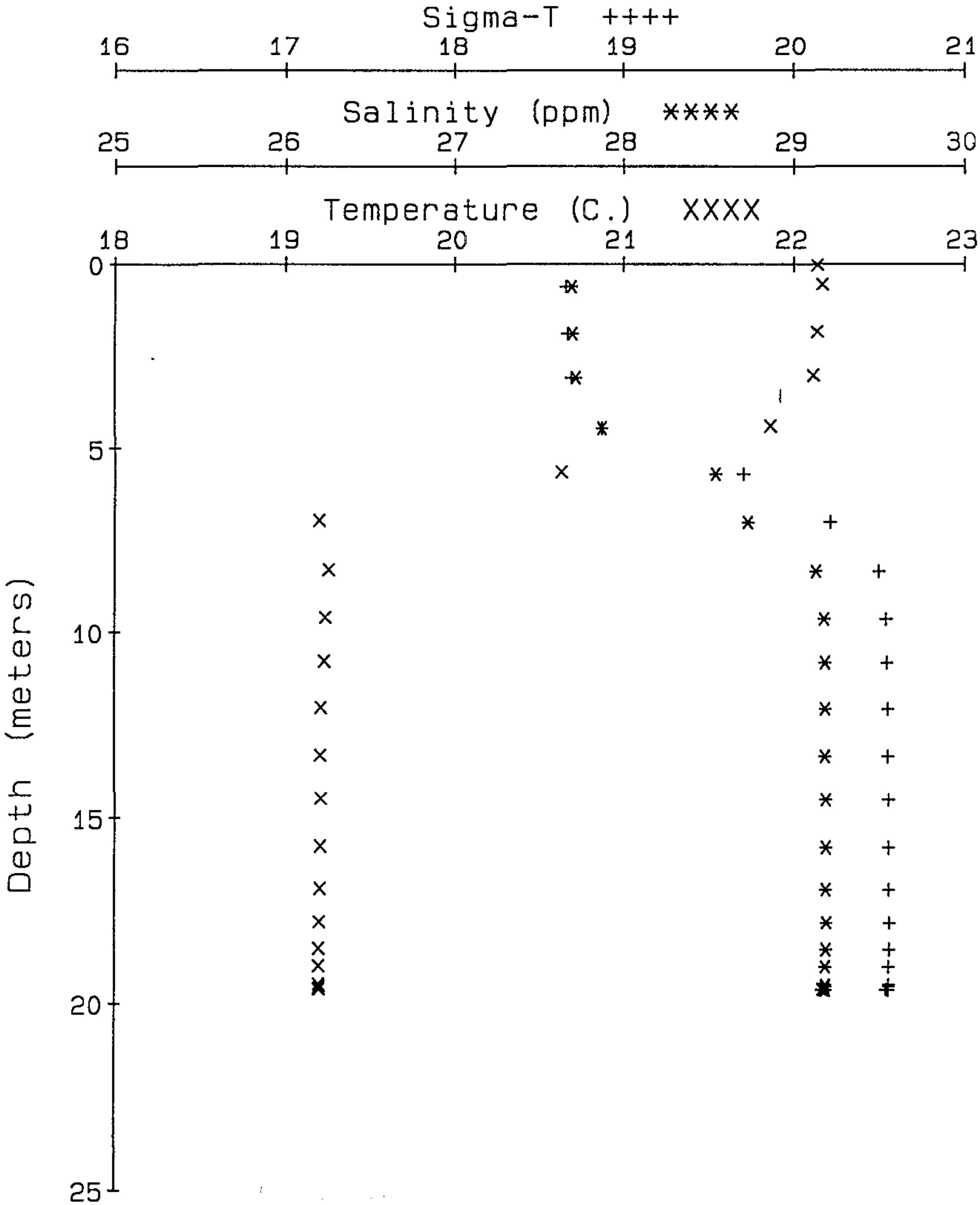
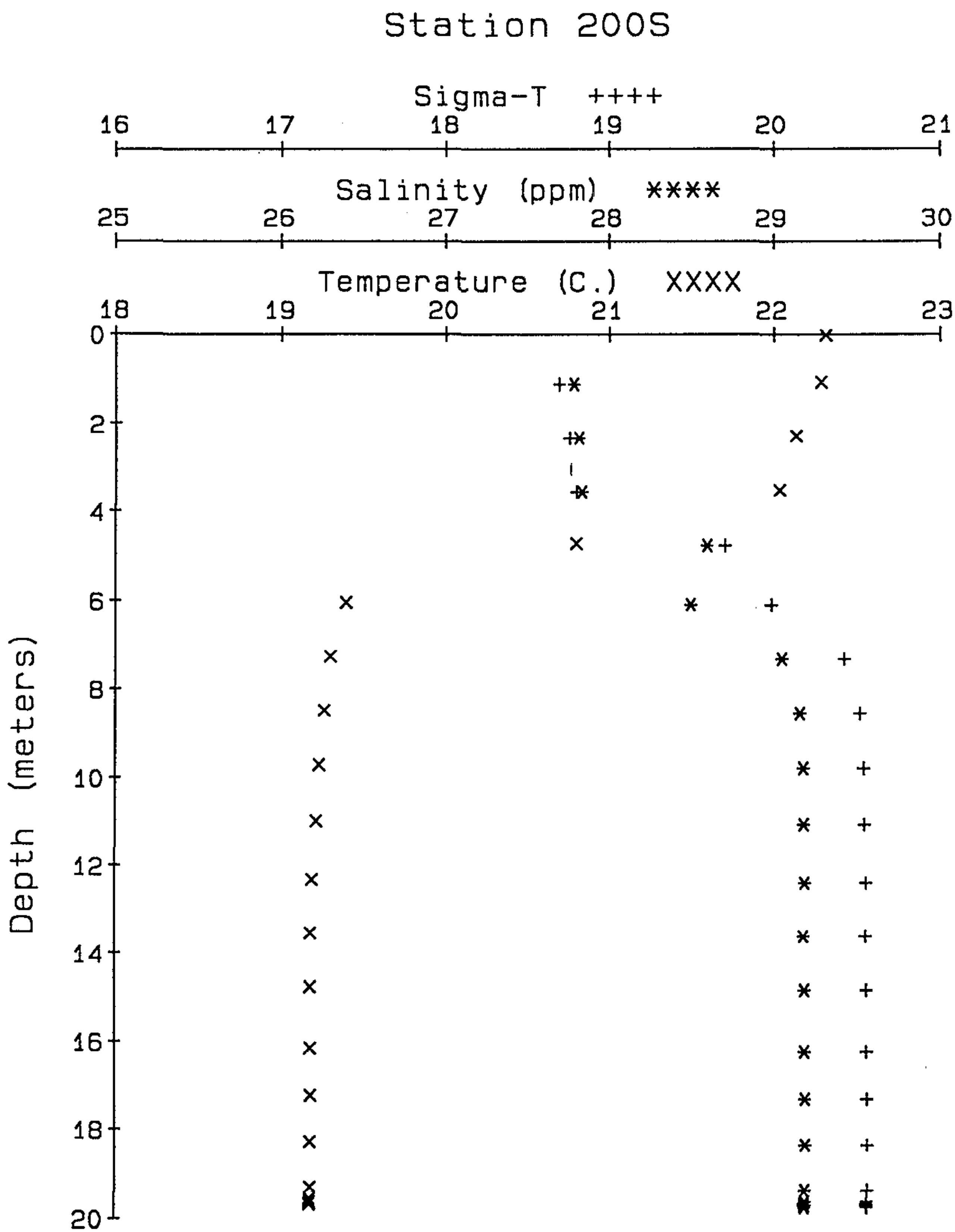
Sigma-T ++++
16
17
18
19
20
21
Salinity (ppm) ****
25
26
27
28
29
30
Temperature (C.) XXXX
18
19
20
21
22
23
0
5
10
15
20
25
Depth (meters)

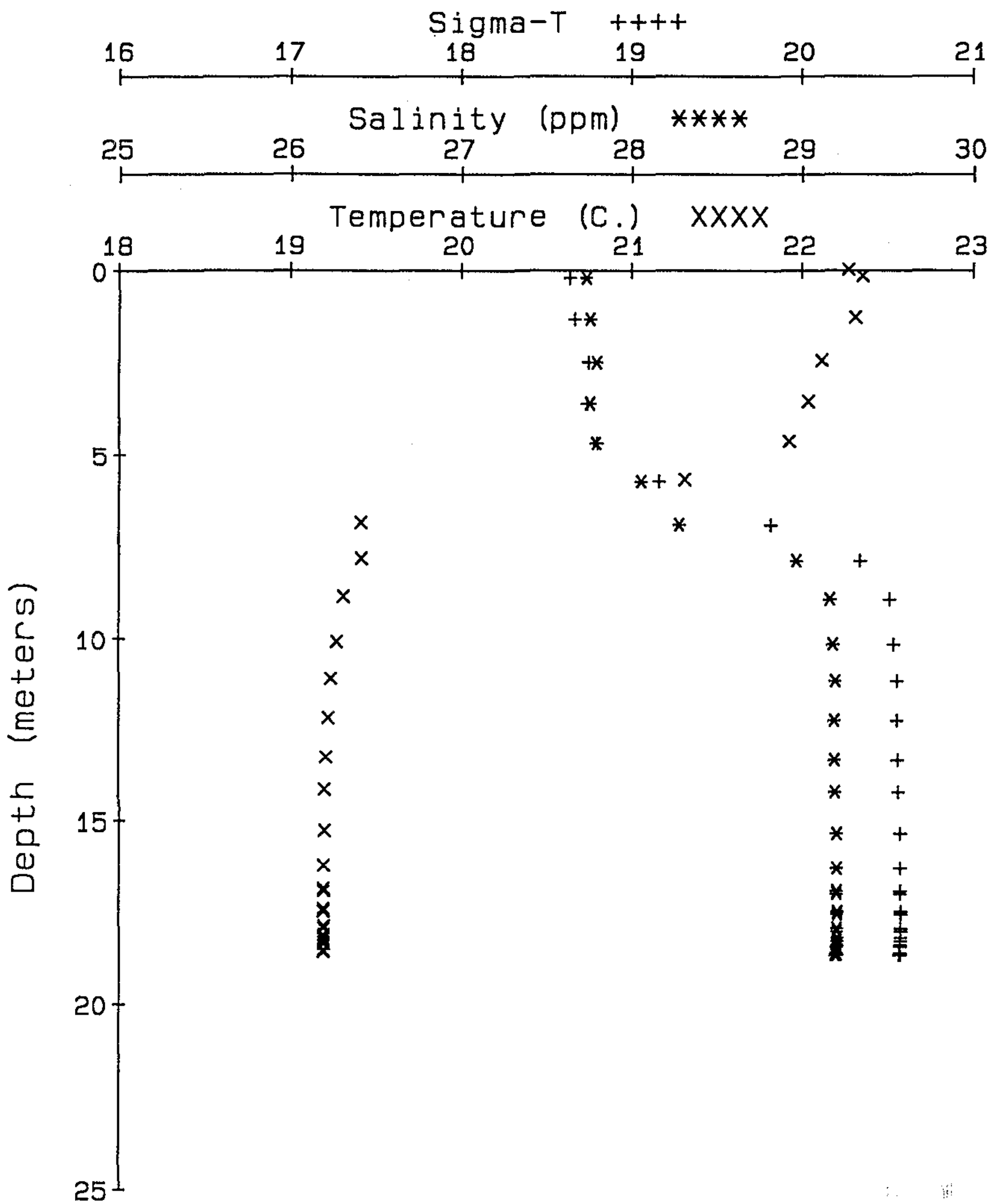
Station 200E

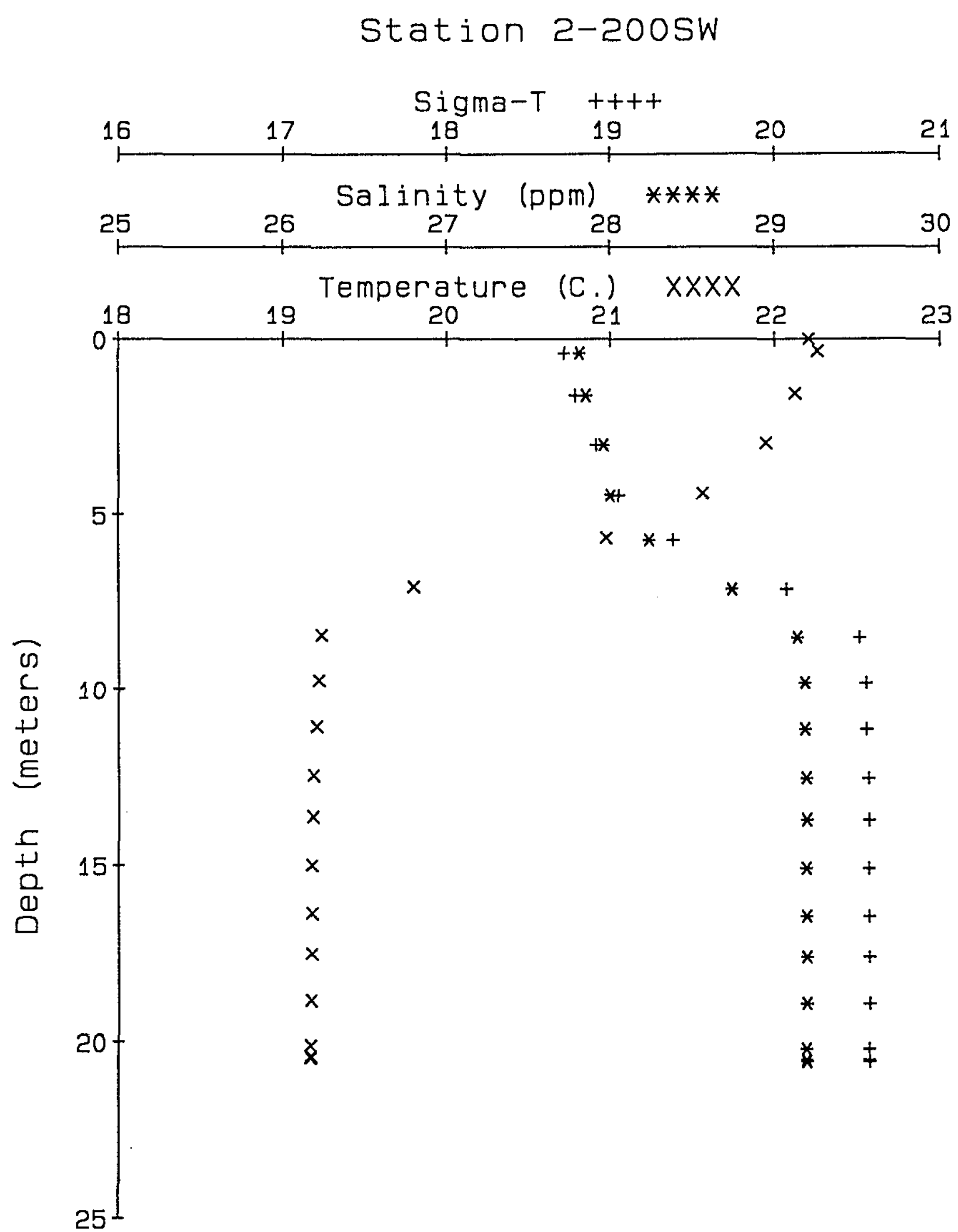




Station 200S
Sigma-T ++++
16
17
18
19
20
21
Salinity (ppm) ****
25
26
27
28
29
30
Temperature (C.) XXXX
18
19
20
21
22
23
0
2
4
6
8
10
12
14
16
18
20
Depth (meters)

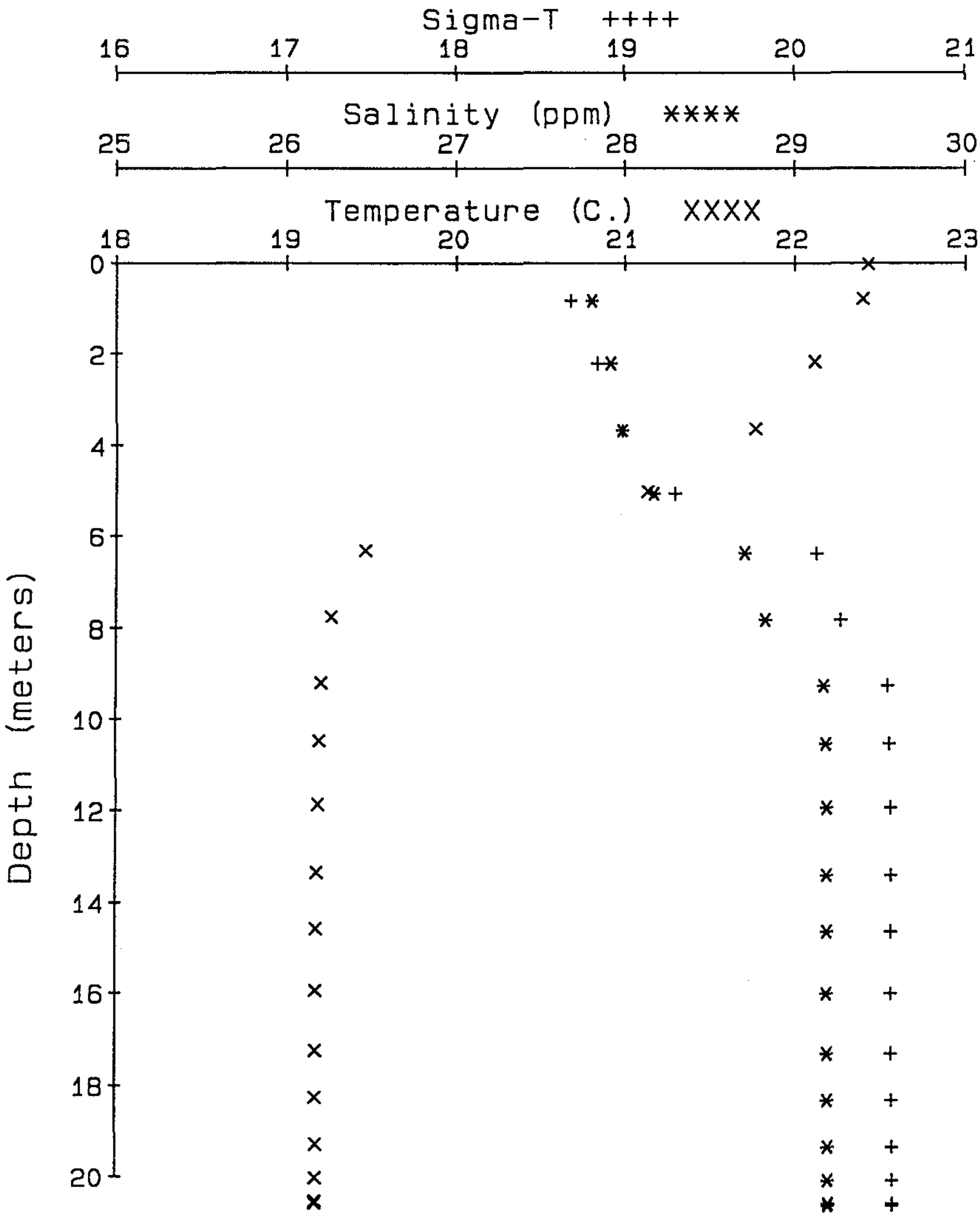
Station 2-200SE

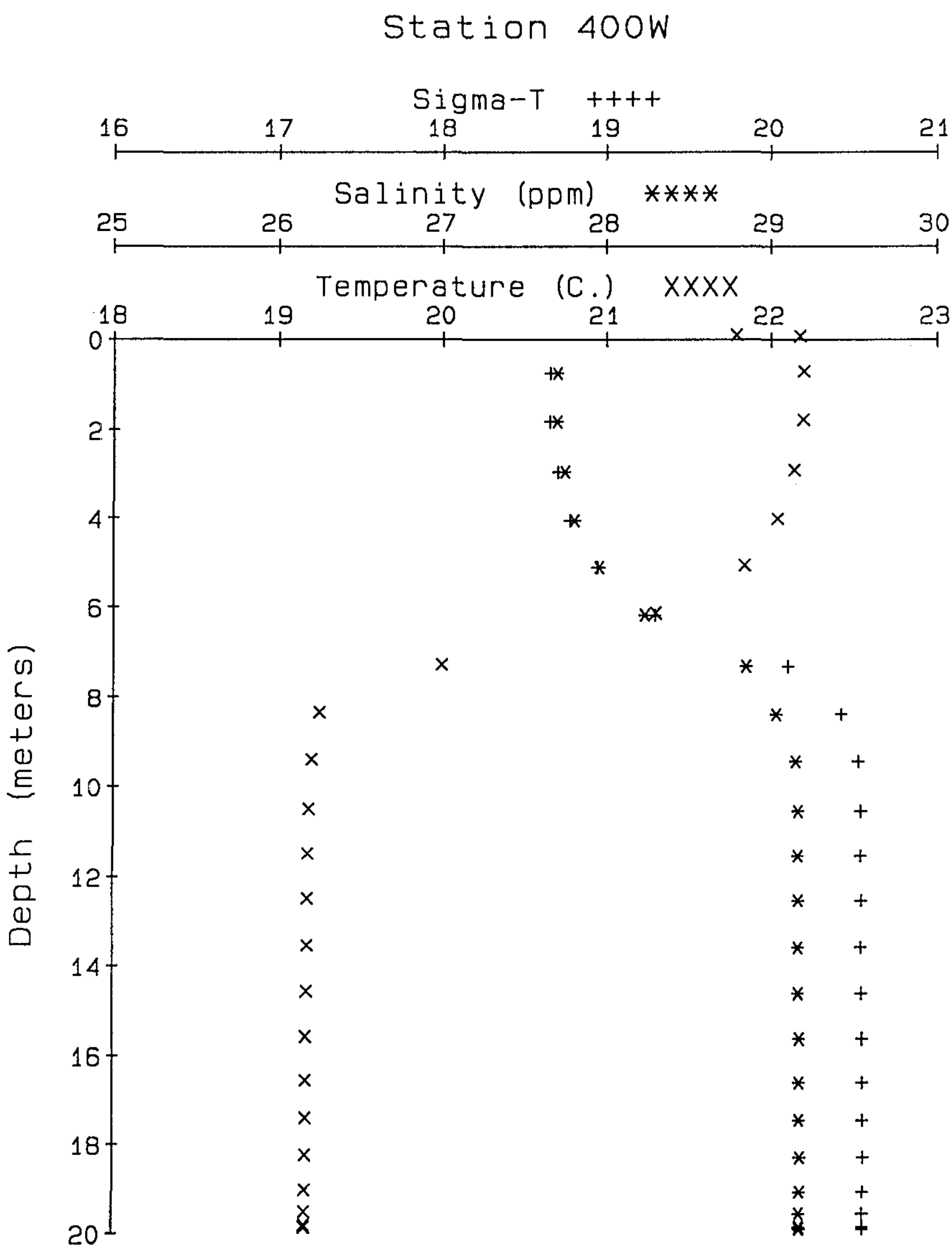




Station 2-200SW
Sigma-T ++++
16
17
18
19
20
21
Salinity (ppm) ****
25
26
27
28
29
30
Temperature (C.) XXXX
18
19
20
21
22
23
0
5
10
15
20
25
Depth (meters)

Station 400S

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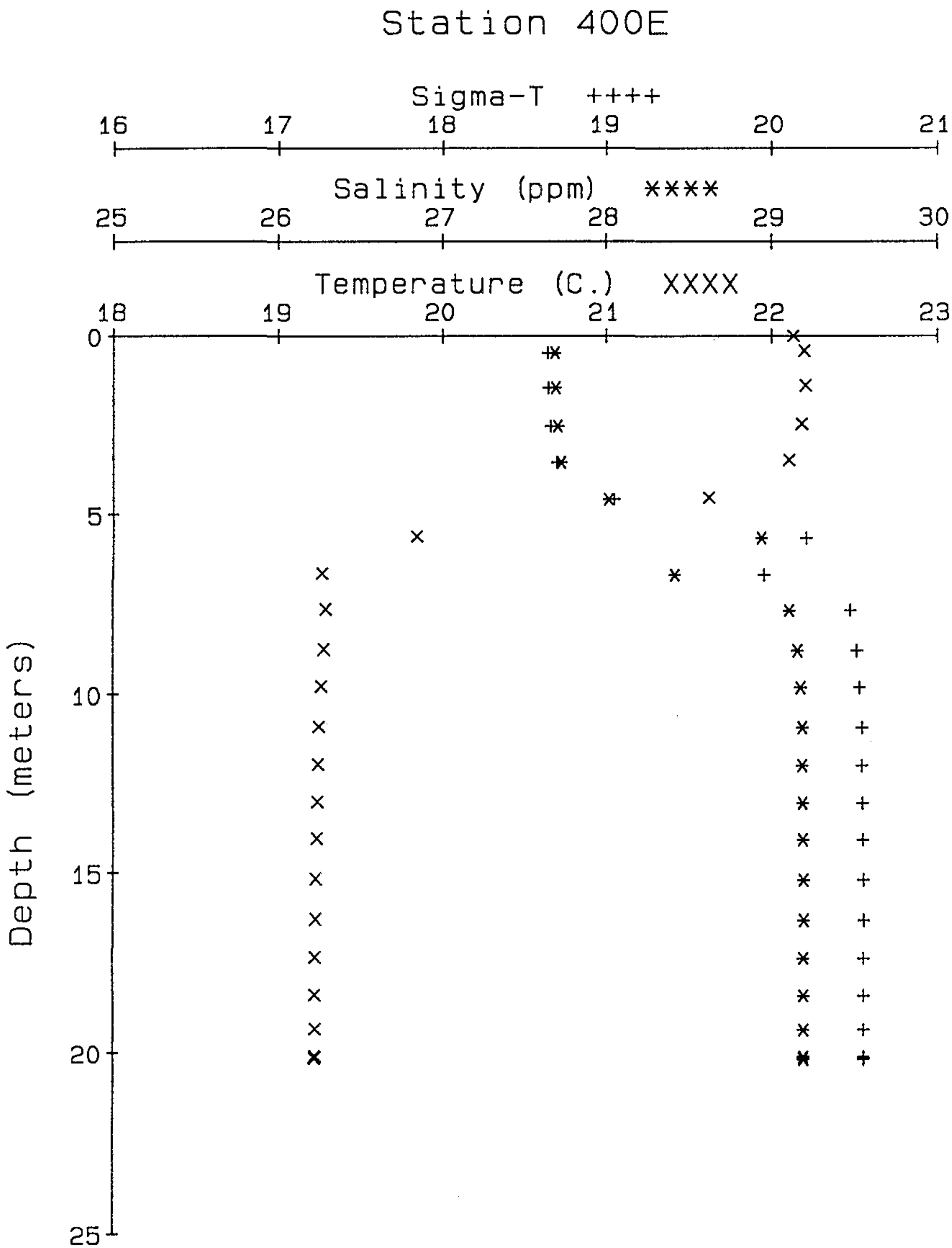
Sigma-T ++++
16 17 18 19 20 21
Salinity (ppm) ****
25 26 27 28 29 30
Temperature (C.) XXXX
18 19 20 21 22 23
Depth (meters)
0 2 4 6 8 10 12 14 16 18 20


Station 400E
Sigma-T ++++
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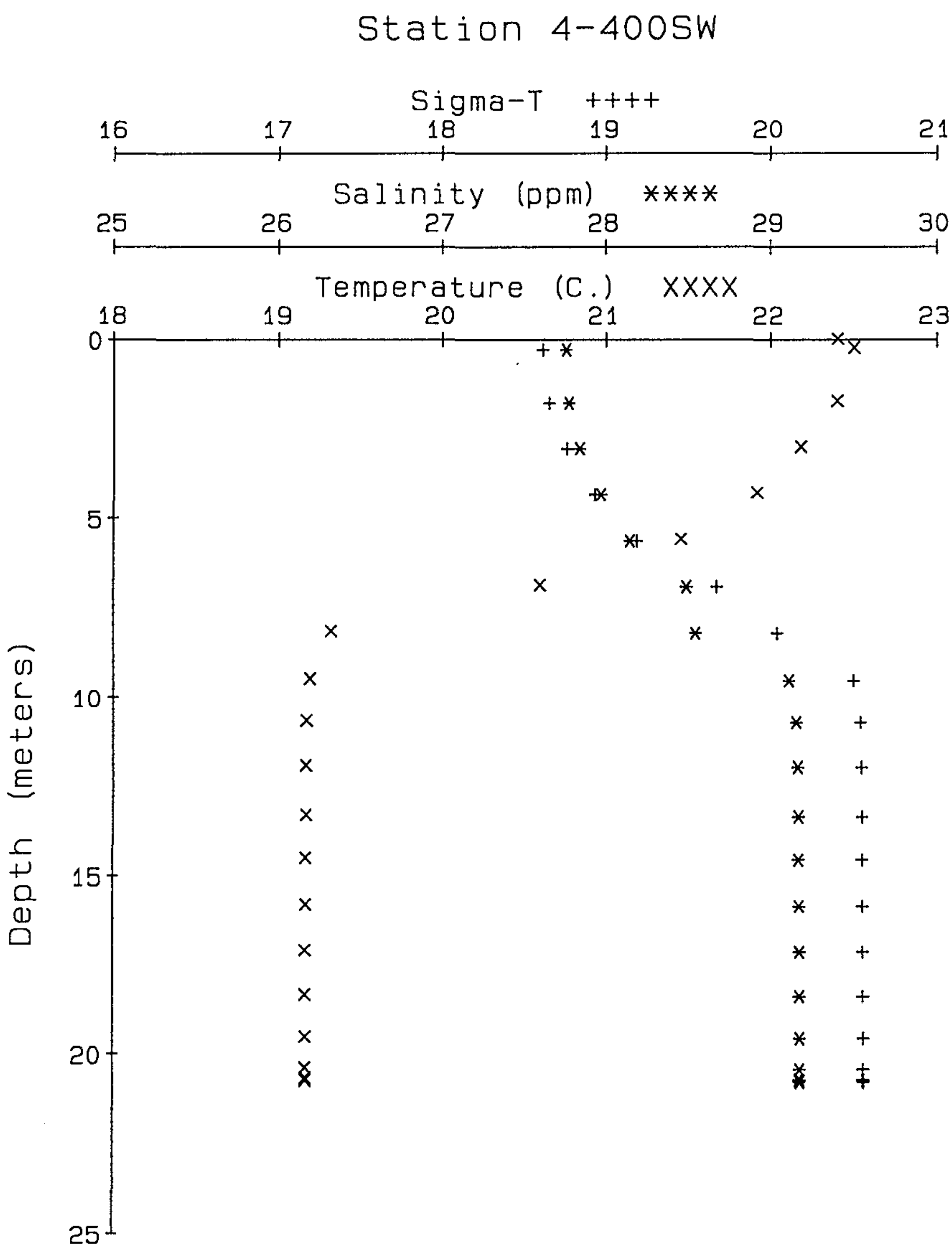
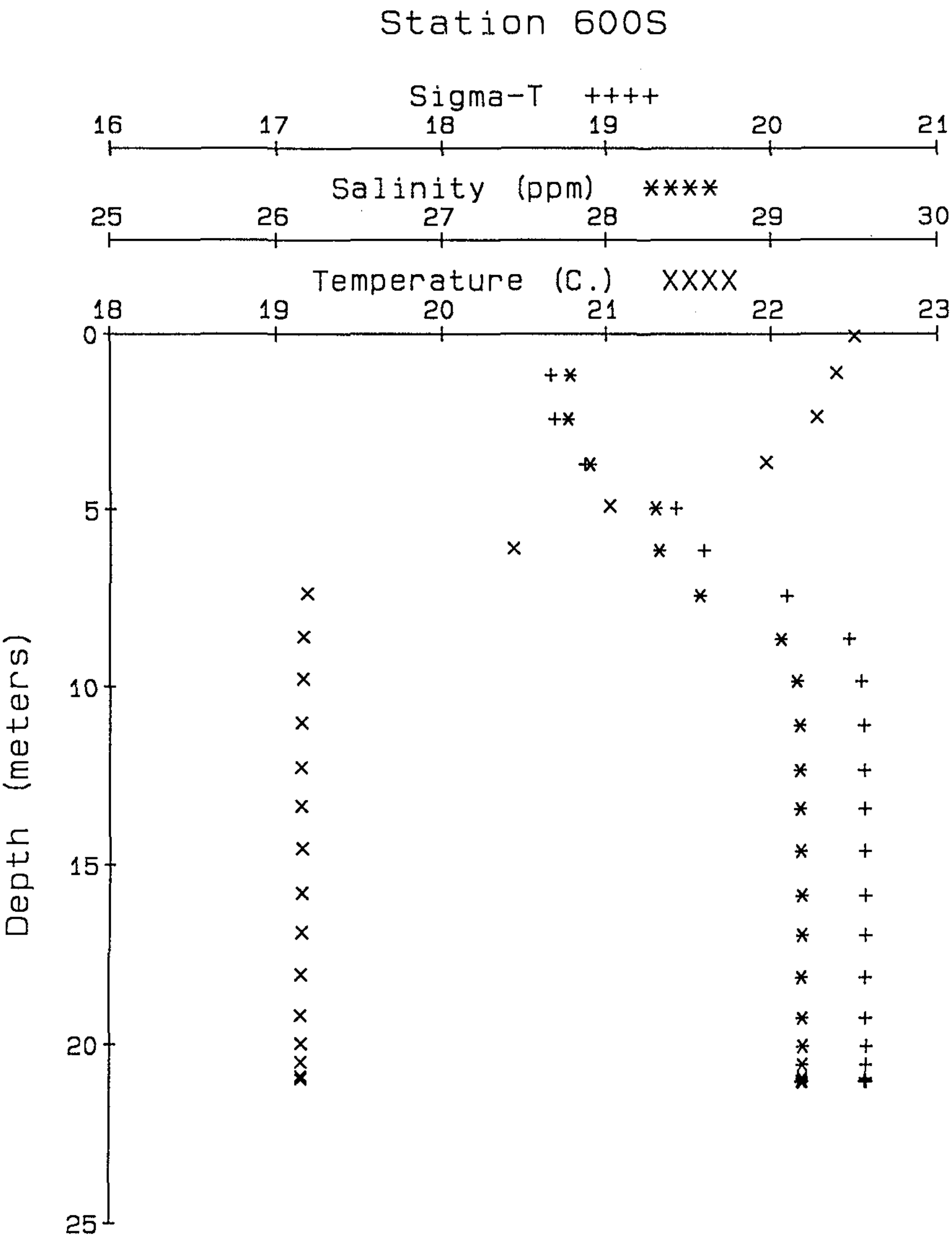
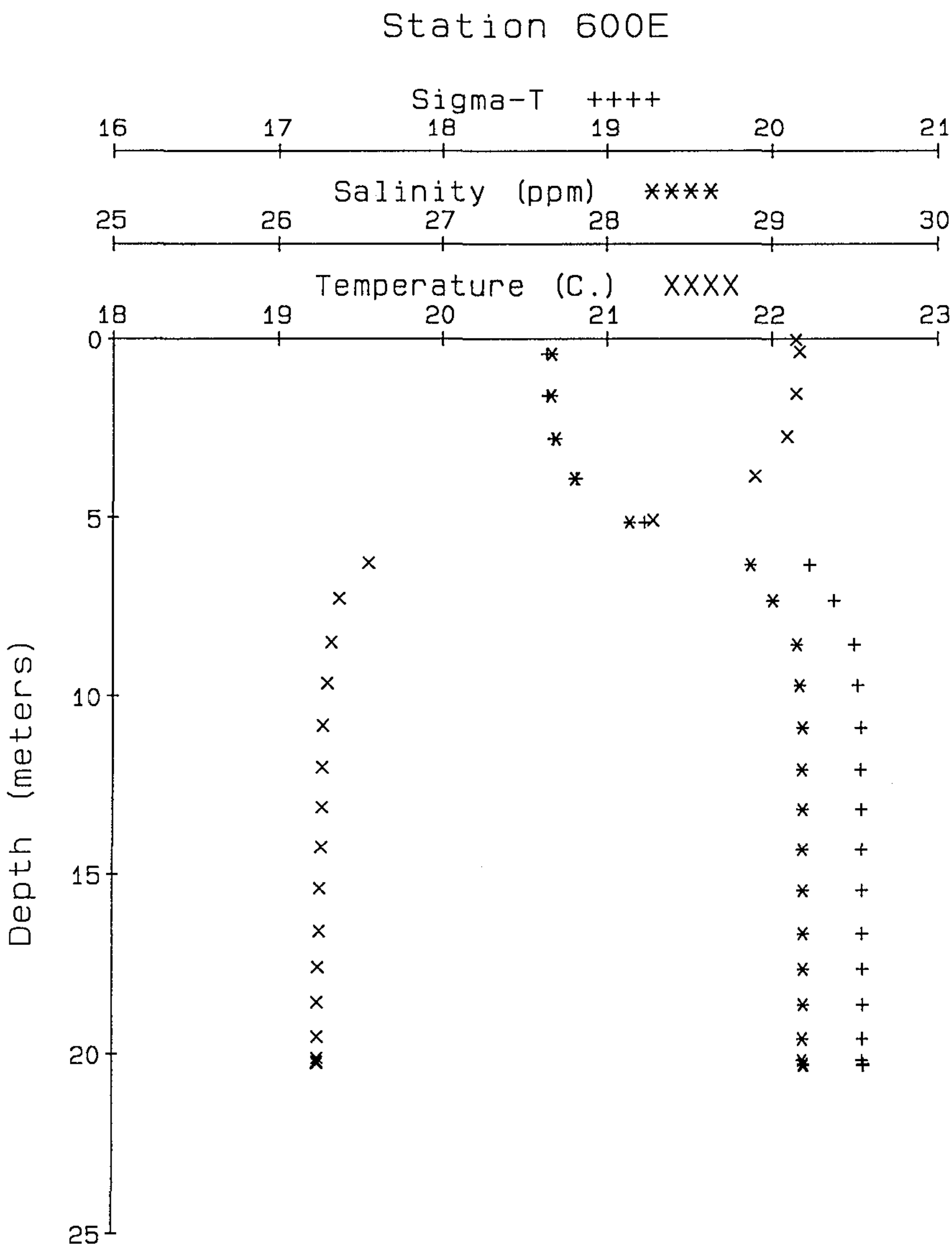
Salinity (ppm) ****
25 26 27 28 29 30
Temperature (C.) XXXX
18 19 20 21 22 23
Depth (meters)
0 5 10 15 20 25


Station 4-400SW
Sigma-T ++++
16
17
18
19
20
21
Salinity (ppm) ****
25
26
27
28
29
30
Temperature (C.) XXXX
18
19
20
21
22
23
Depth (meters)
0
5
10
15
20
25


Station 600S
Sigma-T ++++
16
17
18
19
20
21
Salinity (ppm) ****
25
26
27
28
29
30
Temperature (C.) XXXX
18
19
20
21
22
23
0
5
10
15
20
25
Depth (meters)



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