Environmental
Studies
Research
Funds

061

Seafloor Stability Study, Inner Scotian Shelf

Canada

May 1987

Environmental Studies Revolving Funds
Report No. 061

May 1987

SEAFLOOR STABILITY STUDY, INNER SCOTIAN SHELF

J.T. Judge
R.K. Watanabe
J.L. Warner

Martec Limited
5670 Spring Garden Road
Halifax, Nova Scotia
B3J 1H6

Scientific Advisor: D.L. Forbes

The correct citation for this report is:

Judge, T.J., R.K. Watanabe and J.L. Warner. 1987. Seafloor stability study, inner Scotian Shelf. Environmental Studies Revolving Funds Report 061. Ottawa, 80 p.

Published under the auspices of the Environmental Studies Revolving Funds
ISBN 0-920783-60-0

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Mr. J.R. Moir and the rest of the ESRF Sediment Transport Sub-committee for their patient understanding of the difficulties that arise during oceanographic field studies.

The practical and positive support given by the scientific advisor, Dr. D.L. Forbes of the Atlantic Geoscience Centre, was of immeasurable value. Without the practical advice and guidance offered by Dr. Forbes, the study could not have achieved the high degree of success that it did.

The management and professional staff at Dominion Diving International Ltd. took a priority interest in the success of this study from its beginning. Without their professional approach, enthusiasm and perseverance in the face of bitter and dangerous conditions, the study would not have been possible. The principal professional divers that made the study possible are D. Bolstad, P. Collins, K. Falle, D. Misner and D. Smith.

Finally we would like to thank B. Campbell, T. Reynolds and P. Richard of Martec for handling the typing and drafting requirements of this report.

SUMMARY

This report describes a measurement program designed to monitor the behaviour of seafloor sediments on the Scotian Shelf under winter storm conditions. The project was initiated in January 1986, ran throughout the duration of the Canadian Atlantic Storms Program (CASP) and continued into the summer.

Four measurement sites were spaced along a transect line established earlier for CASP. This transect line ran seaward from Martinique Beach, Nova Scotia, on a bearing of approximately 156° true. One site was located on gravel in 30 m water depth. The other three sites were on sand in depths of 20 m, 30 m and 37 m.

The main measuring device was a rod, driven into the sea bottom, onto which was placed a specially designed washer assembly to monitor changes in seafloor elevation with time. Other equipment used included video and time lapse cameras, chain-type scour detectors, current meters and a box corer. Visual observations and photographs taken by divers were a major component of the field work. The observations were restricted to periods of relatively calm weather in order to obtain the required visibility at the sea bottom.

Bedform features observed at the sand sites consisted of ripples varying from 20 to 100 mm in height and 100 to 500 mm in wavelength. Larger ripples were observed at the gravel site, ranging from 0.3 to 0.4 m in height and 1.2 to 1.9 m in wavelength.

Measured values of erosion were small at all sites. The maximum erosion was 97 mm and the maximum accretion was 129 mm. The small values of erosion may be attributed to the relatively storm-free winter period. The largest characteristic wave height recorded was 5.2 m, much less than the extreme values of 7.5-8.0 m in an 11-year wave rider record at a nearby site. Thus, no wave heights approached the values of 10 to 15 m used in design for off-shore structures and pipelines.

While working near the 30 m sand site, divers discovered large depressions in the sandy seafloor 10 to 30 m wide and 0.8 to 2.4 m deep. These features displayed vertical walls of mud and were partially infilled with sand. Their origin remains unclear.

RESUMÉ

Le présent rapport décrit un programme de mesures élaboré en vue de suivre le comportement des sédiments des fonds marins de la plate-forme continentale de Nouvelle-Écosse dans les conditions créées par les tempêtes d'hiver. Le projet, lancé en janvier 1986, a continué pendant toute la durée du Programme Canadien d'Étude des Tempêtes dans l'Atlantique (PCETA), et a été prolongé jusqu'en été.

Quatre sites de mesures ont été échelonnés le long d'un profil établi auparavant pour le PCETA. Ce profil, partant de la plage de Martinique Beach (Nouvelle-Écosse), se dirigeait en mer vers l'azimuth géographique de 156°. L'un des sites était sur fond de gravier par 30 m de profondeur. Les trois autres sites étaient sur fond sablonneux, par 20 m, 30 m et 37 m de profondeur respectivement.

Le principal appareil de mesures était une verge enfoncée dans le fond de la mer, et sur laquelle on avait placé un assemblage de rondelles spécialement construit pour suivre les changements d'élévation du fond marin en fonction du temps. Le reste de l'équipement comprenait des caméras vidéo et à prises de vues au ralenti, des détecteurs d'affouillement du type à chaîne, des courantomètres, et un carottier à boîte. Une part importante du travail de terrain a consisté en observations visuelles et photographies effectuées par des plongeurs. Les observations ont été restreintes à des périodes où le temps était relativement calme, afin de bénéficier du minimum de visibilité nécessaire au fond de la mer.

Les structures du fond marin observées aux sites sablonneux, consistaient en ondulations variant de 20 à 100 mm de hauteur et de 100 à 500 mm de longueur d'onde. Au site à gravier, l'on a observé des ondulations plus grandes, allant de 0.3 à 0.4 m de haut et de 1.2 à 1.9 m de longueur d'onde.

Les valeurs d'érosion mesurées ont été faibles à tous les sites. L'érosion maximum a été de 97 mm et l'accrétion maximum de 129 mm. Les faibles valeurs de l'érosion peuvent être attribuées au fait que la période d'hiver a été relativement dépourvue de tempêtes. La plus grande hauteur caractéristique de vagues enrigistrée, a été de 5.2 m, soit bien moins que les valeurs extrêmes de 7.5 à 8.0 m observées sur un enregistrement de 11 ans fourni par un flotteur enregistreur sur un site voisin. Ainsi, la hauteur des

vagues n'a jamais approché les valeurs de 10 à 15 m prises comme base pour la construction des structures industrielles pour le grand large et des oléoducs.

Au cours de leur travail près du site sablonneux de 30 m de profondeur, les plongeurs ont découvert, dans le fond marin sablonneux, de grandes dépressions de 10 à 30 m de large et de 0.8 à 2.4 m de profondeur. Ces structures étaient bordées par des parois verticales de boue, et étaient partiellement remplies de sable. Leur origine reste incertaine.

1.0 INTRODUCTION

During the winter and spring of 1986, Martec Limited conducted measurements of sea bed stability at four sites in 20 to 37 m water depth at the locations shown in Figure 1-1. Dominion Diving International Limited provided the diving vessels and conducted all of the diving operations under the supervision of Martec Limited. This report summarizes the procedures employed and the results. Some analysis of the results is presented, but it was not part of the terms of reference of this study to enter into detailed data analysis. This report is principally a data report.

The overall objective of the study was to obtain a better understanding of the stability of unconsolidated non-cohesive sea beds (e.g. sand and gravel) in water depths of 20 to 40 m during winter storms. This requirement was precipitated by the ongoing planning of the oil and gas industry to bring hydrocarbons onshore. Knowledge of sea bed stability during storms is of particular interest to designers of submarine pipelines that cross nearshore areas, and any offshore areas, that exhibit water depths and bottom characteristics similar to those existing in the study area.

The study was conducted at the inshore end of the Canadian Atlantic Storms Program (CASP) control line off Martinique Beach, Nova Scotia (Figure 1-1). This area was selected in order to take advantage of the CASP wave and current data being collected during that study (January to March 1986). The present study covered the period from January 17 to July 7, 1986. Due to weather and water visibility requirements (see Section 2.5), the study was not completed at the end of the CASP project, as originally intended. Wave conditions for the time from April to July can be estimated by first correlating ongoing Osborne Head waverider data (collected by Marine Environmental Data Service) with appropriate CASP wave data collected prior to April and then employing the Osborne Head data, suitably adjusted, for the April to July time period.

The locations for the study were selected on the basis of sidescan data available prior to the field program and data from an additional sidescan operation that was conducted as part of this study. The selected sites were in 20 m water depth on sand, 30 m on sand, 30 m on gravel, and 37 m on sand. These depths are below mean water level (not chart datum), which is why, for example, site S-1 is not on the 20 m depth contour of Figure 1-1. It was not possible to locate sand in water deeper than 37 m. A fifth site, 30 m north of the 30 m sand site, consisted of a series of sea

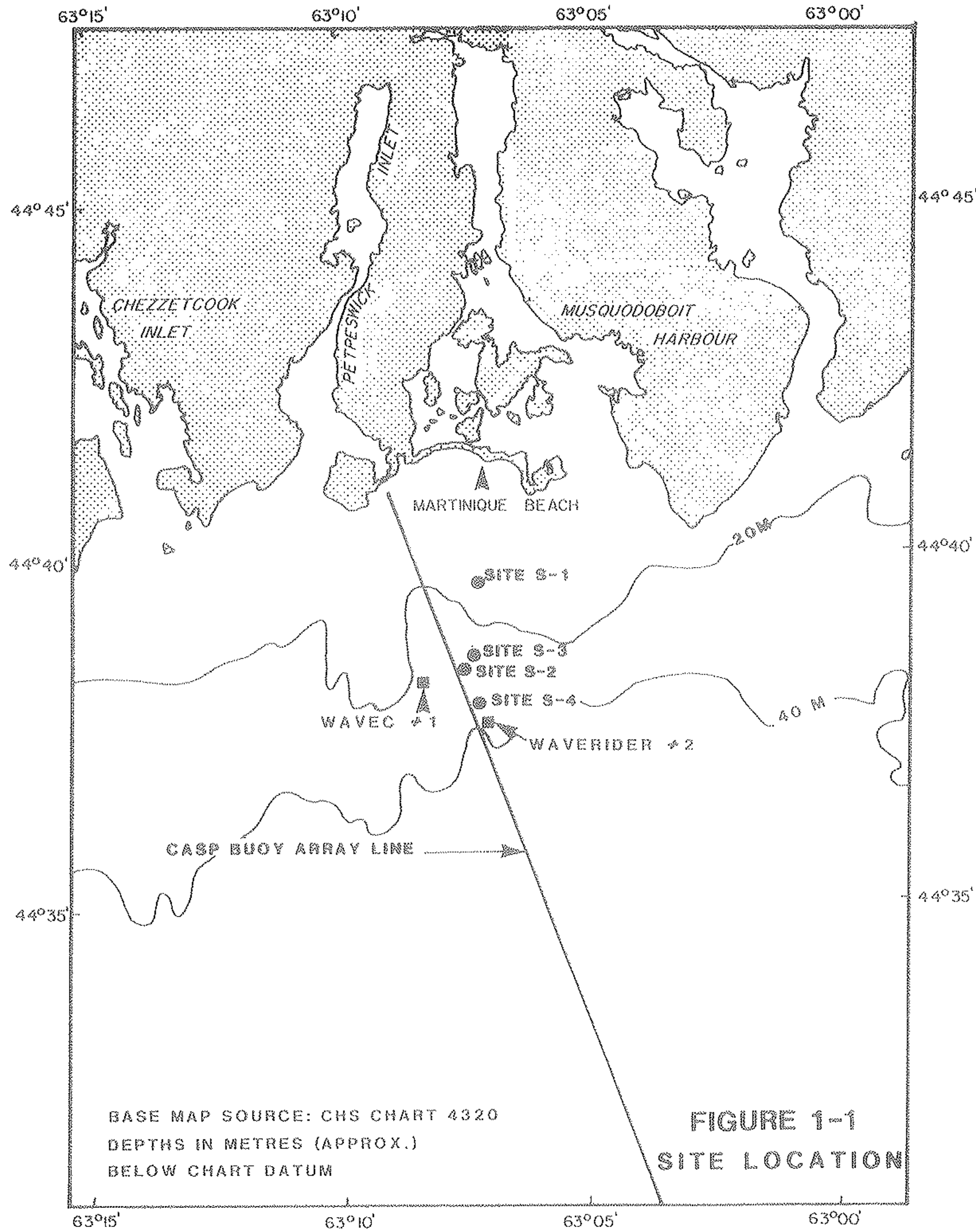
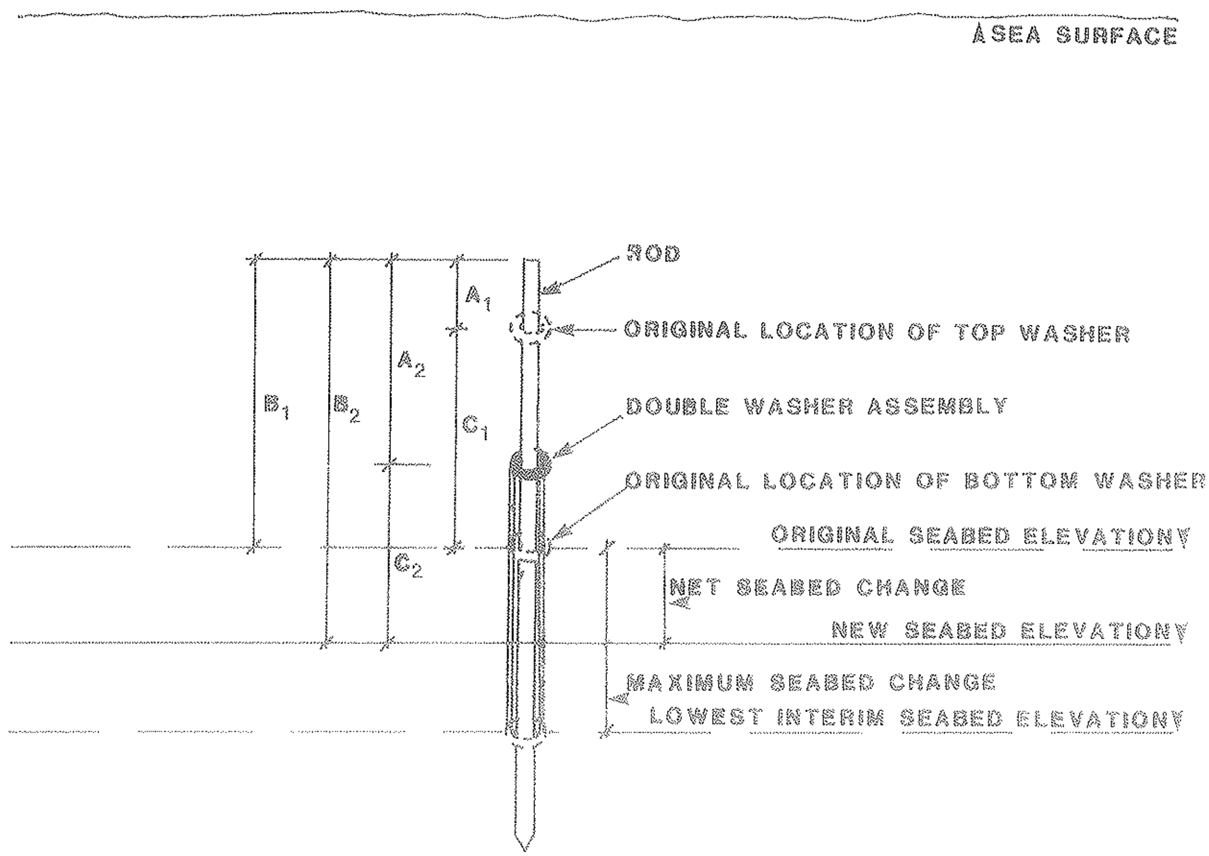


FIGURE 1-1
SITE LOCATION

bed depressions having depths of 0.8 to 2.4 m and lateral expanses of 10 to 30 m. Section 2.7 describes these features in more detail.

Current meters were deployed at each site and sea bed stability was measured by taking repeated measurements on arrays of steel rods and the depth of disturbance indicators (washers) placed on them. This apparatus is schematized in Figure 1-2. The complete methodology and results of the study are presented in the following sections.



MEASUREMENTS TAKEN BY DIVERS:

- A- TOP OF TOP WASHER TO TOP OF ROD
- B- SEABED TO TOP OF ROD
- C- SEABED TO TOP OF TOP WASHER (REDUNDANT MEASUREMENT TO SERVE AS DATA QUALITY CONTROL)

NET SEABED CHANGE = $B_2 - B_1$
MAXIMUM SEABED CHANGE = $A_2 - A_1$

N.B. SEE SECTION 2.2 FOR MATERIALS USED FOR ROD AND WASHER ASSEMBLIES

FIGURE 1-2

TYPICAL ROD AND WASHER SET-UP

2.0 METHODOLOGY

2.1 Summary

The study followed a four-phase course of action. Phase I included the initial equipment design, testing, final design and final procurement. This was conducted at the same time as Phase II, the site selection. Phase III was the installation of measuring equipment at individual sites. This started before, but overlapped with, Phase IV, the site monitoring program.

Phase I included field and laboratory testing of the equipment and testing of the installation procedures. The testing was required in order to finalize the design of the equipment and to establish the installation procedures. This phase of the work was primarily qualitative in order to aid in the final equipment design.

Phase II of the work covered site selection, as described in Section 2.3, with the results of that exercise being the selection of the sites shown in Figure 1-1.

Phase III, the site installation procedure, was modified by experience at the sites and is described in Section 2.4.

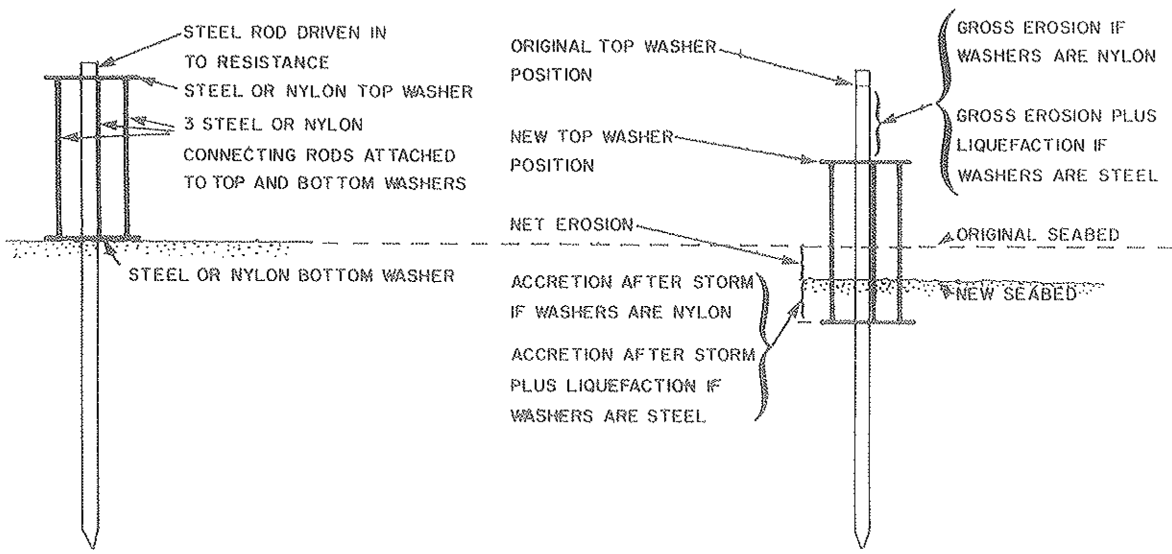
Phase IV of the study covered site monitoring, video reconnaisance and the investigation of the seafloor depressions near the 30 m sand site, as described in Sections 2.5, 2.6, and 2.7, respectively. Section 2.8 summarizes activities of each cruise carried out during the study in order to provide a synopsis of the site installation and monitoring procedures.

2.2 Preliminary Testing and Equipment Design

Three types of scour detection devices were used:

(1) a steel rod fitted with a steel double washer assembly;
(2) a steel rod fitted with a nylon double washer assembly; and
(3) a chain scour detector.

The rod and washer assemblies are shown schematically in Figure 2-1. At each site, half of the rods were fitted with steel washer assemblies and the other rods were fitted with nylon washer assemblies.



a) AS INSTALLED

b) AFTER STORM

NOTES:

1. WASHERS AND CONNECTING RODS EITHER STEEL OR NYLON.
2. WASHERS SIZED TO PREVENT JAMMING WITH SEDIMENT GRAINS.
3. NOT TO SCALE

FIGURE 2-1

SCHEMATIZED
ROD AND WASHER ASSEMBLY

The washer assemblies are installed with the bottom washer resting on the sea bed. During a storm, the bottom washer sinks to the lowest level of sediment disturbance. Due to the different density of steel and nylon, the steel washers should sink to the bottom of a liquefied layer of sediment, while the nylon washers should float near the top of a liquefied layer (should such a layer exist). The nylon washers indicate the depth of disturbance due to bedload and suspended load transport and the steel washers indicate this depth of disturbance plus any depth of liquefaction that exists during the storm.

The maximum erosion (plus liquefaction, if the washers are steel) that occurred during the storm is found from the difference between the original and new positions of the top washer with respect to the top of the rod. If accretion of sediment occurred after a storm or during the latter part of the storm, net erosion is calculated as the difference between the original and new position of the sea bed with respect to the top of the rod.

The absolute elevations of the rods were checked against a benchmark installed at each site by divers. The geotechnical anchor rod used as a benchmark is shown schematically in Figure 2-2. The anchor rod is driven into the sea bed with the anchor points retracted. The driving extension is then inserted into the pipe and used to force the anchor points out of the bottom end of the rod. A clamp installed by divers on the pipe serves as the benchmark for the site.

The chain scour detector, which served as a backup system for the erosion rod and steel washer assembly, is shown schematically in Figure 2-3. This device gives an independent check of the depth of disturbance in the event that local scour or vibrations of the rod and washer assembly cause the washers to work themselves into otherwise undisturbed sediment. The location of the device is documented and the chain is cut off at the sea bed. As sediment is eroded or liquefied during a storm, the chain collapses onto the firm sediment to indicate the maximum depth of disturbance (plus liquefaction) by the length of collapsed chain. If accretion of sediment occurred during or after passage of a storm, the accretion is calculated as the difference between the collapsed length of chain and the new position of the sea bed after the chain is dug out by the divers.

Laboratory and field tests resulted in modifications of the equipment design during the course of the project.

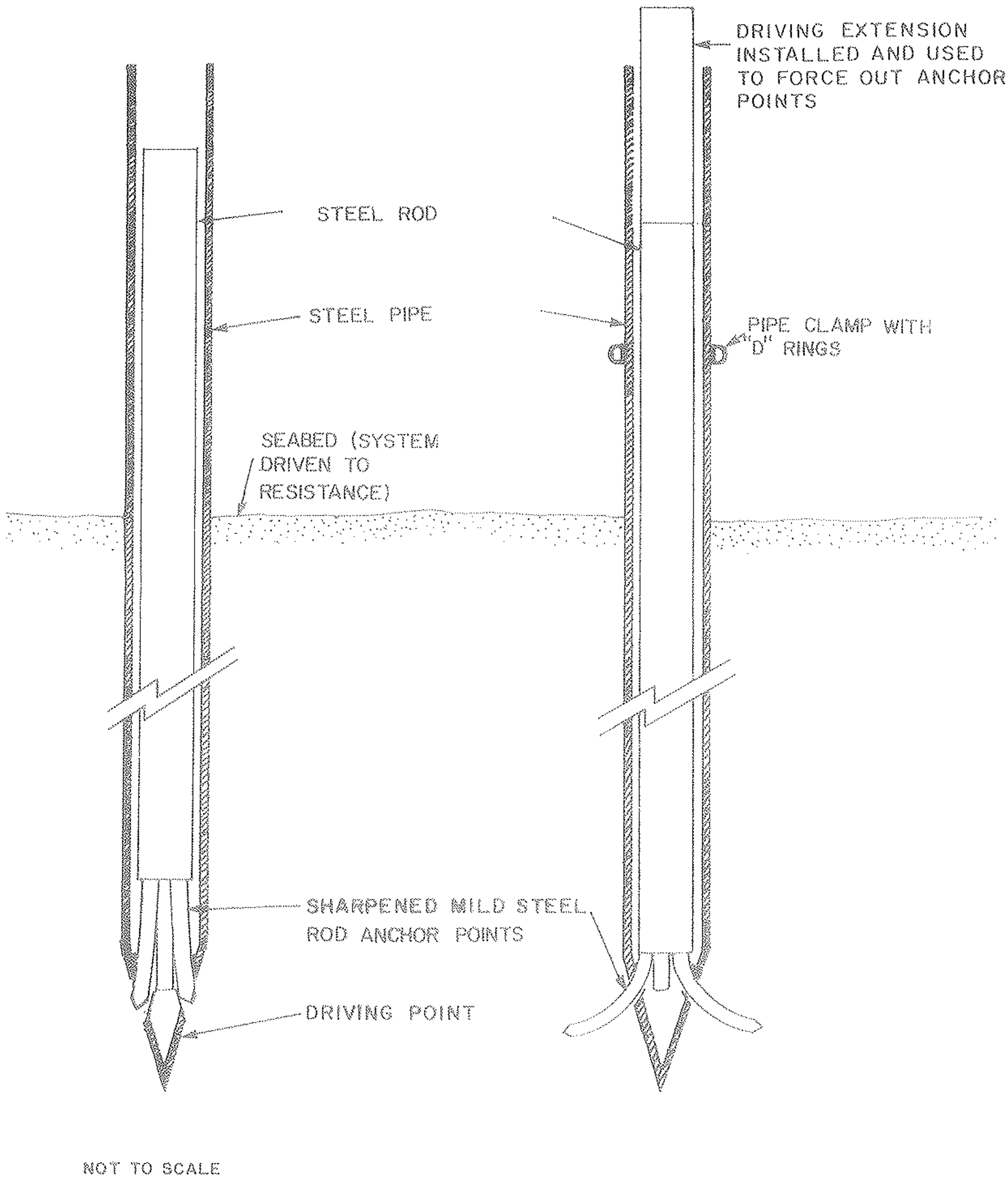


FIGURE 2-2

SCHEMATIZATION OF BENCHMARK ANCHOR ROD

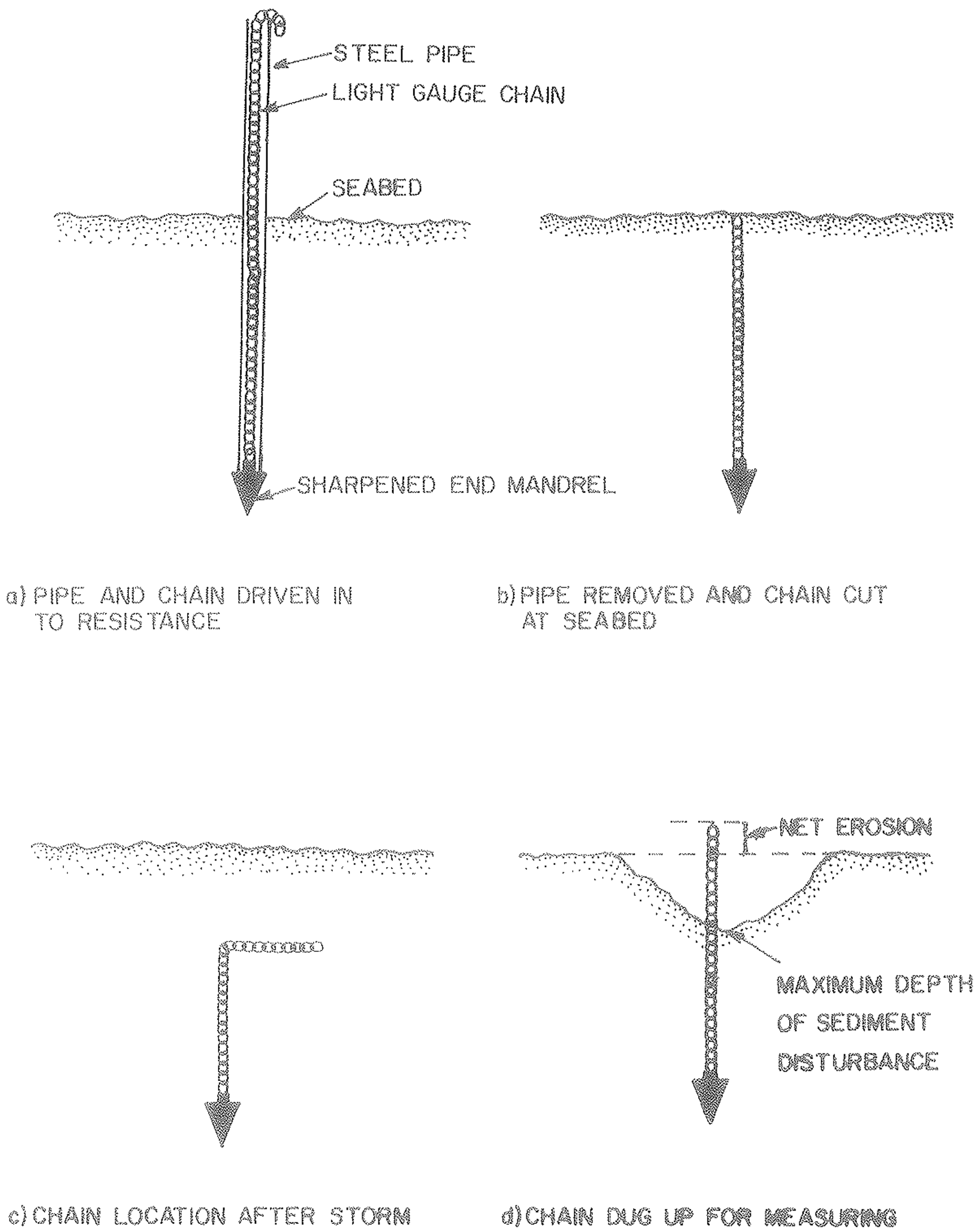


FIGURE 2-3
SCHEMATIC OF CHAIN SCOUR DETECTOR

The final specifications for the equipment are presented below.

The laboratory testing program involved placing the rod and washer assemblies in a sand bed comparable to that expected at the survey sites. The tests were conducted in the later part of December 1985 in the wave flume of the Technical University of Nova Scotia. A test section of sand 0.9 m by 0.9 m and 0.4 m thick was placed in the bottom of the flume. The water depth over the sand in the test section was approximately 0.42 m. The sand was exposed to wave action for an extended period to ensure that the sediments were properly consolidated prior to installation of the test apparatus.

The test rods were 610 mm long and were installed with about 280 mm of the rod buried in the sand. The tops of the rods were monitored by reference levels marked on the observation window and opposing back wall of the wave flume and the critical aspects of the experiment were recorded on video. The behaviour of the rod and washer assemblies was examined during ten tests with wave heights of 50 to 190 mm and periods of 1 to 3 seconds. Each test was typically 25 minutes long. All of the tests used sand with grain size ranging from 0.21 to 0.42 mm (D_{50} approximately 0.3 mm), except for the final test which used silica flour, with a grain size between 0.11 and 0.15 mm (D_{50} approximately 0.12 mm).

The laboratory tests indicated that the rods were vertically and horizontally stable under the wave action in the flume. However, they did cause local scour and affected the configuration of the bedforms. Consequently, the clearances between the rods and washers were reduced to minimize rocking motions and the washers were made as thin as possible. The new washer assemblies were re-tested and the local scour around the washers was found to be minimal (less than the accuracy of the measurements to be made in the field). There was no apparent alteration in the behaviour of the rod and washer assemblies when installed in the finer sand.

Preliminary field testing of the equipment was conducted on December 13 and 28, 1985 by installing the rod and washer assemblies, anchor rods and chain detectors in the swash zone of Lawrencetown Beach, N.S. An additional field test was performed on December 30th in a water depth of 4 m off of Eastern Passage, N.S. Modifications were made to the equipment design based on the results of the laboratory and field testing. The final design specifications for the rod and washer assemblies are presented in Figure 2-4(a) for two of the sand sites and in Figure 2-4(b) for the gravel site and the deep sand site. The rods were longer and the washer assemblies had closer tolerances than in the original design.

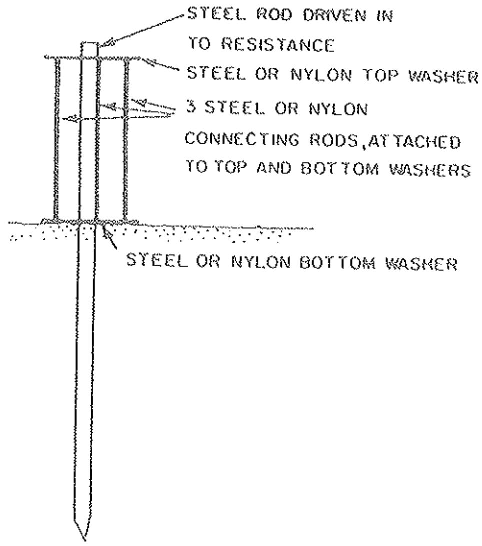
The final design of the chain detector is presented in Figure 2-5. The loose end of the chain was taped to the top of the pipe to prevent the chain from becoming kinked and jamming in the pipe. A polypropylene string was tied to the top link and to the "spearhead" to permit divers to keep the chain taut while removing the outer pipe and also to assist in finding the chain detector on subsequent cruises. Polypropylene was used because it floats up from the sea bed after the exposed chain is severed.

2.3 Site Selection

Preliminary sites were selected in consultation with the scientific advisor, D.L. Forbes, and with Dr. R. Boyd of Dalhousie University's Centre for Marine Geology. The existing sidescan sonar was used to identify potential sites with the largest horizontal expanses of uniform sediment conditions. Potential sites where there appeared to be sufficient sand or gravel at the requisite water depths were selected as close as possible to the CASP transect line. An additional sidescan survey was carried out on January 11th to verify the site conditions and four potential sites were marked with highflyers. Miniranger and Loran C were the navigation systems used. On subsequent cruises, diver or ROV observations and grab samples were used to confirm that each site was suitable for the study. All sites were more than 30 m from any change in sea bed conditions. The locations of the sites are shown in Figure 1-1 and Table 2-1.

2.4 Site Installation

Plan views of the measurement sites are presented in Figures 2-6 to 2-9. All sites had a vessel mooring, current meter, and rod and washer assemblies installed. The rod and washer assemblies were established in arrays as shown in the site plans. The even numbered rods carried nylon washers and the odd numbered rods had steel washers. An anchor rod benchmark was used at all sites except site S-4. Six chain scour detectors were deployed at site S-1 and a single chain detector was deployed at each of sites S-2 and S-3. Grab samples were taken and bedform size and orientation were measured by divers at each site. A time lapse camera was deployed at site S-1. One paddle-equipped Aanderaa current



a) FOR SITES S-1 AND S-3

STEEL ROD
2.44m (8') LENGTH
16mm (5/8") DIAMETER

TOP WASHER
44mm (1 3/4") OD
19mm (3/4") ID
3mm (1/8") THICKNESS

BOTTOM WASHER
76 mm (3") OD
19 mm (3/4") ID
3 mm (1/8") THICKNESS

CONNECTING RODS
606 mm (23 7/8") LENGTH
6 mm (1/4") DIAMETER

b) FOR SITES S-2 AND S-4 *

STEEL ROD
1.83m (6') LENGTH
19 mm (3/4") DIAMETER

TOP WASHER
44 mm (1 3/4") OD
22 mm (7/8") ID
4 mm (5/32") THICKNESS, STEEL
3 mm (1/8") THICKNESS, NYLON

BOTTOM WASHER
76 mm (3") OD
23 mm (29/32") ID
3 mm (1/8") THICKNESS

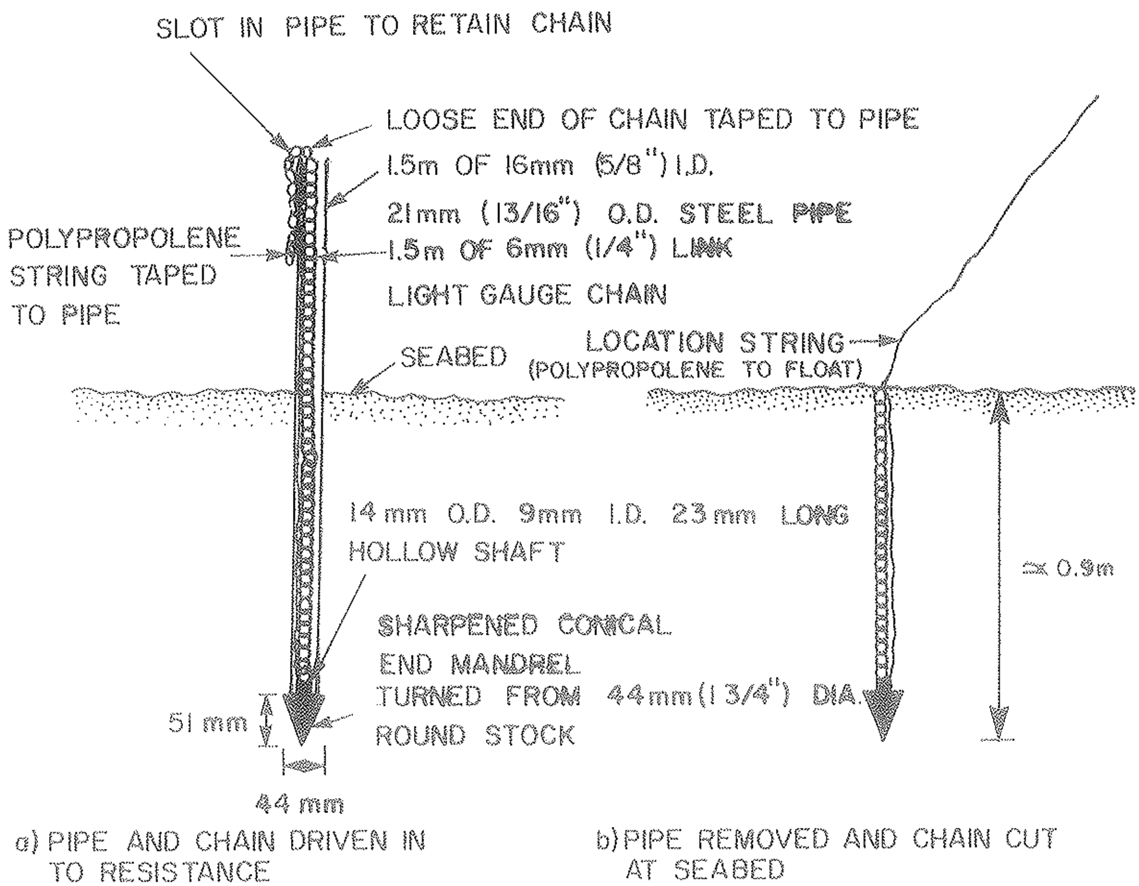
CONNECTING RODS
606 mm (23 7/8") LENGTH
6 mm (1/4") DIAMETER

NOTES:

1. HALF OF THE CONNECTING RODS STEEL, THE OTHER HALF NYLON.
2. WASHERS SIZED TO PREVENT JAMMING WITH SEDIMENT GRAINS.
3. NOT TO SCALE.
*4. DUE TO LIMITED DIVER BOTTOM TIME IN DEEP WATER THE SHORTER 3/4" DIAMETER RODS WERE INSTALLED AT SITE S-4 SINCE THEY WERE NOT ALL USED AT SITE S-2 AND BECAUSE THEY COULD BE INSTALLED MORE QUICKLY THAN THE LONGER 5/8" DIAMETER RODS.

FIGURE 2-4

SPECIFICATIONS FOR
ROD AND WASHER ASSEMBLIES



NOTES:
- NOT TO SCALE
- CHAIN FASTENED TO END OF MANDREL SHAFT WITH 3mm Ø SPRING PIN

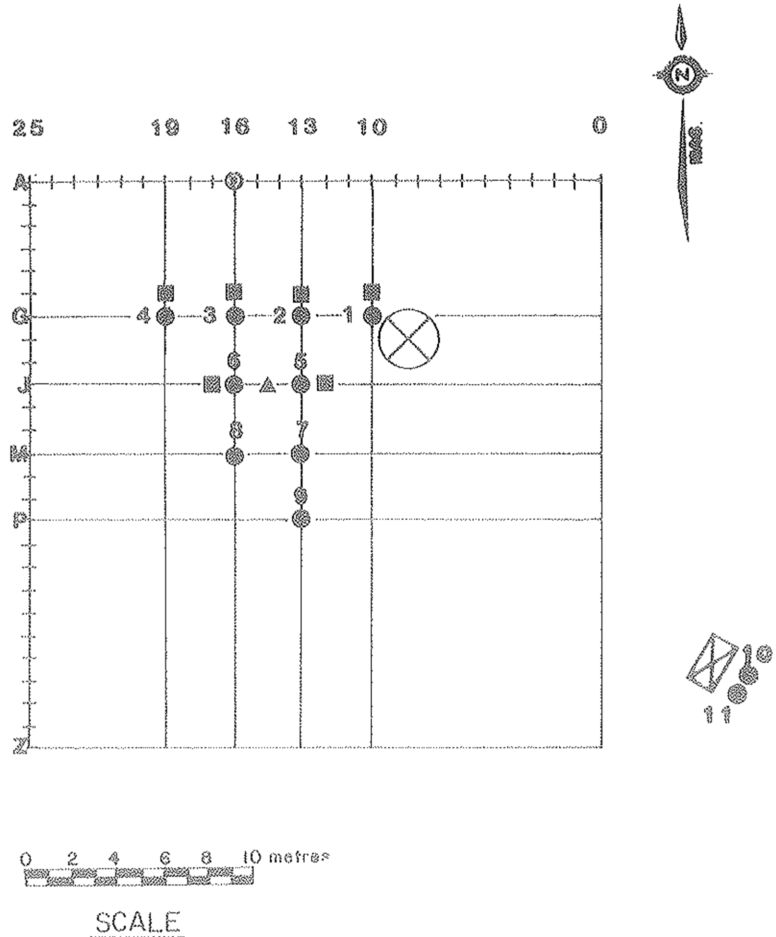
FIGURE 2-5

SPECIFICATIONS FOR CHAIN SCOUR DETECTOR

TABLE 2-1

SITE COORDINATES

Site	Description	Location	
		Longitude/ Latitude	Loran C 5930-X 5930-Y
S-1	20 m depth sand	63°07'18" W 44°39'33" N	13901.4 29970.1
S-2	30 m depth gravel	63°07'36" W 44°38'18" N	13893.4 29972.1
S-3	30 m depth sand	63°07'24" W 44°38'33" N	13894.7 29970.5
S-4	37 m depth sand	63°07'21" W 44°37'45" N	13889.1 29968.6



LEGEND

- ● ROD AND WASHER ASSEMBLY
- ■ CHAIN DETECTOR
- ▲ ANCHOR ROD
- ⊙ VESSEL MOORING
- ⊗ CURRENT METER
- ⊠ CAMERA

FIGURE 2-6

PLAN VIEW OF SITE S-1
20M DEPTH, SAND

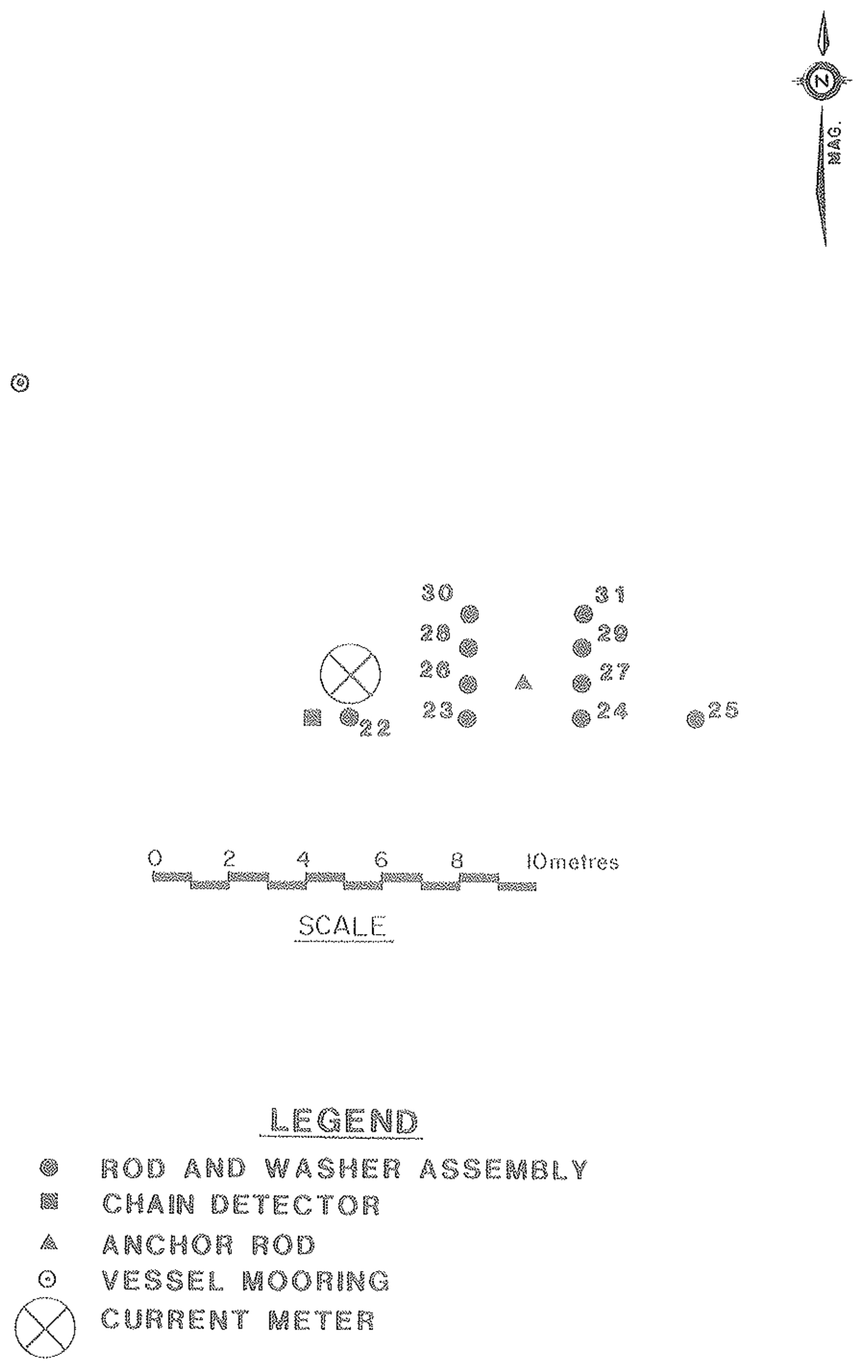


FIGURE 2-7

PLAN VIEW OF SITE S-2
30M DEPTH, GRAVEL

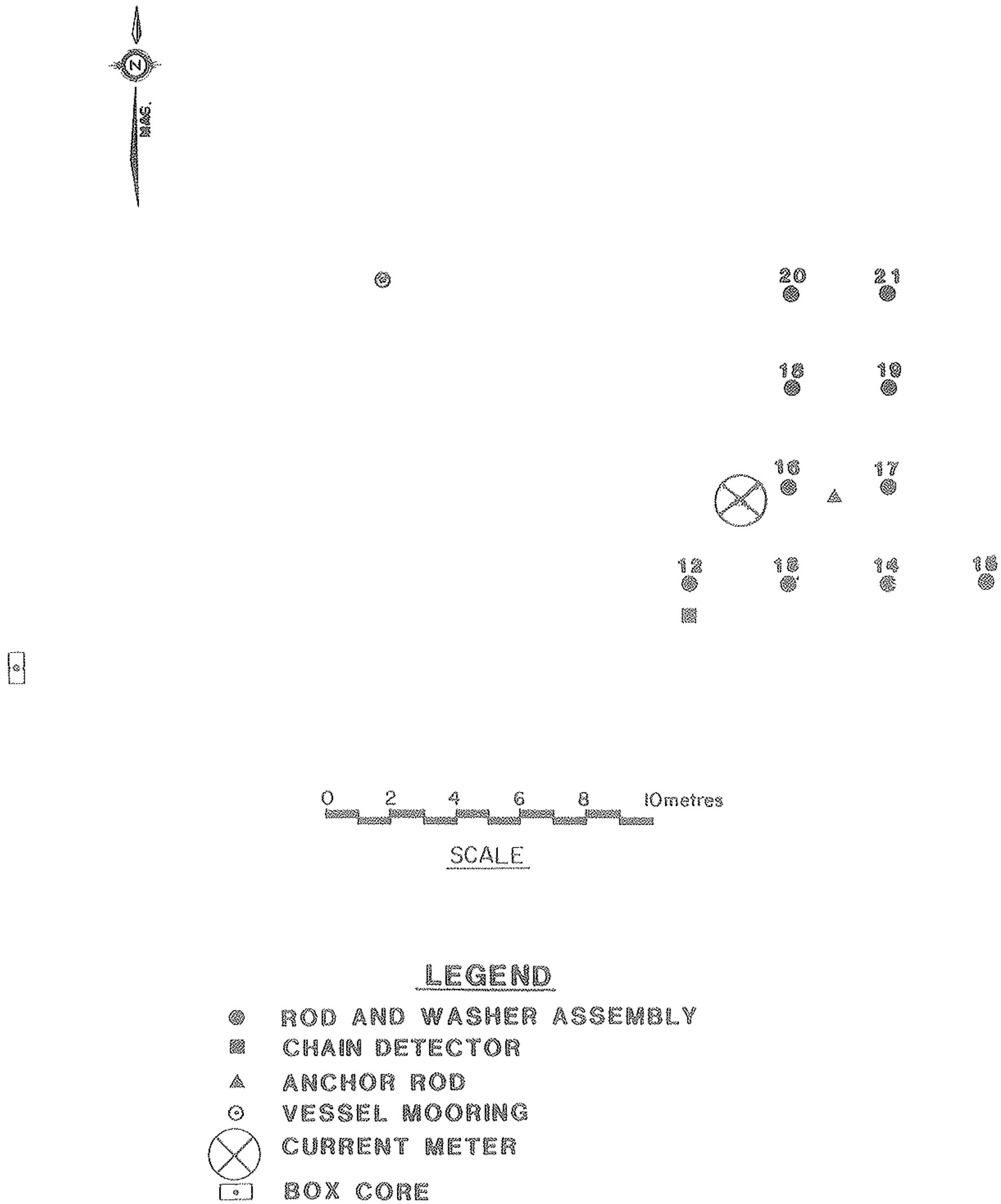


FIGURE 2-8

PLAN VIEW OF SITE S-3
30M DEPTH, SAND

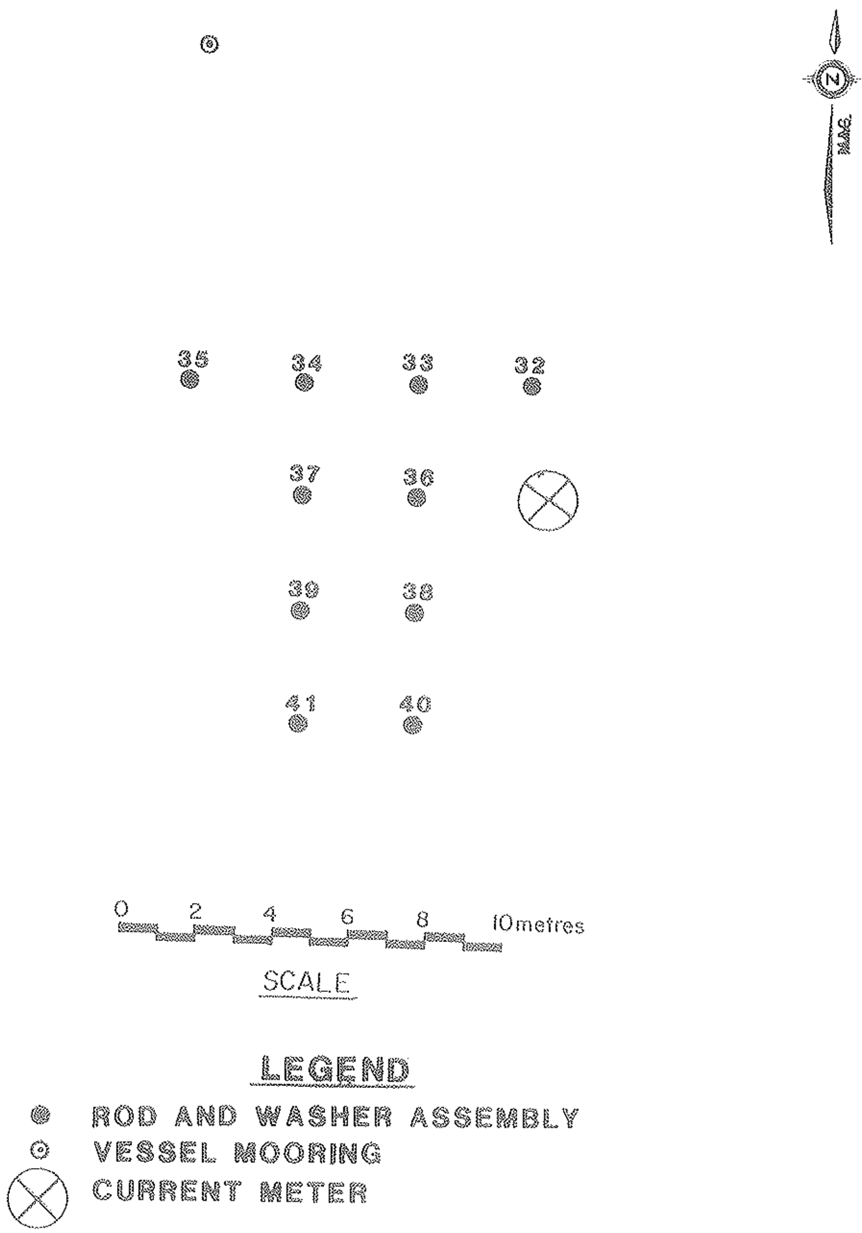


FIGURE 2-9

PLAN VIEW OF SITE S-4
37M DEPTH, SAND

meter was deployed at each site, mounted 1 m above the bottom. The deployment and recovery dates are given in Table B-1 (Appendix B). The Aanderaa current meters recorded a 30-minute average speed and instantaneous direction every 0.5 hours. Near site S-1, the Atlantic Geoscience Centre (AGC) deployed an instrument system ('Ralph'), including an S4 electromagnetic current meter provided by INRS-Oceanologie (Rimouski), while another S4 current meter was deployed approximately 100 m east of site S-3. The S4 meters were mounted at 0.6 m (site S-1) and 1.0 m (site S-3) above the seafloor, and collected 1-hour samples of x-y (magnetic N-E) current data at 1-s intervals. Data from these instruments may be obtained by contacting D.L. Forbes at AGC and G. Drapeau at INRS, respectively.

2.5 Site Monitoring

The site monitoring procedure followed the general sequence of events listed below.

1. Divers took measurements at each rod and washer assembly by placing a T-square on the crests of the small bedforms in the vicinity of the rod. The vertical distances from the sea bed to the top of the rod and to the top of the washer assembly were measured. As a check, the distance along the rod from the top edge of the top washer to the top of the rod was measured. The error for individual measurements should be no more than ±5 mm, although for some conditions of adverse lighting and visibility it may be somewhat greater.

2. Divers measured bedform size and orientation, made general observations and took photographs of the sediment conditions at the site.

3. After the measurements were completed, approximately half of the washer assemblies were repositioned such that the bottom washer was at the sediment surface. A still photograph was taken of each rod with the sediment surface and top of the washer assembly in the file of view.

4. Sediment grab samples were collected at each site.

Some deviations from this general procedure occurred because of poor visibility near the seafloor, limited bottom time, lack of daylight, or rough weather conditions.

2.6 Video Reconnaissance

Video data were collected at sites S-1 and S-3 during the installation phase of the project using a mini-ROV and a diver-held camera. Detailed video records were obtained using a larger ROV (Hysub-10) on May 29 at all sites except S-3, which was not found because the vessel mooring had been removed in error by the CASP project team.

During the search for the lost site S-3, large anomalous seafloor depressions described below were discovered in the seafloor. The Hysub-10 was used to conduct a video reconnaissance in this area on June 21st.

2.7 Seafloor Depression Survey

While searching for site S-3 on May 29, a diver encountered large seafloor depressions with horizontal dimensions of 10 to 30 m and depths (below the adjacent seabed) of 0.8 to 2.4 m. During a later investigation of this site (SD) on June 21, four rod and washer assemblies were installed across the end of one U-shaped depression, with two rods located inside the hole and the other two outside on opposite sides of the depression. The rods were positioned along a transect running approximately 95° magnetic. A level line was installed and vertical measurements were taken at each rod and washer assembly relative to the level line and the seafloor. Horizontal measurements were then taken from rod 1 to each of the other rods and to the top and bottom of the banks near rods 1 and 4. Grab samples were collected from the bank on the edge of the hole and from the seafloor in the base of the depression and on the adjacent surface outside. Still photographs were taken of the banks forming the sides of the depression near each of the rods.

3.0 RESULTS

3.1 Seafloor Scour and Accretion

In order to establish values for sea bed changes that took place between measurements, three distinct parameters - net erosion, gross erosion, and post-storm accretion are defined.

The net erosion (Table 3-1) is defined as the total apparent change in seafloor elevation as indicated by measurements taken at the start and end of a monitoring period.

The gross erosion (Table 3-2) is defined as the maximum erosion of the seafloor that took place at any time between detections (as indicated by total settlement of the washer assembly).

Post-storm accretion (Table 3-3) is the height of sediment accumulated at the measurement location subsequent to the occurrence of the lowest sea bed level during a particular monitoring period.

Occassionally, there was evidence of physical disturbance of the wash assemblies. In some cases, divers returning to the site found the top of the washer assembly free from the steel rod. Negative values were occassionally calculated for gross erosion. This was attributed to disturbance of the washer assemblies by the vessel mooring line. Also, it is speculated that when this occurred the bottom washer had been covered with accreted sediment and either kelp or the mooring line pulled the washer assembly up through this sediment so that the washer was higher than its previous location.

3.2 Bedforms

The bedforms (Figure 3-1) were measured at each of the four sites on each visit. Measurements included ripple height, ripple wavelength, and ripple orientation (crest alignment).

During the initial cruise to site S-1 on January 17th, the diver reported ripples 30 to 40 mm high and 150 to 200 mm apart, with the crests running E-W. Measurements taken on January 25th indicated that there were two sets of ripples present. The small ripples had crests from 25 to 100 mm high and 140 to 240 mm apart running about 240° from magnetic north. The large ripples were at right angles to the small ones and had crests 150 mm high and 500 mm apart. There was a fairly large sea state after January 25th and on

TABLE 3-1

SUMMARY OF ROD MEASUREMENTS

		Sea Bed to Top of Rod (mm)									Net Erosion (mm) From Previous Measurements									
Site No.	Rod No.	Jan 25	Feb 1	Feb 4	Feb 8	Feb 11	Feb 25	Mar 4	Mar 23	July 7	Jan 25	Feb 1	Feb 4	Feb 8	Feb 11	Feb 25	Mar 4	Mar 23	July 7	Net Over Period
S-1	1	927	945				920	-----	902	890		18				-25		-18	-12	-37
	2	1000	1010				990	-----	1020	1017		10				-20		30	-3	17
	3	974	994				970	-----	981	965		20				-24		11	-16	-9
	4	1103*	1133				1122	-----	1114	1102		30				-11		-8	-12	-1
	5	1030	1052				1032	1037	1082	1072		22				-20	5	45	-10	+42
	6	976	1015				1000	1000	1020	960		39				-15	0	20	-60	-16
	7	993	1010				995	-----	998	1017		17				-15		3	+19	24
	8	985	998				984	-----	1000	990		13				-14		16	-10	5
	9	975	996				990	-----	991	1000		21				-6		1	9	25
	10	-----	1533				-----	-----	-----	-----										
	11	-----	1294				-----	-----	-----	-----										
S-3	12			1329*	1328*		1312	1313	1347					-1		-16	1	34		18
	13			1369*	1334*		1552	1560	1552					-35		RD	+8	-8		RD
	14			1336*	1316*		-----	-----	1319					-20				3		-17
	15			1269*	1272*		-----	-----	1274					3				2		5
	16			1357*	1374*		-----	-----	1546					17				RD		RD
	17			1258*	1256*		-----	-----	1265					-2				9		7
	18			1414*	1411*		-----	-----	1323					-3				-88		-91
	19			1350*	1336*		-----	-----	1308					-14				-28		-42
	20			1358*	1332*		-----	-----	1321					-26				-11		-37
	21			1372*	1376*		-----	-----	1374					4				-2		2
S-2	22					1132*		1162	1172	1192							30	10	20	60
	23					1119*		1136	1135	1167							17	-1	32	48
	24					1156*		1147	1162	1227							-9	15	65	71
	25					1152*		1168	1204	1202							16	36	-2	50
	26					1201*		1202	1142	1147							1	-60	5	-54
	27					1262*		1274	1202	1197							12	-72	-5	-65
	28					1148*		1152	1192	1194							4	40	2	46
	29					1309*		1322	1322	1357							13	0	35	48
	30					1338*		1308	1225	1187							-30	-83	-38	-151
	31					1270*		1287	1160	1182							17	-127	22	-88
S-4	32					1025*	1072		1066	1051						47		-6	-15	+26
	33					935*	1032		948	1012						97		-84	64	77
	34					976*	985		970	981						9		-15	11	5
	35					1044*	1082		1092	1052						38		10	-40	8
	36					982*	983		1029	1000						1		46	-29	18
	37					979*	978		990	980						-1		12	-10	1
	38					1036*	1031		1050	1019						-5		19	-31	-17
	39					1049*	1047		1052	1028						-2		5	-24	-21
	40					1036*	1030		1037	1027						-6		7	-10	-9
	41					1120*	1136		1142	1132						16		6	-10	+12

* Not a direct measurement but deduced from adding distance from sea bed to top of washer plus distance from top of wash to top of rod.

RD = Rod disturbed.

TABLE 3-2

SUMMARY OF WASHER MEASUREMENTS

		Top of Washer to Top of Rod (mm)									Gross Scour (mm) From Previous Measurements									
Site No.	Rod No	Jan 25	Feb 1	Feb 4	Feb 8	Feb 11	Feb 25	Mar 4	Mar 23	July 7	Jan 25	Feb 1	Feb 4	Feb 8	Feb 11	Feb 25	Mar 4	Mar 23	July 7	Net* Over Period
S-1	1	440	515				W/420	-----	410	400		75				W		N	N	-----
	2	425	518				W/435	-----	490	480		93				W		55	N	45
	3	411	492/ 334				W/400	-----	465	465		81				RW		65	0	65
	4	498	552/ 523				573	-----	564	565		54				50		N	1	42
	5	476	566				565	557	595/ 535	545		90				N		38	10	10
	6	380	462				458	438	454/ 416	430		82				N		16	14	14
	7	432	488				487	-----	490	520		56				N		3	30	88
	8	375	455				W/380	-----	451	430		80				W		71	N	50
	9	426	506				510	-----	513	510		80				4		3	N	84
	10	-----	960				-----	-----	-----	-----										
	11	-----	840				-----	-----	-----	-----										
S-3	12			747	758		755	748	778					11		N	N	30		31
	13			819	799		W/1062	1042	1032					N		W	N	N		-----
	14			746	726		W/R	-----	W/737					N		W		RW		-----
	15			714	718		W/R	-----	W/689					4		W		RW		-----
	16			759	777		W/R	-----	W/926					18		W		RW		-----
	17			710	711		-----	-----	729					1				18		19
	18			820	818		-----	-----	747					N				N		-----
	19			756	760		-----	-----	834					4				74		78
	20			736	739		-----	-----	W/752					3				W		-----
	21			815	816		-----	-----	859					1				43		44
S-2	22					550		555	W/545	585							5	W	40	40
	23					528		W/527	574	582							W	47	8	55
	24					548		W/R	620	625							W	R	5	5
	25					538		548	630	635							10	82	5	97
	26					607		598	533	580							N	N	47	47
	27					700		641	640/ 588	610							N	N	22	22
	28					538		W/R	580	608							W	R	28	28
	29					714		W/707	778/ 722	778							W	71	56	56
	30					721		W/R	605	610							W	R	5	5
	31					694		689	691	700							N	2	9	6
S-4	32					435	W/278		W/465	W						W		W	W	-----
	33					364	W/437		440	W						W		3	W	-----
	34					391	W/386		W/405	W						W		W	W	-----
	35					490	510		W/509	W						20		W	W	-----
	36					404	W/446		W/430	W						W		W	W	-----
	37					383	392		440	445						9		48	5	62
	38					430	439		464	449						9		25	N	19
	39					440	443		487	495						3		44	8	55
	40					438	418		456	440						N		38	N	2
	41					510	529		594	583						19		65	N	73

Notes:

R - Redeployed washer assembly, but no measurement taken.
W - Washer assembly off rod.
N - Negative value (indicates either no change within measuring accuracy or a disturbance of washer assembly took place).
/ - Separates measurements taken before/after washer assembly redeployed.
* - Change since last time washer assembly was redeployed.

TABLE 3-3

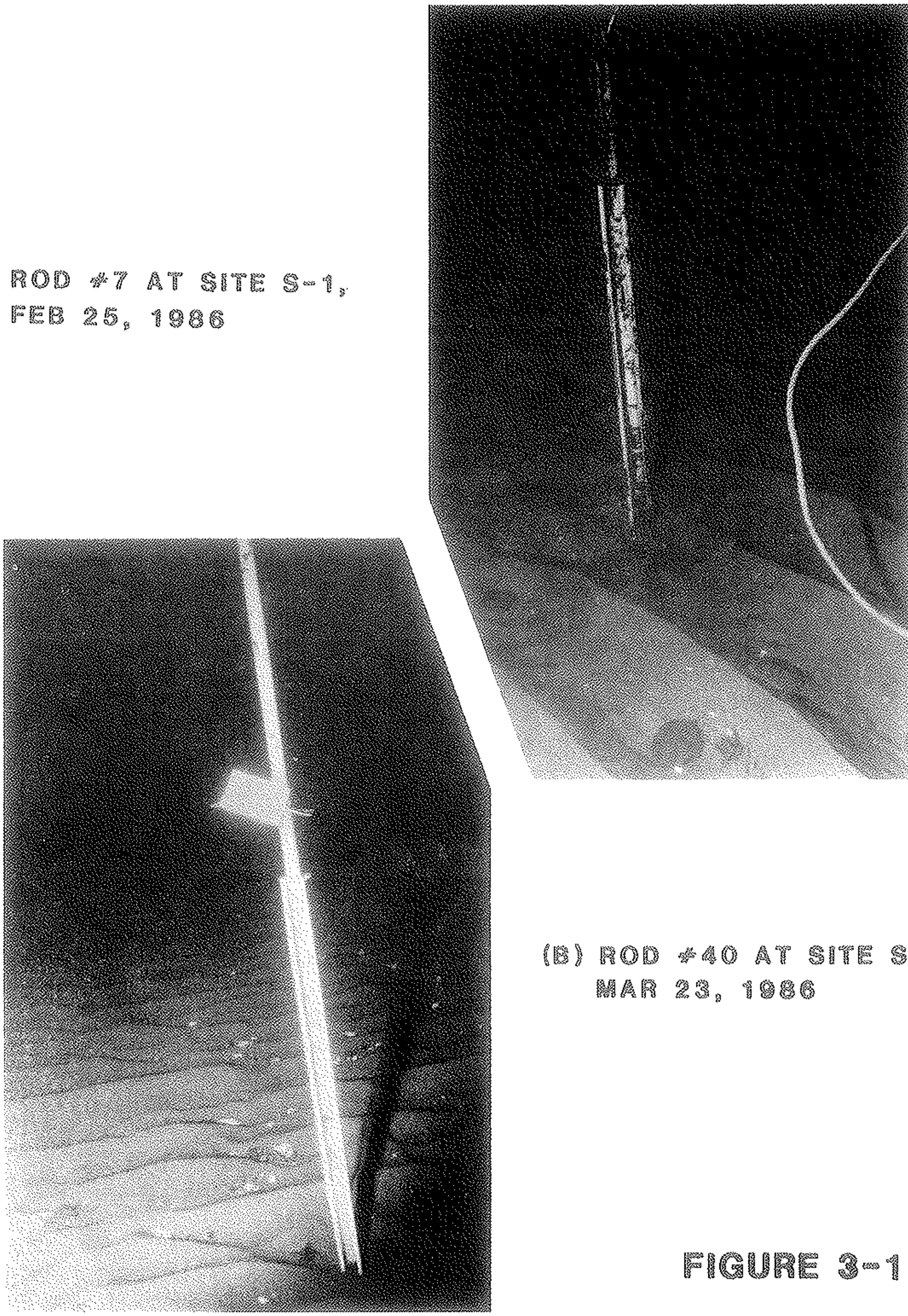
SUMMARY OF POST-STORM SEDIMENT ACCRETION
(where calculable)

Site No.	Rod No.	Accretion (mm) Jan 25	Feb 1	Feb 4	Feb 8	Feb 11	Feb 25	Mar 4	Mar 23	July 7
S-1	1		57						18	0
	2		83						25	0
	3		61						54	16
	4		14							27
	5		68				20		0	20
	6		43				15		0	74
	7		39				15		0	11
	8		67						55	0
	9		59				10		2	0
	10									
	11									
S-3	12				12		16	0	0	
	13									
	14									
	15									
	16									
	17				3				9	
	18									
	19				18				102	
	20				29					
	21				0				45	
S-2	22								48	20
	23									
	24								46	
	25							0		7
	26							0		42
	27									27
	28									26
	29								71	21
	30									43
	31							0	129	
S-4	32									
	33								87	
	34									
	35							0		
	36									
	37							10	36	15
	38							14	6	0
	39							5	39	32
	40							0	31	0
	41							3	59	0

Note:

The occurrence of accretion as presented in this table is conditional on the occurrence of some gross erosion occuring between measurements. It is calculated as the downward shift in the washer assembly minus the downward shift in the seafloor with respect ot the top of the rod. If there was negligible shift in the washer assembly or the washer assembly was found to be disturbed, then post-storm accretion could not be measured.

(A) ROD #7 AT SITE S-1,
FEB 25, 1986



(B) ROD #40 AT SITE S-4,
MAR 23, 1986

FIGURE 3-1

PHOTOS OF ROD AND WASHER ASSEMBLIES AND BEDFORMS the following cruise of February 1st, the diver reported that there were small ripples with crests 30 to 40 mm high and 170 mm apart, with the crests running in a NE direction. On February 25th, the bedforms at site S-1 were reported to be small regular ripples 20 to 30 mm high with crests 76 mm apart and running E-W. During a subsequent cruise on March 23rd, the ripples were found to have a height of 38 mm and a wavelength of 110 mm, running in an E-W direction. On the final cruise of July 7th, the bedforms at site S-1 had crests 38 to 51 mm high and 200 to 254 mm apart, running E-W.

During the initial cruise to site S-2 on February 8th, large gravel ripples were observed. These were 0.30 m high, with a wavelength of 1.83 m and crests orientated E-W. On the following cruise, February 11th, the ripples were reported to be 0.36 m high and 1.52 m apart. Measurements taken on March 4th indicated that the ripples were 0.44 m high with a wavelength of 1.89 m. The diver stated that a shift in crest orientation appeared to have taken place, with the crest of the gravel ripple staked by rods No. 22 to No. 25 being concave to the north (i.e. the crest had migrated south about 0.3 m by rods No. 23 and No. 24). On March 23rd, the ripples were found to have crests 0.29 m high and 1.22 m apart. During a subsequent cruise on May 29th, the diver reported that the gravel troughs were infilling with coarse-fine sand bedforms running at right angles to the gravel ripples. The ripples appeared to be reorientated as they were on February 8th. On the final cruise of July 7th, the bedforms at site S-2 had crests 0.16 m high and were 1.5 m apart.

During the initial cruise to site S-3 on February 4th, the measurements indicated that the bedforms were small ripples 13-25 mm high with crests 100 mm apart running E-W. On the following cruise of February 8th, two sets of ripples were reported. One set had crests 19 mm high and 290 mm apart, orientated E-W, and the other ripples had crests 13 mm high and 570 mm apart, orientated N-S. On February 25th, the diver reported ripples with crests 15 mm high and 170 mm apart orientated E-W. On the final cruise to site S-3 on March 23rd, the ripples had crests 20 to 40 mm high and 90 to 210 mm apart running in a variety of directions (i.e. a three dimensional ripple field).

During the initial cruise to site S-4 on February 11th, the diver reported ripples 25 to 51 mm high with crests 305 mm apart, aligned in an E-W direction. Measurements taken on February 25th indicated that the crests were 10 to 25 mm high and 130 to 180 mm apart orientated E-W.

During the cruise of March 23rd, the ripples were reported to be 25 mm high with crests 178 mm apart, orientated ENE-WSW. On the final cruise of July 7th, the bedforms at site S-4 had crests 30 mm high and 230 mm apart orientated E-W.

3.3 Grain Size

The results of the grain size sieve analysis of 45 sediment samples taken from the measurement sites are presented in Table 3-4 and Appendix C. The time series of average D_{50} for each site are plotted in Figures 3-2 to 3-5.

Analysis of samples taken from the box core at site S-3 shows that the material near the bottom of the core is slightly coarser than the material near the top. Figure 3-6 shows the resin peel prepared from this box core. The grain size distribution for the disturbed top of the box core may not be accurate because some sand was lost when recovering the box core.

Results of the grain size analysis of grab samples taken at the seafloor depression site indicate that the sediments both inside and outside the depression were sand, with D_{50} of about 0.2 mm. The sand inside the depression had a slightly coarser fraction with D_{90} of 10 mm, while the sand outside the depression had D_{90} of 0.22 mm. The sediment on the walls of the depression was silt and clay with 6% sand.

3.4 Oceanographic Conditions

The two principal sets of oceanographic data obtained during the study were measurements of surface gravity waves and near-bottom water velocities.

The wave data were collected hourly by CASP for the period from January 10 to March 31, 1986, and every three hours by Marine Environmental Data Service, using a permanent waverider located off Osborne Head, N.S. There were two CASP wave instruments located near the study site as shown on Figure 1-1. Tables 3-5 and 3-6 provide a summary of wave conditions during the study.

The near-bottom Aanderaa current meter data show that the largest mean currents recorded were 0.23 m/s. More typically the daily current maxima were in order of 0.1 m/s and the average current was roughly 0.05 m/s. This demonstrates that the study area was one of wave dominated near-bottom water velocities.

TABLE 3-4

SUMMARY OF GRAIN SIZES

Site	Sample No.	D_{50} (mm)	Date	Location*	Grain Size Distribution Figure ****
S-1	S1-1	0.17	86/1/25	G-10	C-1
	S1-2	0.16	86/1/25	G-10	C-2
	S1-3	0.15	86/1/25	G-19	C-3
	S1-4	0.15	86/1/25	G-25	C-4
	S1-5	0.16	86/2/1	by rod #5	C-8
	S1-6	0.19	86/2/1	by rod #2	C-9
	S1-7	0.23	86/2/25	S of rod #2	C-24
	S1-8	0.19	86/2/25	S of rod #6	C-25
	S1-9	0.22	86/3/4	S of rod #5	C-27
	S1-10	0.20	86/3/23	by rod #7	C-32
	S1-11	0.22	86/3/23	by rod #5	C-33
	S1-12	0.19	86/7/7	by rod #7	C-41
	S1-13	0.20	86/7/7	by rod #5	C-42
S-2	S2-1	13.0	86/1/25	at highflyer	C-5
	S2-2	4.0	86/2/8	between rods #23 (crest) and #24 (trough)	C-13
	S2-3	11.0	86/2/8	between rods #30 and #31	C-14
	S2-4	9.0	86/3/4	by rod #26	C-26
	S2-5	13.0	86/3/23	by rod #25	C-34
	S2-6	6.0	86/3/23	by rod #26	C-35
	S2-7	7.0	86/7/7	by rod #29	C-44
	S2-8	2.6	86/7/7	by rod #31	C-45
S-3	S3-1	2.0	86/1/25	by mooring **	C-6
	S3-2	0.18	86/2/4	by mooring ***	C-10
	S3-3	0.18	86/2/4	17 m E of highflyer	C-11
	S3-4	0.17	86/2/4	at highflyer	C-12
	S3-5	0.19	86/2/8	by rod #16	C-15
	S3-6	0.17	86/2/8	by rod #17	C-16
	S3-7	0.30	86/2/25	by clump	C-22
	S3-8	0.30	86/2/25	by current meter	C-23
	S3-9	0.24	86/3/4	bottom 10 cm of box core	C-28
	S3-10	0.20	86/3/4	10-20 cm of box core	C-29
	S3-11	0.19	86/3/4	0-10 cm of box core	C-30
	S3-12	0.21	86/3/4	disturbed top of box core ***	C-31
	S3-13	0.22	86/3/23	by rod #20	C-36
	S3-14	0.25	86/3/23	by rod #14	C-37
S-4	S4-1	14.0	86/1/25	at highflyer	C-7
	S4-2	0.18	86/2/11	22.9 m SE mooring	C-17
	S4-3	0.18	86/2/11	by mooring	C-18
	S4-4	0.20	86/2/25	by current meter	C-19
	S4-5	0.27	86/2/25	by rod #37	C-20
	S4-6	0.27	86/2/25	by rod #37	C-21
	S4-7	0.22	86/7/7	by rod #36	C-43
SD	SD-1		86/6/21	edge of hole	C-38
	SD-2		86/6/21	inside of hole	C-39
	SD-3		86/6/21	outside of hole	C-40

* See site plans in Section 2.3 for locations.
** This vessel mooring was subsequently moved on Cruise No. 6.
*** Some fines may have been lost.
**** Appendix E figure numbers are sequential in the chronological order in which the samples were obtained.

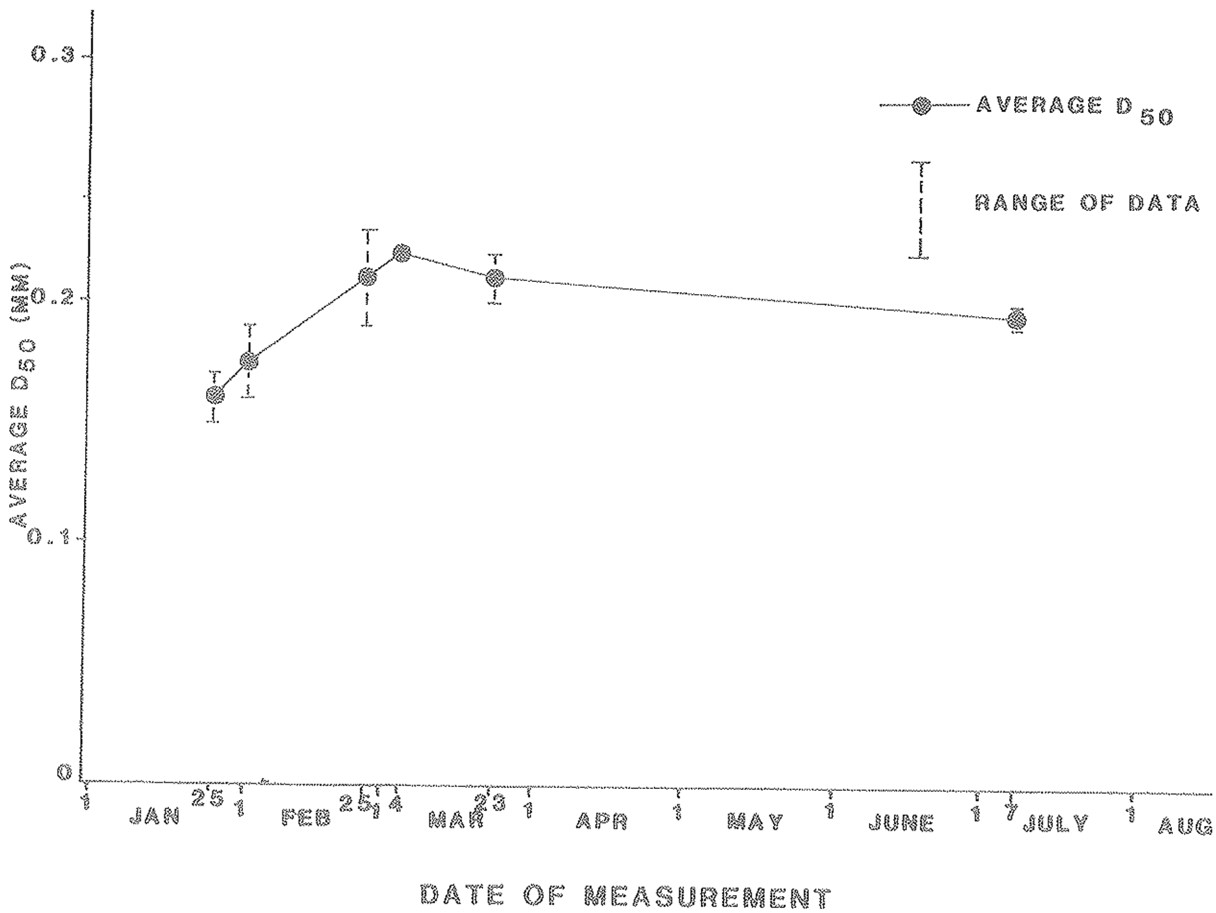


FIGURE 3-2

AVERAGE D_{50} GRAIN SIZE FOR SITE S-1

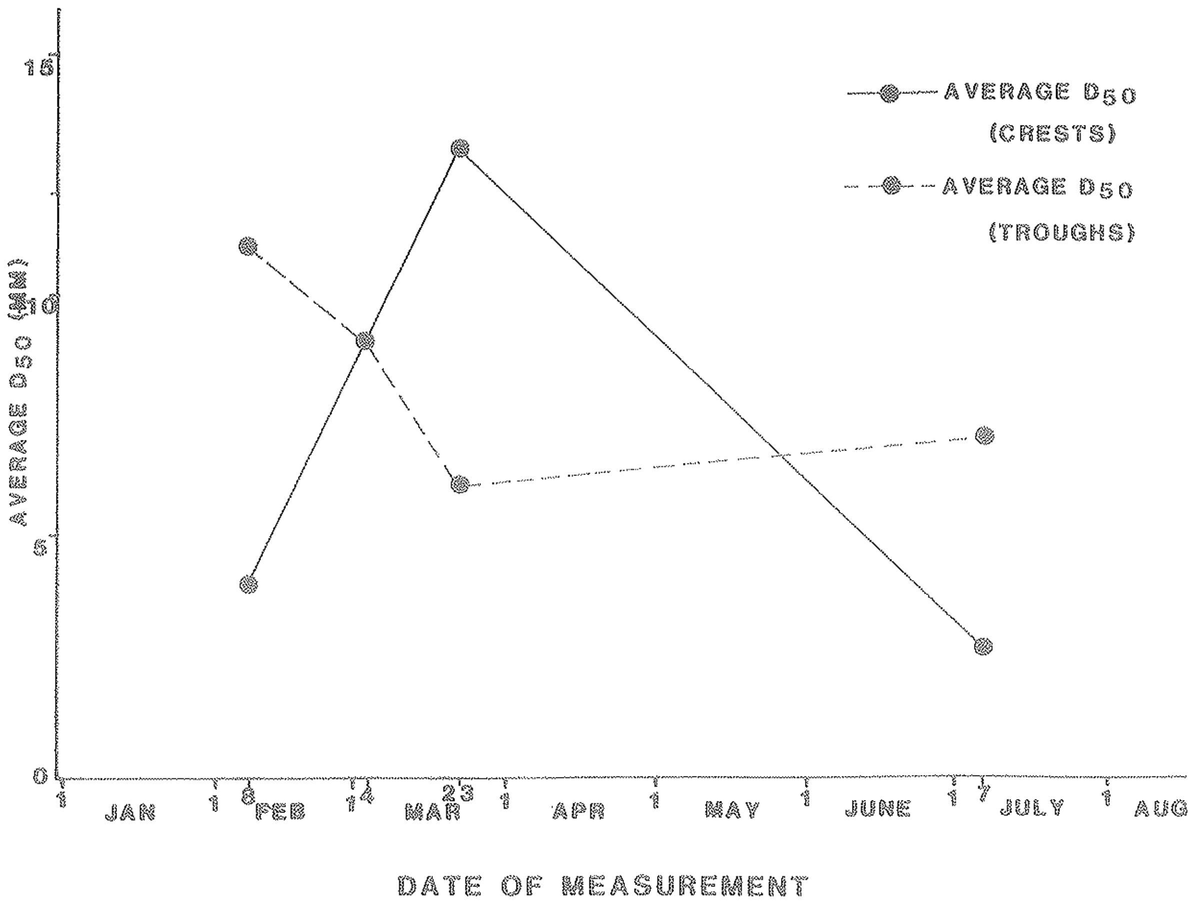


FIGURE 3-3

AVERAGE D_{50} GRAIN SIZE FOR SITE S-2

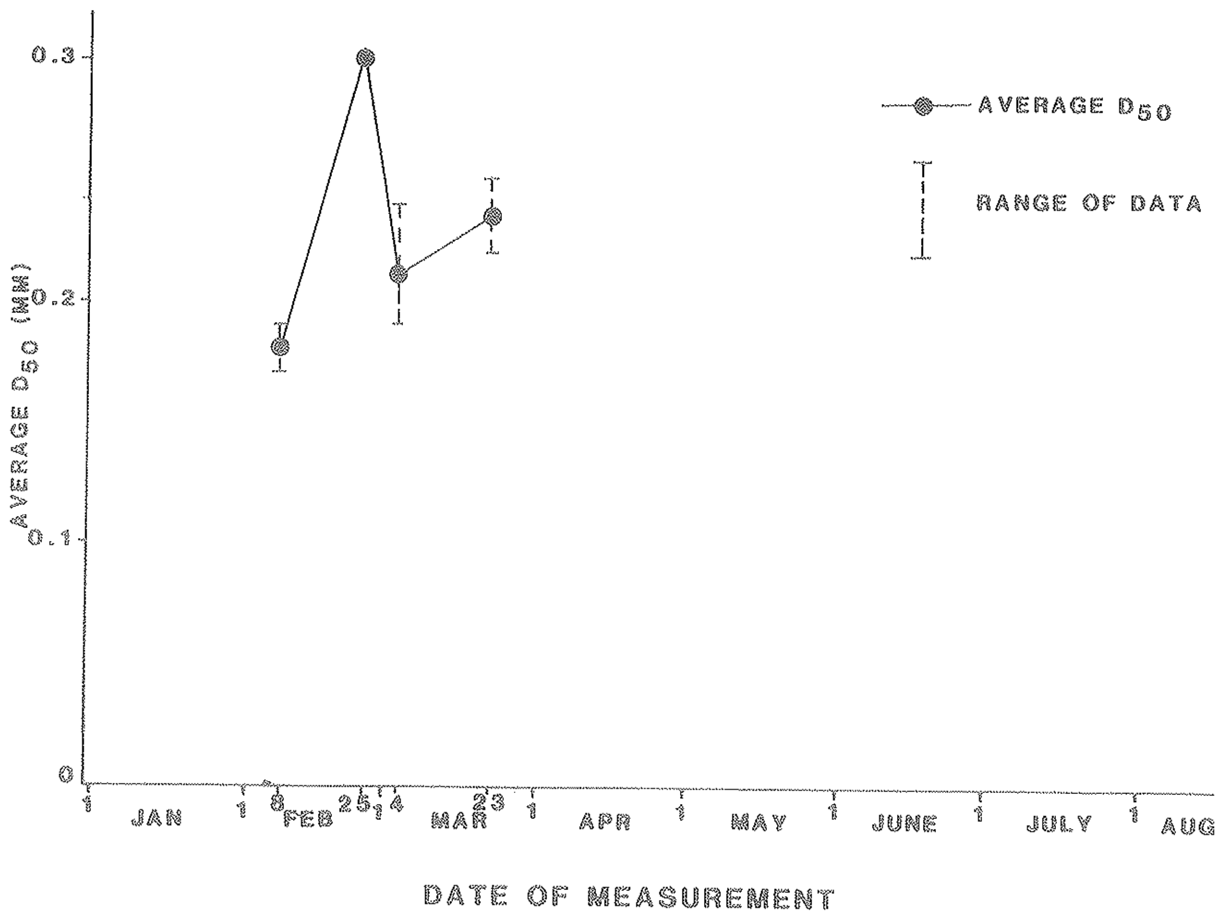


FIGURE 3-4

AVERAGE D_{50} GRAIN SIZE FOR SITE S-3

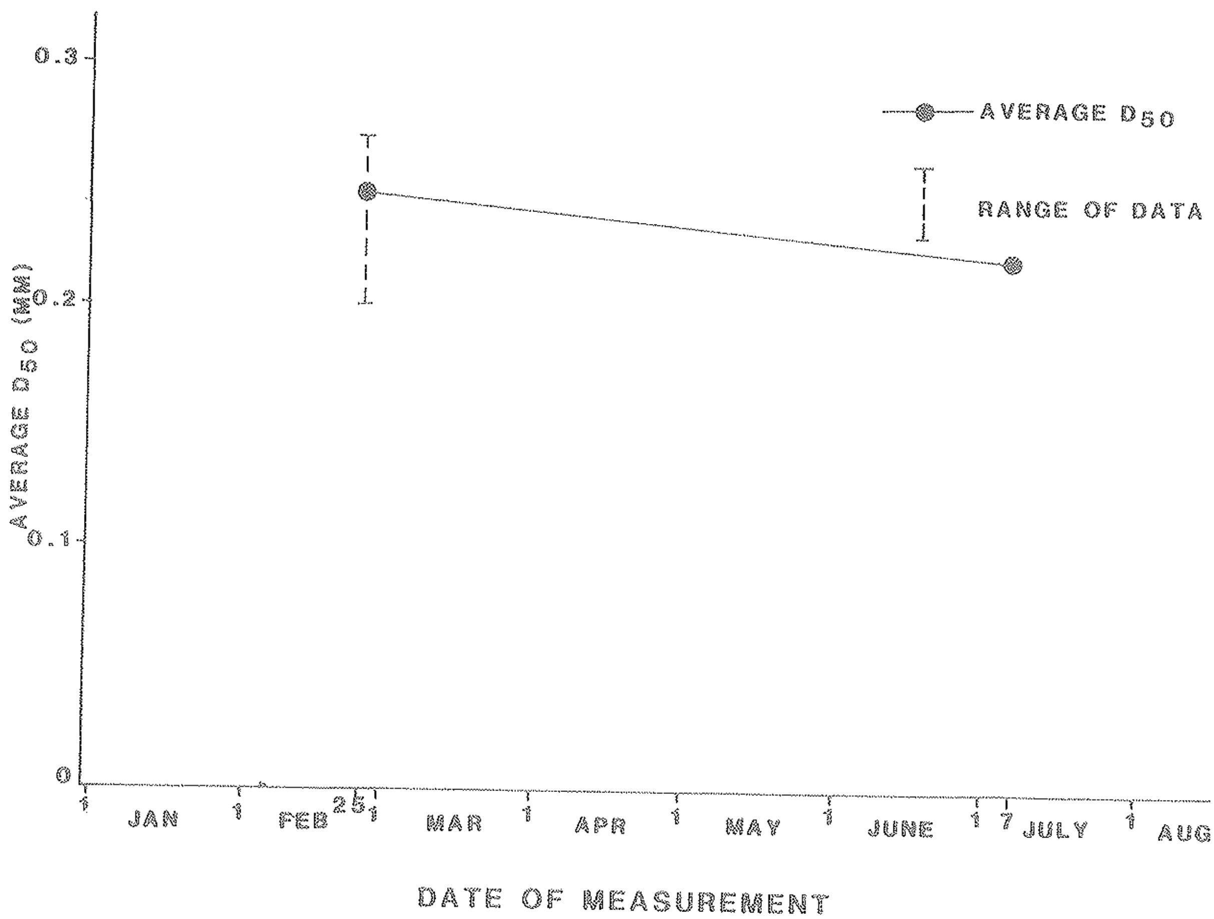


FIGURE 3-5

AVERAGE D_{50} GRAIN SIZE FOR SITE S-4

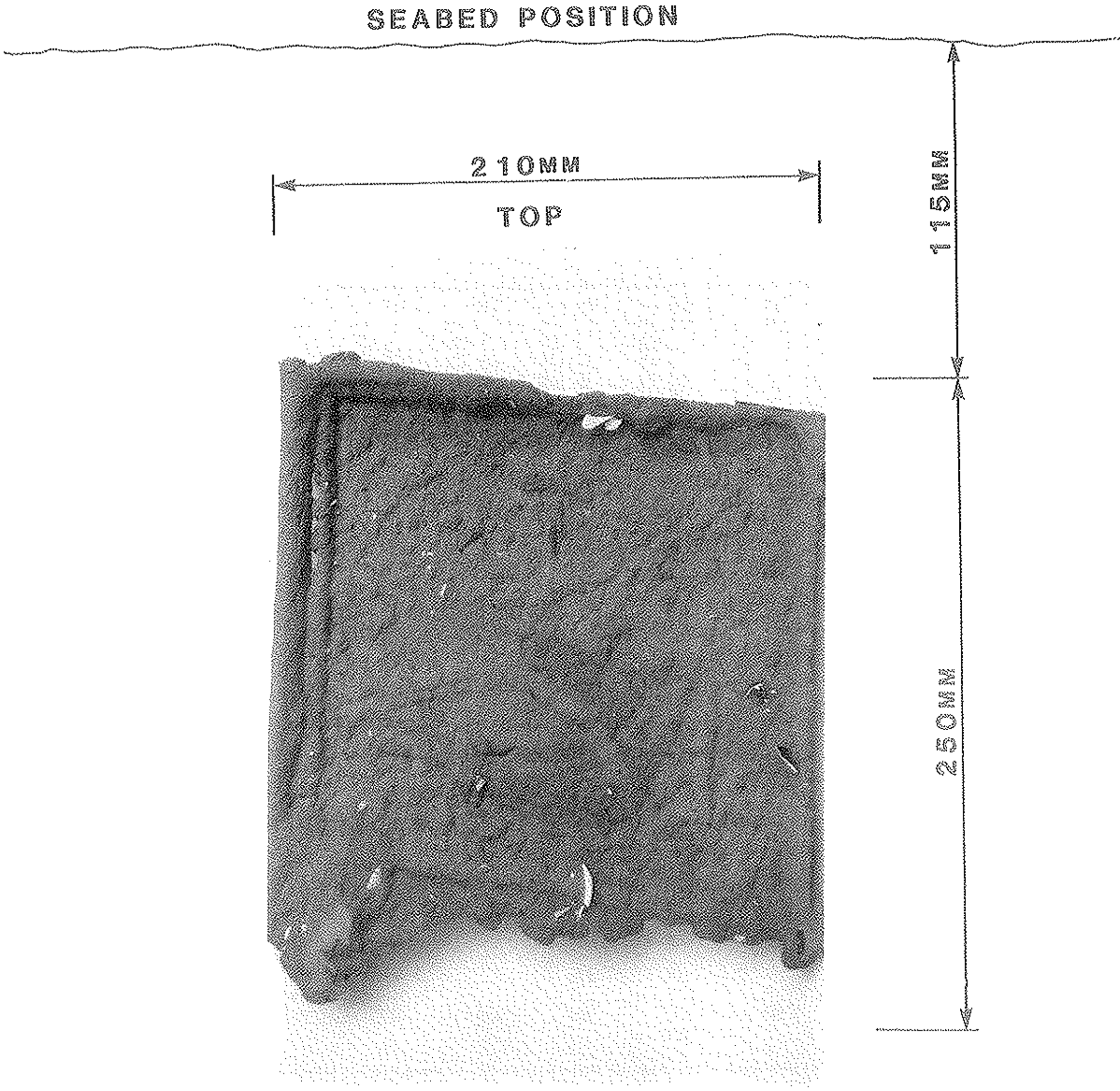


FIGURE 3-6

PHOTO OF RESIN PEEL

TABLE 3-5
SUMMARY WAVE STATISTICS FOR CASP WAVERIDER #2
(Covering the Times Between Cruises)

Start Time	End Time	Highest Height* m	Peak Spectral Period** s	Time**	Lowest Height* m	Peak Spectral Period** s	Time**	Average Height* m	Average Spectral Period** s
Jan. 11 (1200)	Jan. 17 (1200)	.85	7.14	Jan. 16 (0000)	.0	7.7	Jan. 15 (2100)	.28	3.5
Jan. 17 (1200)	Jan. 22 (1200)	4.2	12.5	Jan. 21 (0200)	1.1	8.0	Jan. 19 (2100)	2.3	9.1
Jan. 22 (1200)	Jan. 25 (1200)	2.1	8.7	Jan. 23 (1000)	.3	8.7	Jan. 25 (1000)	1.1	7.2
Jan. 25 (1200)	Feb. 1 (1200)	5.2	12.5	Jan. 29 (0200)	.3	8.7	Jan. 25 (1300)	2.3	9.6
Feb. 1 (1200)	Feb. 4 (1200)	3.8	8.7	Feb. 3 (0000)	.7	8.7	Feb. 2 (1100)	1.5	9.1
Feb. 4 (1200)	Feb. 8 (1200)	2.2	8	Feb. 5 (2300)	.4	9.1	Feb. 5 (0200)	1.2	8.5
Feb. 8 (1200)	Feb. 11 (1200)	1.3	5.4	Feb. 9 (2000)	.5	9.1	Feb. 8 (1600)	.9	5.1
Feb. 11 (1200)	Feb. 25 (1200)	2.8	7.7	Feb. 22 (1400)	.4	8.0	Feb. 12 (1400)	1.2	9.4
Feb. 25 (1200)	Mar. 4 (1200)	3.3	11.8	Mar. 1 (0800)	.8	11.8	Mar. 3 (0200)	1.8	10.1
Mar. 4 (1200)	Mar. 23 (1200)	5.3	11.1	Mar. 7 (2000)	.5	8.3	Mar. 18 (1400)	1.9	9.5
Mar. 23 (1200)	Mar. 31 (2300)	2.6	7.4	Mar. 26 (1900)	.8	4.9	Mar. 26 (0200)	1.5	8.6

* Characteristic wave height (4* signal variance).
** From the spectrum with the corresponding characteristic wave height.

TABLE 3-6
SUMMARY WAVE STATISTICS FOR CASP WAVEC #1
(Covering the Times Between Cruises)

Start Time	End Time	Highest Height* m	Peak Spectral Period** s	Time**	Lowest Height* m	Peak Spectral Period** s	Time**	Average Height* m	Average Spectral Period** s
Jan. 11 (1200)	Jan. 17 (1200)	---	---	---	---	---	---	---	---
Jan. 17 (1200)	Jan. 22 (1200)	3.9	13.3	Jan. 21 (0300)	1.0	7.7	Jan. 19 (0800)	2.1	9.0
Jan. 22 (1200)	Jan. 25 (1200)	2.1	10.5	Jan. 23 (0300)	.2	8.3	Jan. 25 (0500)	1.0	7.9
Jan. 25 (1200)	Feb. 1 (1200)	4.6	15.4	Jan. 29 (0300)	.2	9.1	Jan. 25 (1300)	2.0	9.9
Feb. 1 (1200)	Feb. 4 (1200)	3.5	8.7	Feb. 2 (2300)	.5	0	Feb. 2 (1000)	1.3	7.1
Feb. 4 (1200)	Feb. 8 (1200)	2.1	7.4	Feb. 5 (2200)	.4	8.3	Feb. 5 (0300)	1.1	8.7
Feb. 8 (1200)	Feb. 11 (1200)	1.2	4.1	Feb. 9 (2000)	.4	8.7	Feb. 8 (1400)	.8	5.3
Feb. 11 (1200)	Feb. 25 (1200)	2.4	7.4	Feb. 22 (1400)	.3	8.3	Feb. 12 (1200)	.8	9.0
Feb. 25 (1200)	Mar. 4 (1200)	2.8	12.5	Mar. 1 (0900)	.6	12.5	Mar. 3 (0100)	1.6	10.5
Mar. 4 (1200)	Mar. 23 (1200)	4.4	10.0	Mar. 7 (2000)	.4	6.9	Mar. 10 (1100)	1.6	9.5
Mar. 23 (1200)	Mar. 31 (2300)	2.2	7.4	Mar. 26 (1900)	.6	10.0	Mar. 25 (0800)	1.3	8.6

* Characteristic wave height (4* signal variance).
** From the spectrum with the corresponding characteristic wave height.

3.5 Seafloor Depressions

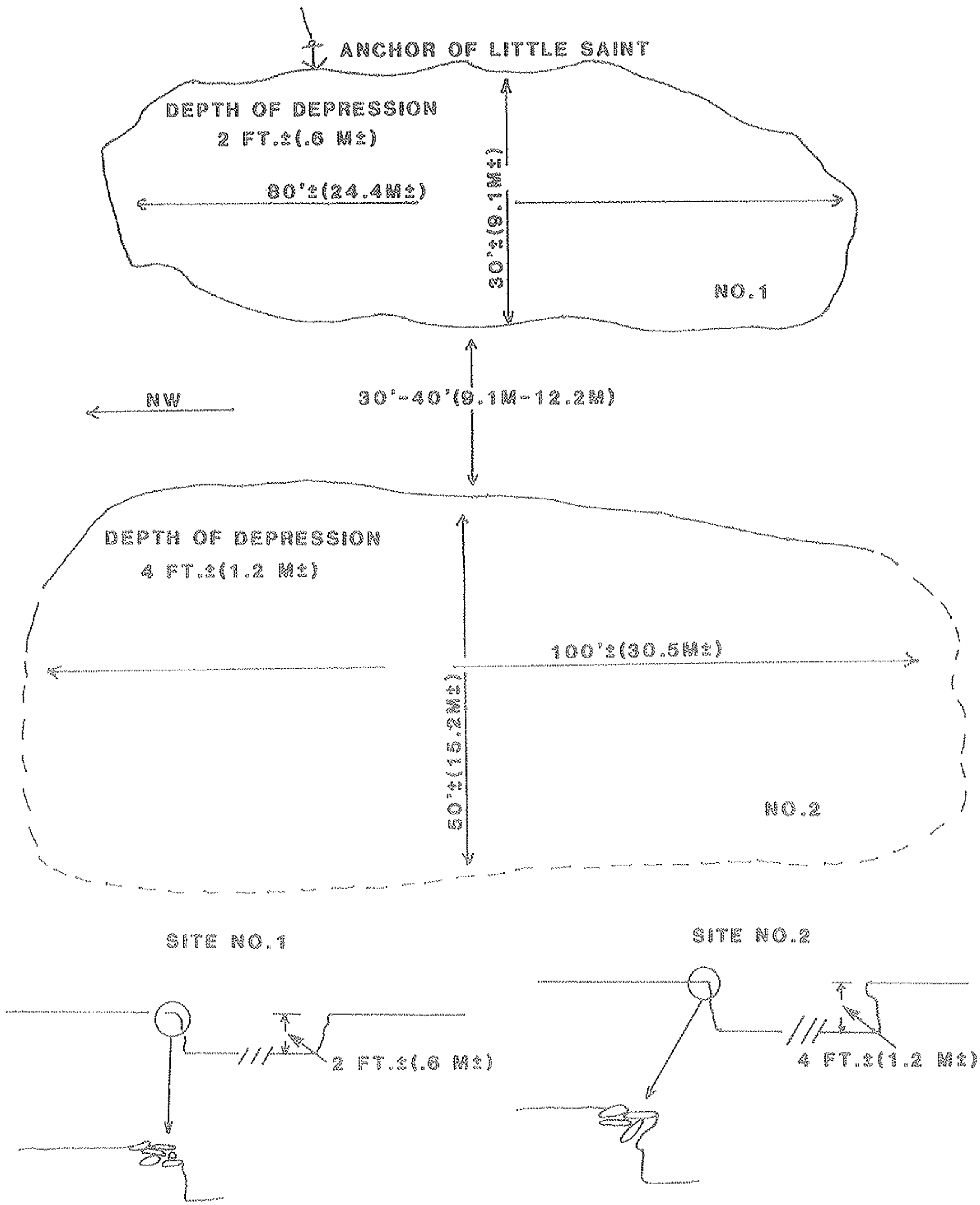
The anomalous depressions discovered on May 29 near site S-3 were reported by the diver (see sketch reproduced as Figure 3-7) as being roughly elliptical in planform, with long axis dimensions of about 24 to 30 m and widths of roughly 9 to 15 m. The depth of the depressions observed on that occasion was between 0.6 and 1.2 m.

Measurements obtained at the site later, on June 21, were used to prepare a plan and profile (Figures 3-8 and 3-9). The profile was taken along a survey line running E-W across the south end of a roughly elliptical depression, which appeared to be partly infilled with sand at the north-east end, giving it a 'horseshoe' appearance. Both the floor of the depression and the adjacent seafloor were approximately horizontal, with ripples 10 mm high, 30 mm in wavelength, aligned roughly E-W. The sidewalls were irregular near-vertical faces developed in mud (see Section 3.3), partly covered by deposits of cobble-sized cohesive sediment rubble. Sidewall faces up to 2.4 m high were observed by the diver. Photographs of the depression site are shown in Figure 3-10.

3.6 Summary of Seafloor Changes

The largest net changes in seafloor elevation (Table 3-1) were 97 mm of erosion between February 11 and February 25 at site S-4 (37 m sand site) and 127 mm of accretion between March 4 and March 23 at site S-2 (30 m gravel site). Note that the relief of the gravel ripple bedforms at site S-2 was 290 mm on March 23 (Section 3.2). In some cases, the measurements indicated no net change in seafloor elevation between visits. The largest gross erosion between detections (as indicated by the washer assemblies) was 93 mm between January 25 and February 1 at site S-1 (Table 3-2). A more detailed examination of the data for site S-1 follows.

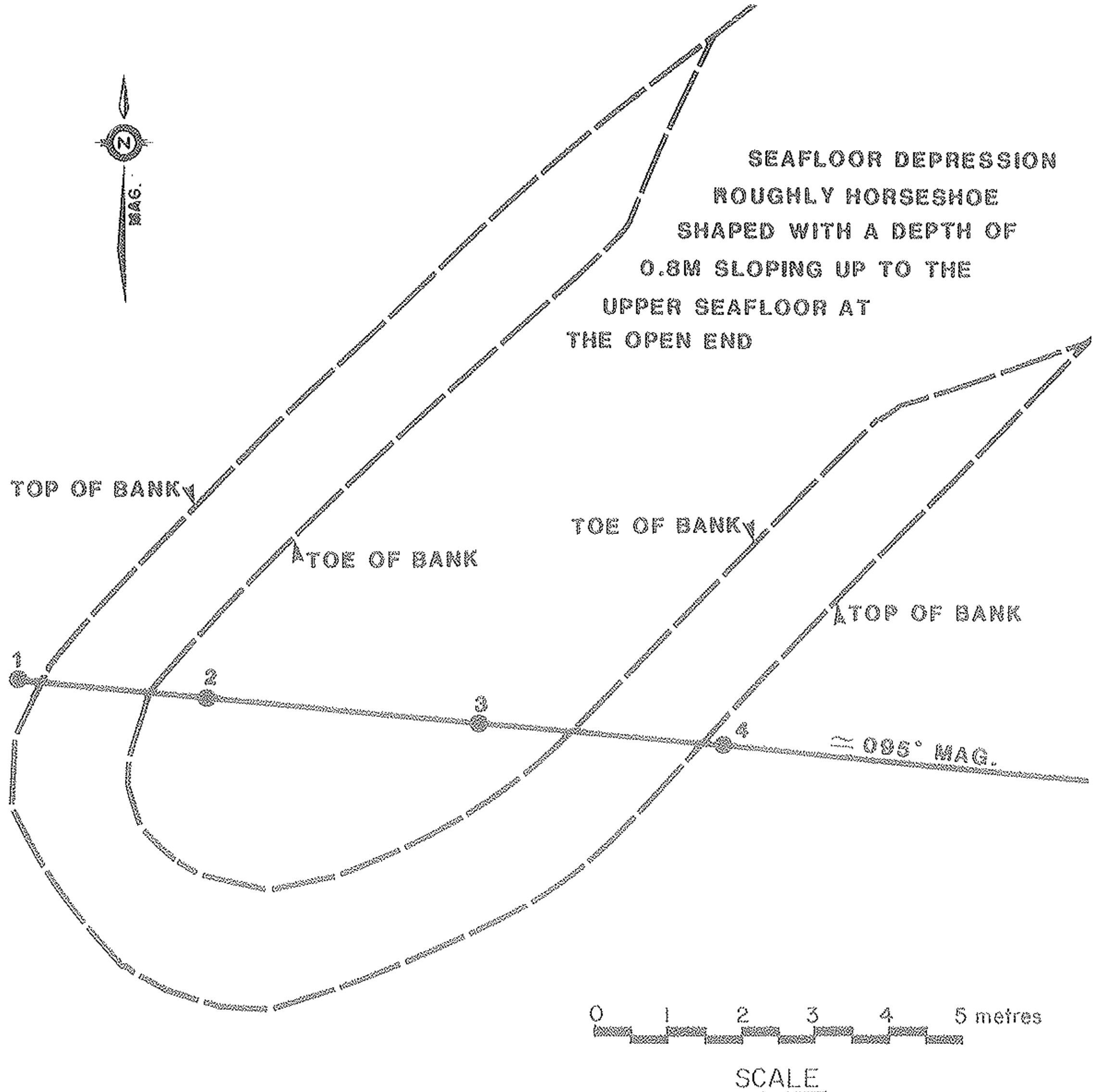
Between January 25 and February 1, site S-1 experienced gross erosion of 77 ±26 mm (mean ±95% confidence in the estimate). By February 1 the seafloor had accreted 56 ±17 mm to bring it back up to 21 ±17 mm below the January 25 level. By February 25, the seafloor had accreted an additional 17 ±12 mm, bringing it back to the January 25 level (within ±5 mm). From February 25 to March 4, there was no apparent change (based on measurements at only two rods). Between March 4 and March 23, there was 64 ±16 mm gross erosion. On March 23 the seafloor was down 11 ±38 mm with respect to the January 25 and February 25 levels. The



REPRODUCED FROM SKETCH BY D. MISNER, DOMINION DIVING

FIGURE 3-7

DIVER'S SKETCH OF SEAFLOOR DEPRESSION MAY 29, 1986

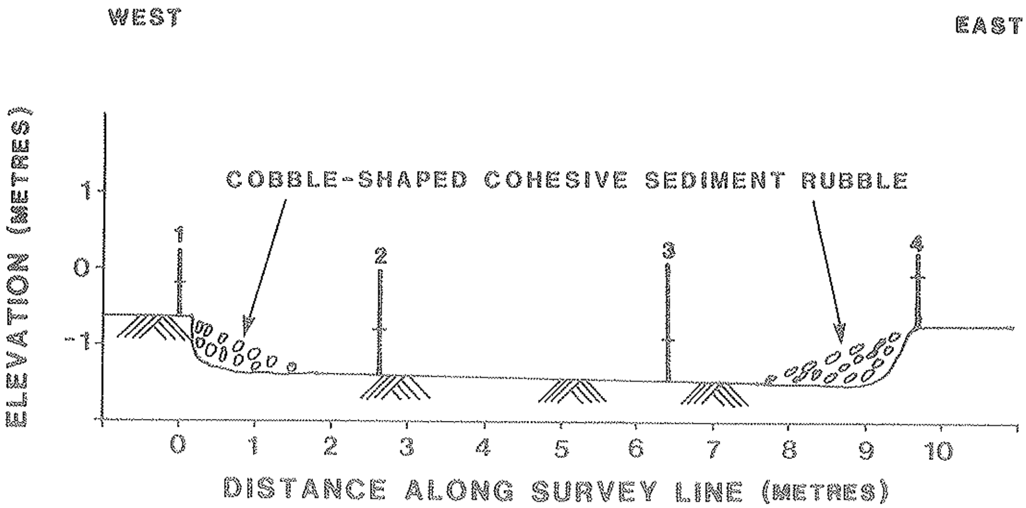


LEGEND

● ROD AND STEEL WASHER ASSEMBLY

FIGURE 3-8

PLAN OF SITE SD
SEAFLOOR DEPRESSIONS



NOTE: ELEVATION DATUM SET BY DIVERS WITH A LINE LEVEL FROM ROD 1 TO ROD 4. ELEVATION DATUM APPROXIMATELY 30M BELOW MSL.

FIGURE 3-9

PROFILE OF SEAFLOOR DEPRESSION

large error in the estimate suggests that there may have been no statistically significant net change between February 25 and March 23, but perhaps changes such as the migration of a long wavelength bedform could have resulted in a more uneven bottom. From March 23 to July 7, there was 12 ±5 mm gross erosion, followed by accretion to bring the seafloor 15 ±37 mm above the March 23 level. The total change from January 25 to July 7 was 4 ±48 mm of net erosion.

For site S-2 (the 30 m gravel site), there was a transient tendency for the gravel ripple crests and troughs to erode, followed by an infilling of the troughs. The final result was a slight shift in the orientation of the crests, with a tendency for the peaks of the crests (where they remained at the rods) to experience 10 to 20 mm of accretion.

For the 30 m and 37 m sand sites (sites S-3 and S-4), there was no statistically significant change in the seafloor elevation. The individual changes were all within the approximate range of the bedform heights with only a few exceptions.

Given the small gross and net changes observed at the monitoring sites, the discovery of anomalous depressions up to 2.4 m deep in the area raises serious questions about the potential for deep scour. These depressions were not apparent on sidescan records obtained in the area in January. Their age and genesis remain unclear.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The data collected during this study may be used for a more rigorous analysis of the behaviour of the seafloor under the oceanographic conditions that existed during the study. However, the oceanographic conditions were not extreme. The sea state never approached what could be considered design conditions for offshore structures and pipelines. Because of this, additional detailed analysis of the information gathered is required in order to make the best use of the data for furthering the understanding of seafloor stability under extreme conditions as well as the more moderate oceanographic conditions experienced during the study.

The cursory interpretation of the data that has been conducted for this report reveals that, while the seafloor was active at all sites, the erosion was less than 0.1 m as was the accretion that followed (except at one location in the gravel ripple site). The gravel ripples are apparently mobile. There is no obvious difference between the behaviour of the steel and nylon washer assemblies. However, detailed checking of the data and evaluation of individual rods should be conducted before it can be concluded that no liquefaction of the sea bed took place.

The cause of the seafloor depressions, that were observed during this study, is not known at this time and further investigation of these features is required. These features are a natural sediment trap, particularly for bed-load transport, and their existence should be exploited to assist in field calibration of numerical sediment transport models. The existence of these features is cause for concern, particularly until the mechanism for their formation is understood. This is because of the potential danger to pipelines and the problems that would arise during pipeline construction, if such features were encountered.

APPENDIX A

ARCHIVED DATA

The following notes, documents, and records produced during the course of this study have been deposited with the Atlantic Geoscience Centre at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. Interested persons may contact D.L. Forbes at 902-426-7737.

1. One copy of unpublished contract report.
2. Laboratory notes providing details of the flume testing program for the rod and washer assemblies (Section 2.2).
3. Original sample grain size data (Section 3.3).
4. CASP wave records (Section 3.4).
5. Aanderaa and S4 current meter records (Section 3.4).
6. One copy of original field notes.
7. All video records, photographs, and time-lapse film.
8. Sidescan sonar survey records and navigation log.

APPENDIX B

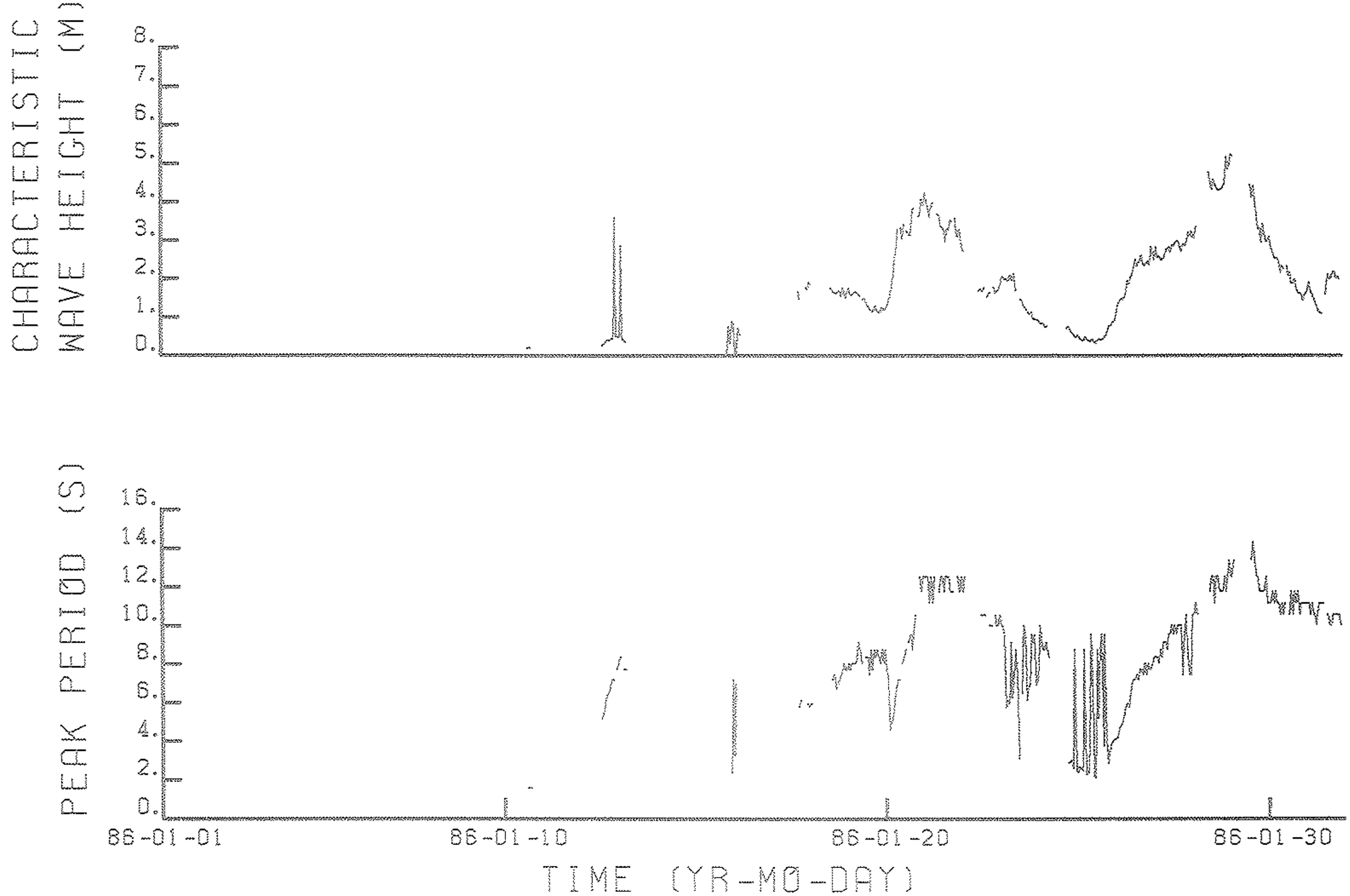
OCEANOGRAPHIC DATA

The CASP wave data stored at the BIO computer centre was accessed and wave data recorded by the CASP Waverider #2 and Wavec #1 were recovered. The significant wave heights H_s and peak spectral periods T_p from January 10th to March 31st are presented in Figures B-1 through B-6. To access this data, refer to Appendix A Item 1.

The locations of all current meters and their dates of deployment and recovery are shown in Table B-1. Analysis of the current water records was performed by the data shop of AOL. Time series plots of these data are presented in Figures B-7 to B-11.

TIME SERIES ØF CASP WAVE DATA

(CASP WAVERIDER #2)

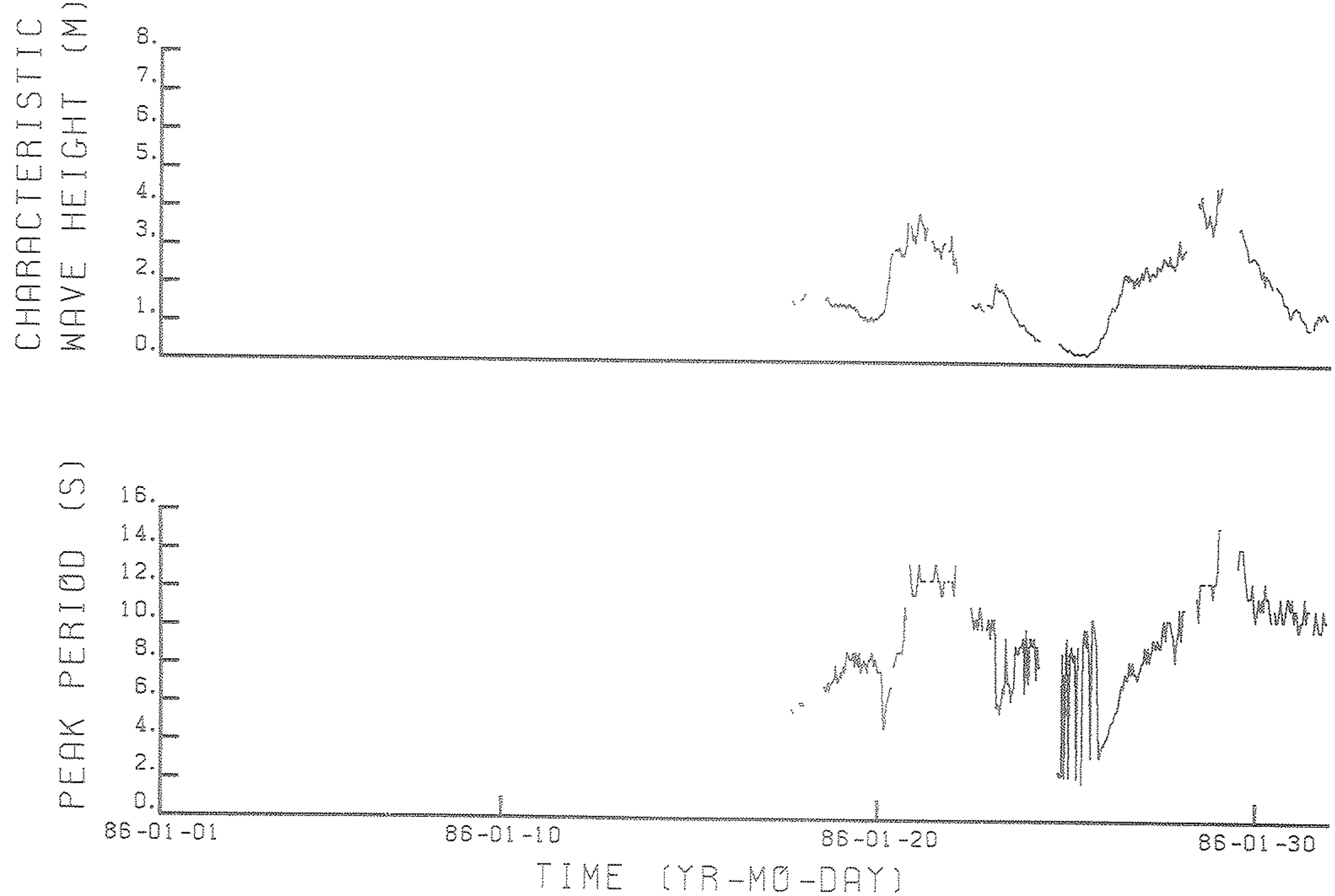


Martec Limited

FIGURE NØ: B-1

TIME SERIES ØF CASP WAVE DATA

(CASP WAVEC #1)

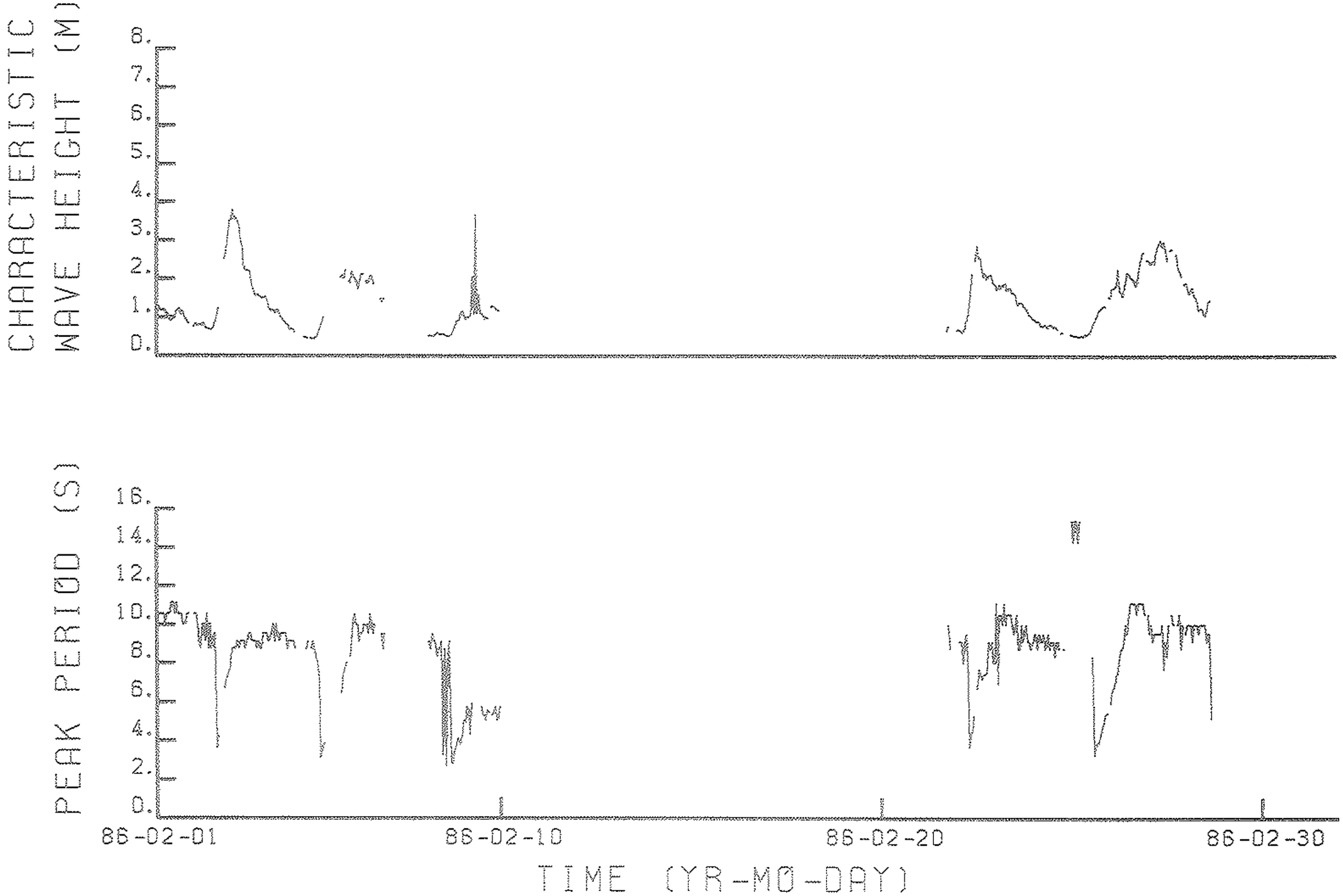


Martec Limited

FIGURE NØ: B-2

TIME SERIES OF CASP WAVE DATA

(CASP WAVERIDER #2)

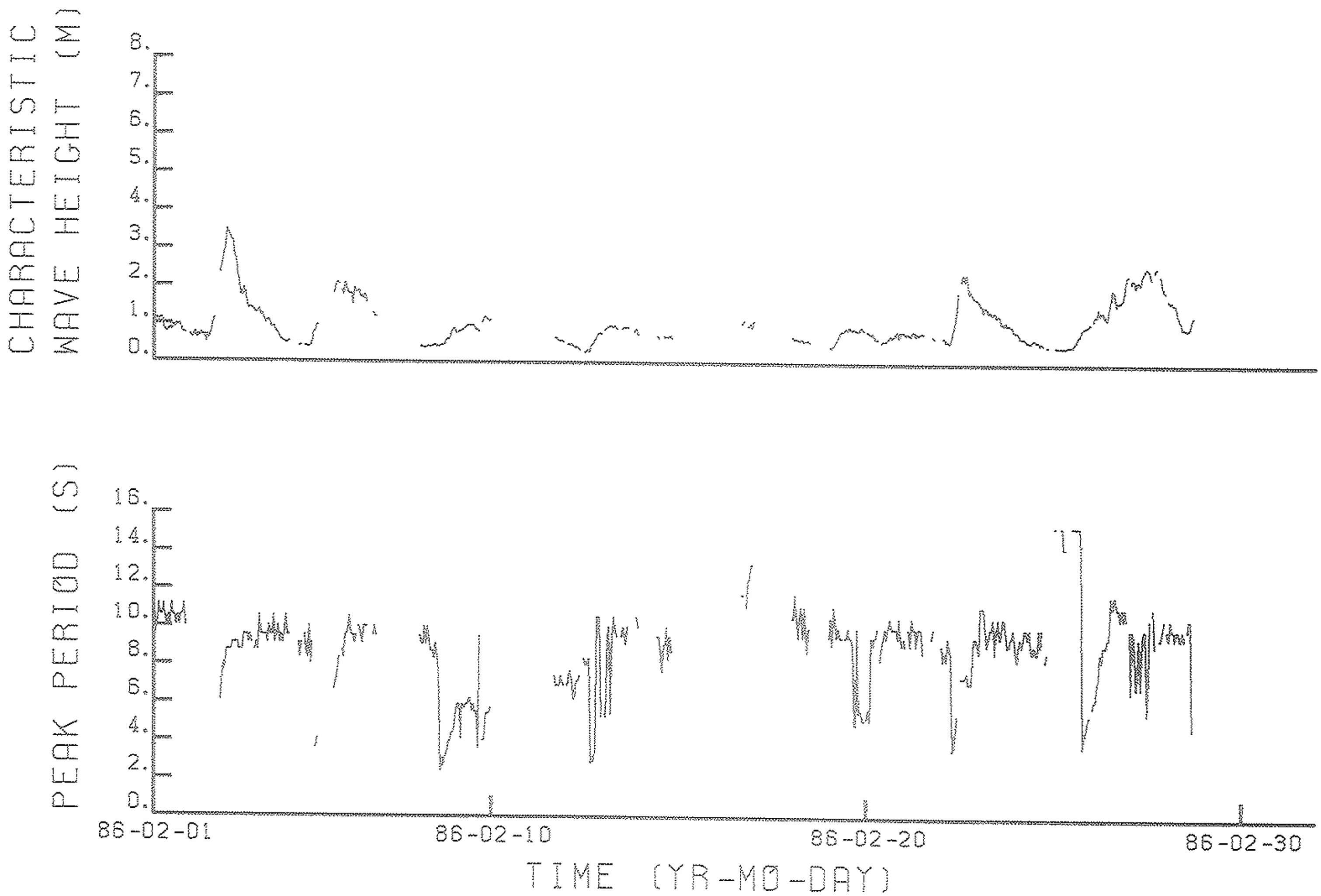


Martec Limited

FIGURE NO: B-3

TIME SERIES ØF CASP WAVE DATA

(CASP WAVEC #1)

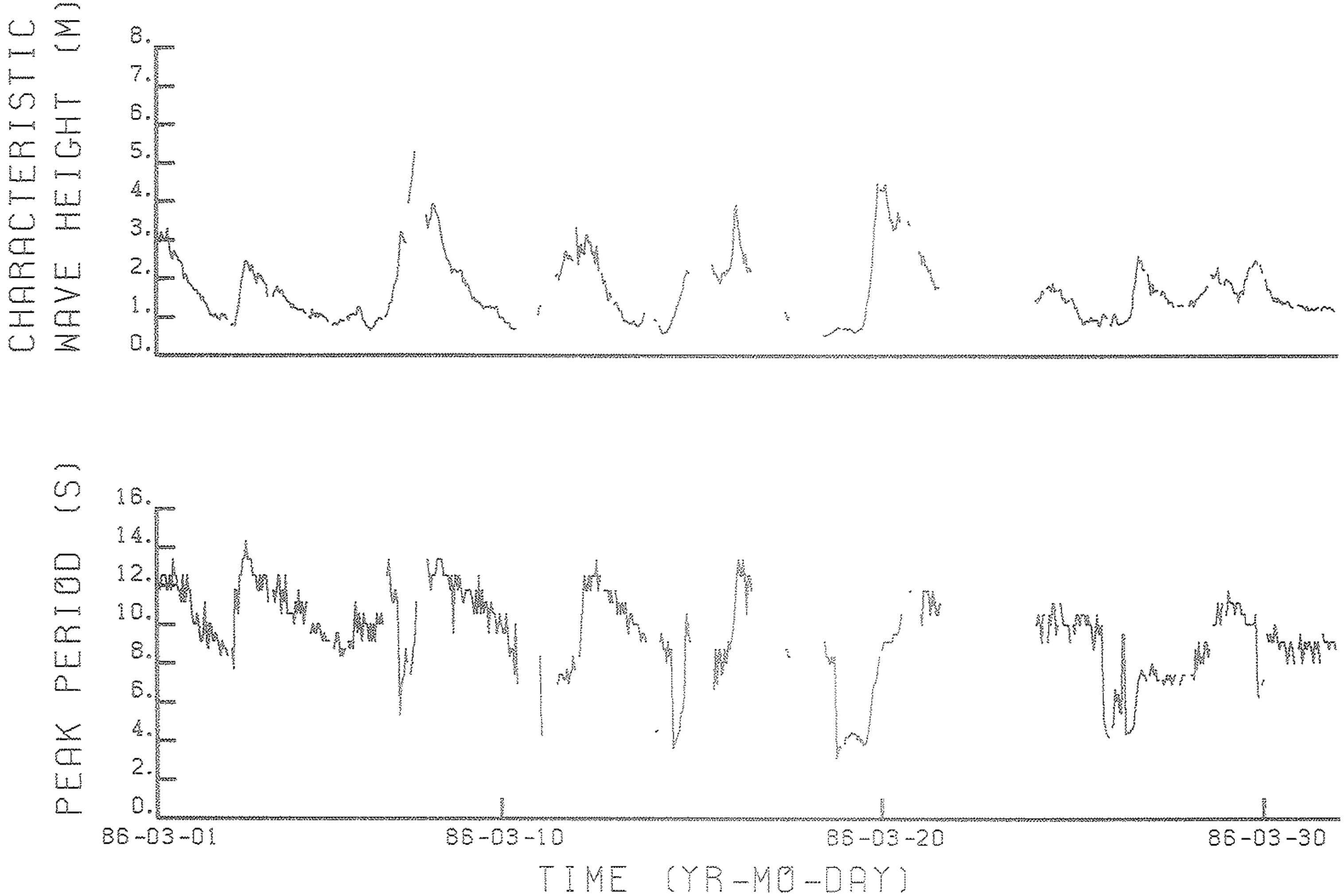


Martec Limited

FIGURE NØ: B-4

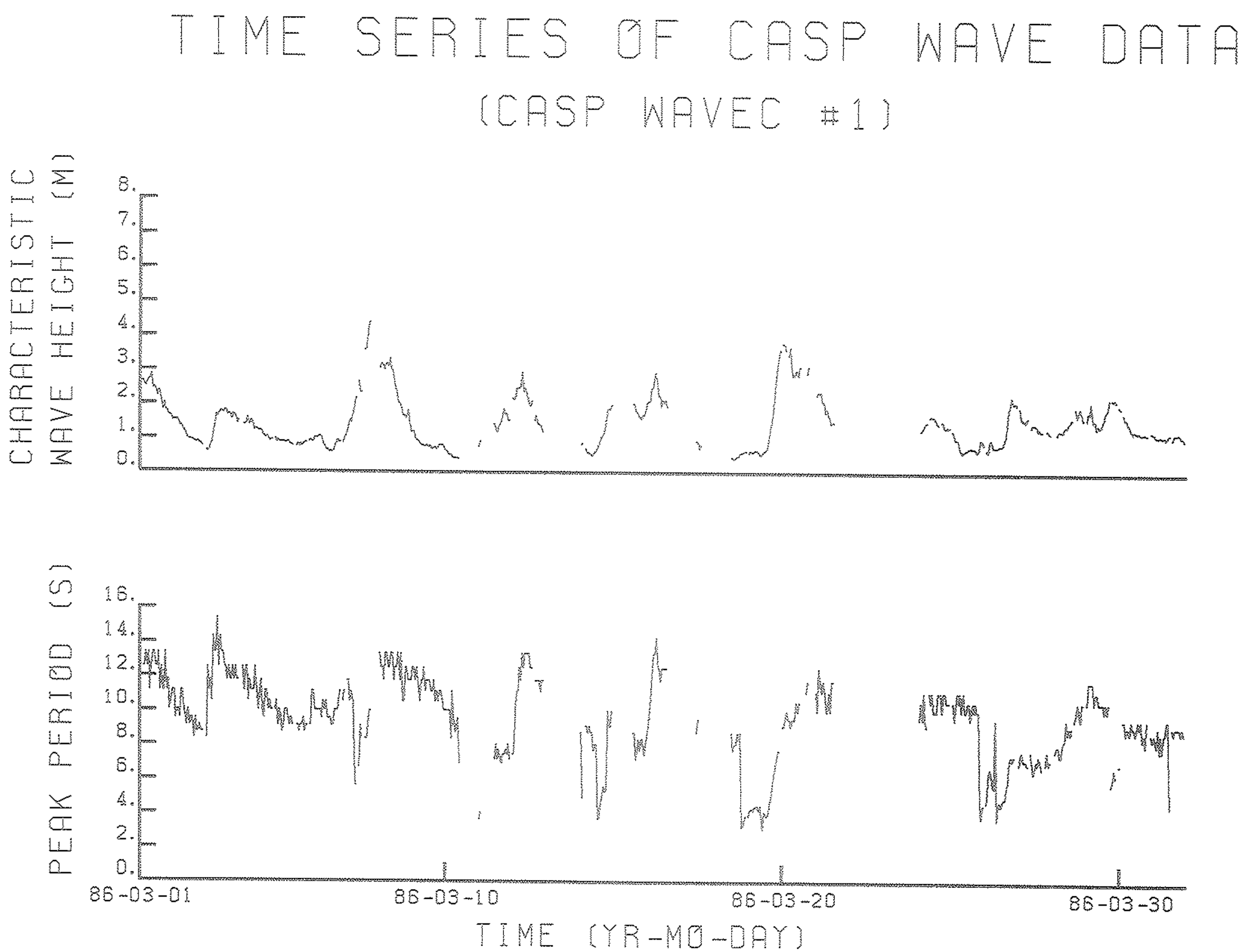
TIME SERIES ØF CASP WAVE DATA

(CASP WAVERIDER #2)



Martec Limited

FIGURE NØ: B-5



Martec Limited

FIGURE NØ: B-6

TABLE B-1

LOCATIONS AND DATES OF DEPLOYMENT
AND RECOVERY OF CURRENT METERS

Aanderaa current meter data (sampling every half hour).

Site	Current Meter Number	Duration
S-1	#1039	In: Jan. 25/86 Out: Feb. 1/86
	#6404	In: Feb. 1/86 Out: May 29/86
S-2	#217	In: Mar. 4/86 Out: May 29/86
S-3	#7132	In: Feb. 4/86 Out: July 7/86
S-4	#1039	In: Feb. 25/86 Out: Mar. 23/86

S-4 type burst sampling current meter data.

Site	Serial Number	Duration
100 m E of Site S-3	#03480552	In: Feb. 1/86 Out: Mar. 4/86

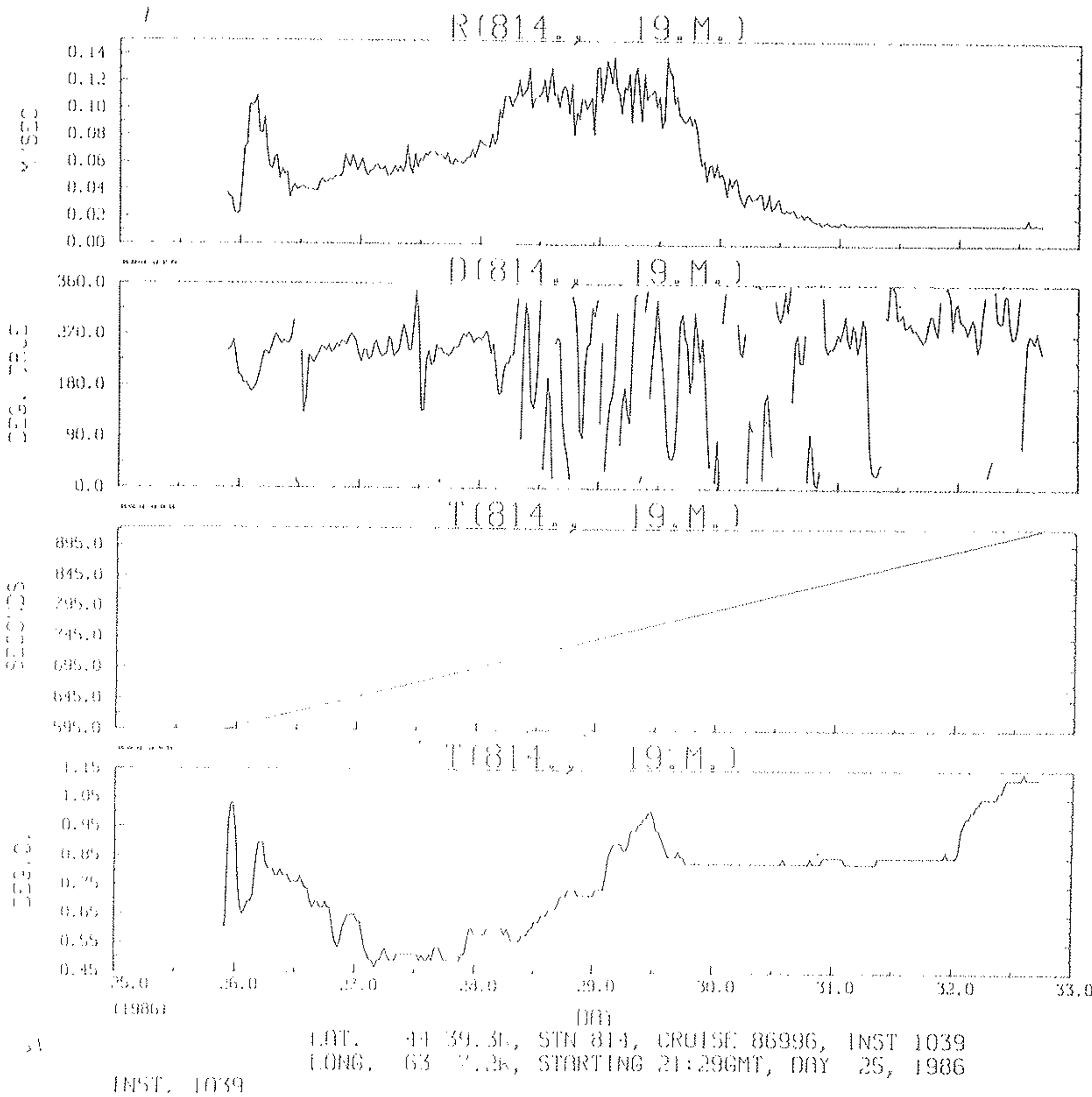


FIGURE B-7

CURRENT METER DATA FOR SITE S-1 (PART 1)

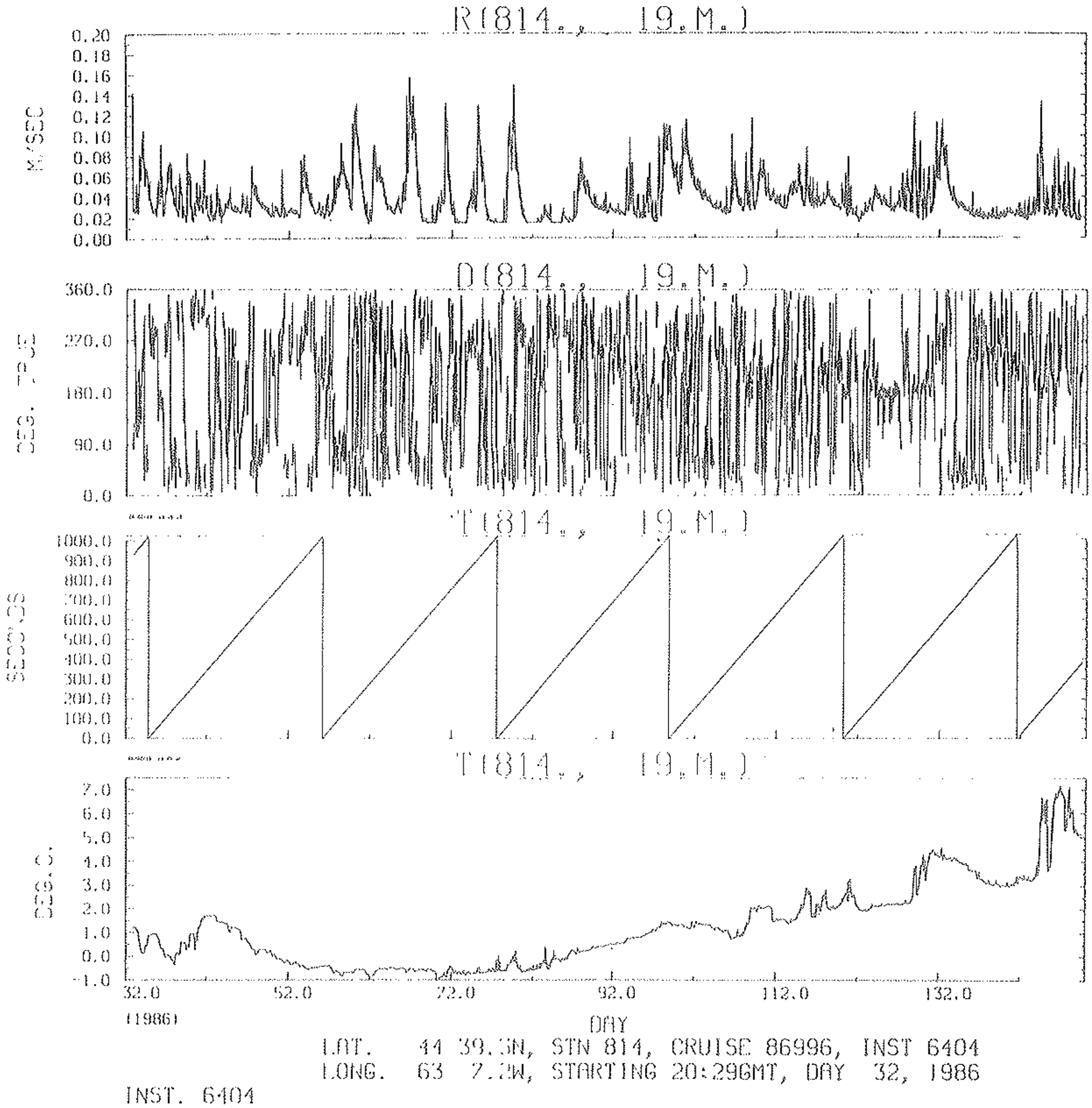


FIGURE B-8

CURRENT METER DATA
FOR SITE S-1 (PART 2)

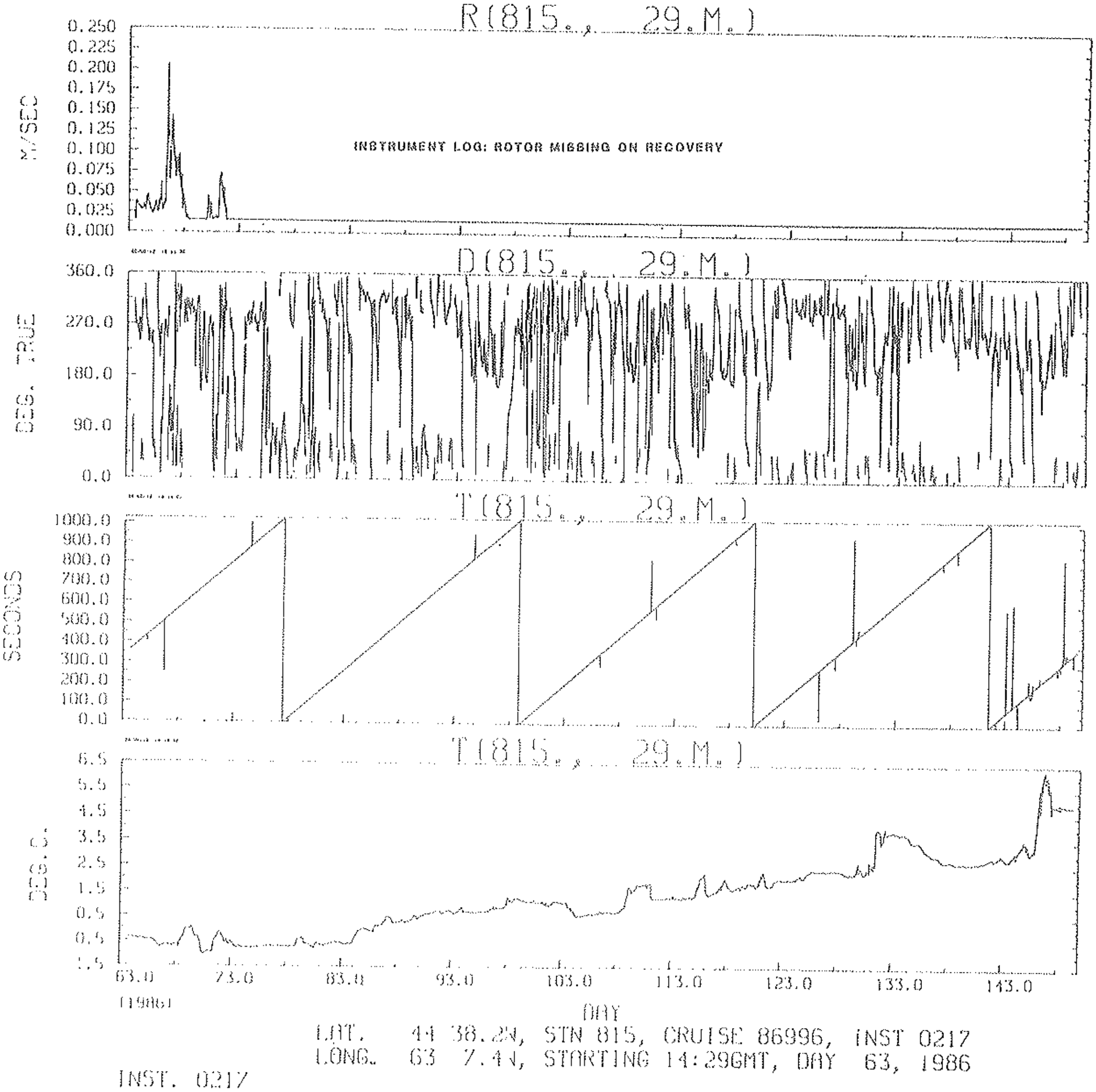


FIGURE B-9

CURRENT METER DATA FOR SITE S-2

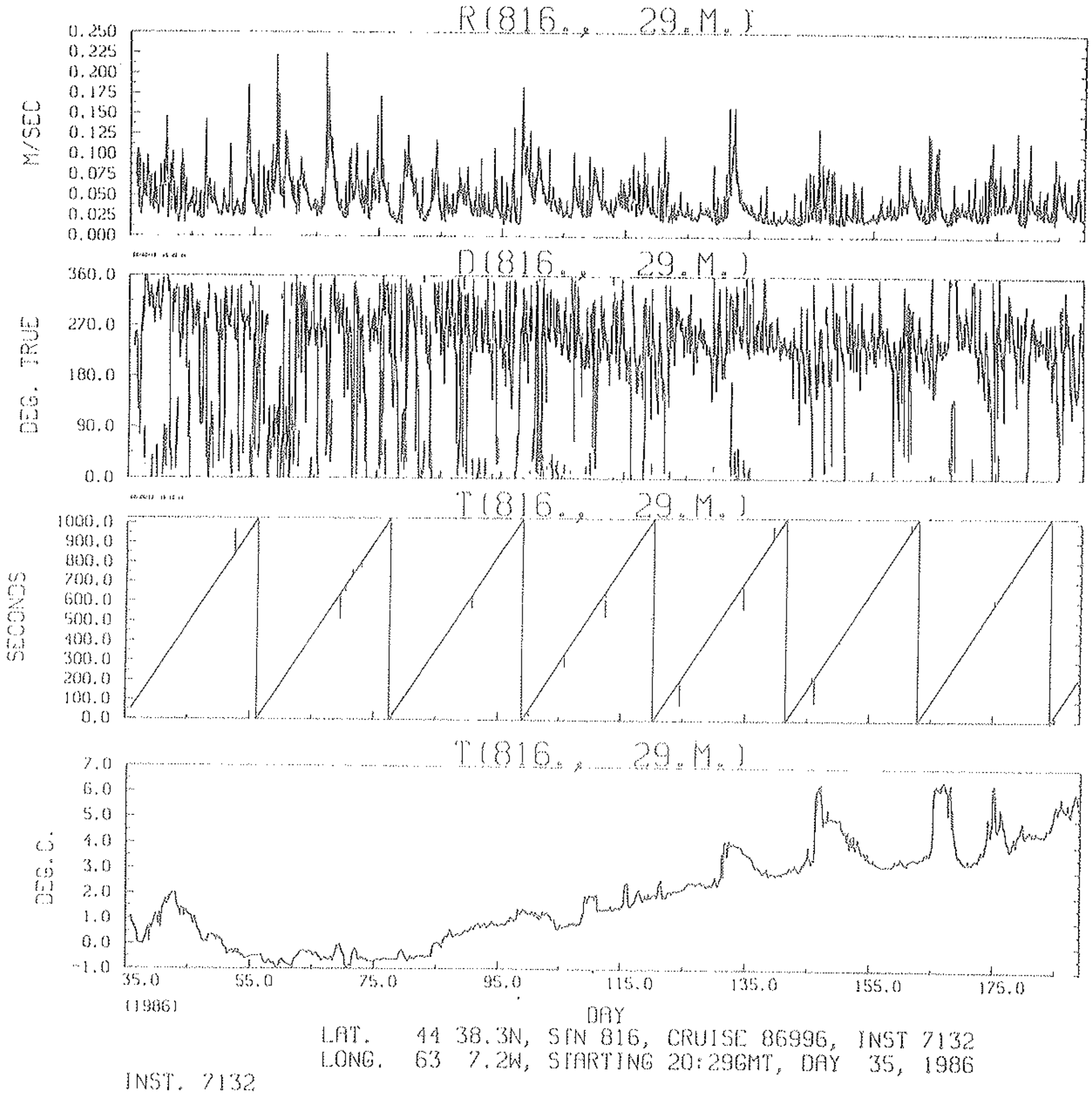


FIGURE B-10

CURRENT METER DATA FOR SITE S-3

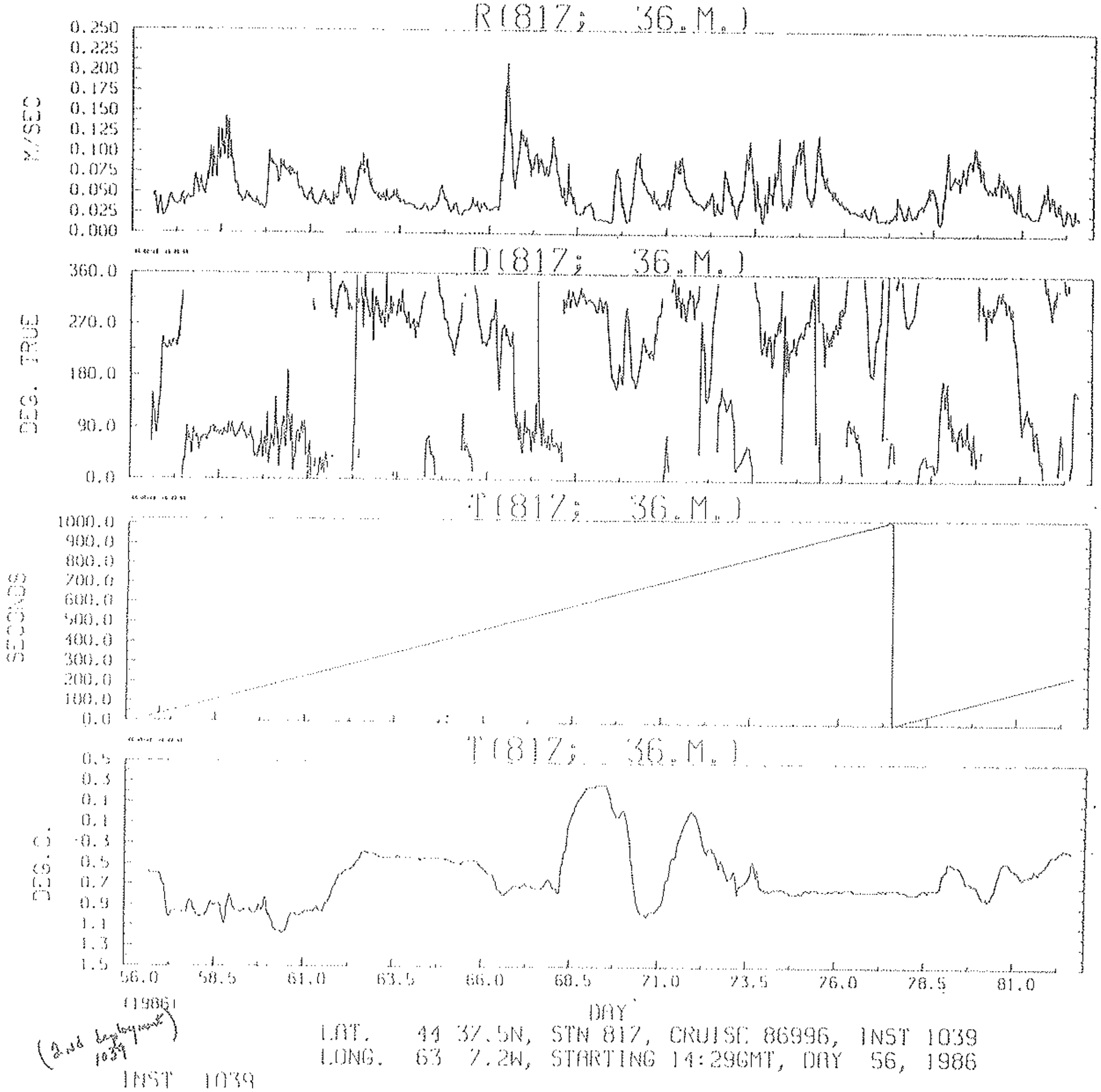


FIGURE B-11

CURRENT METER DATA FOR SITE S-4

APPENDIX C

GRAIN SIZE PLOTS

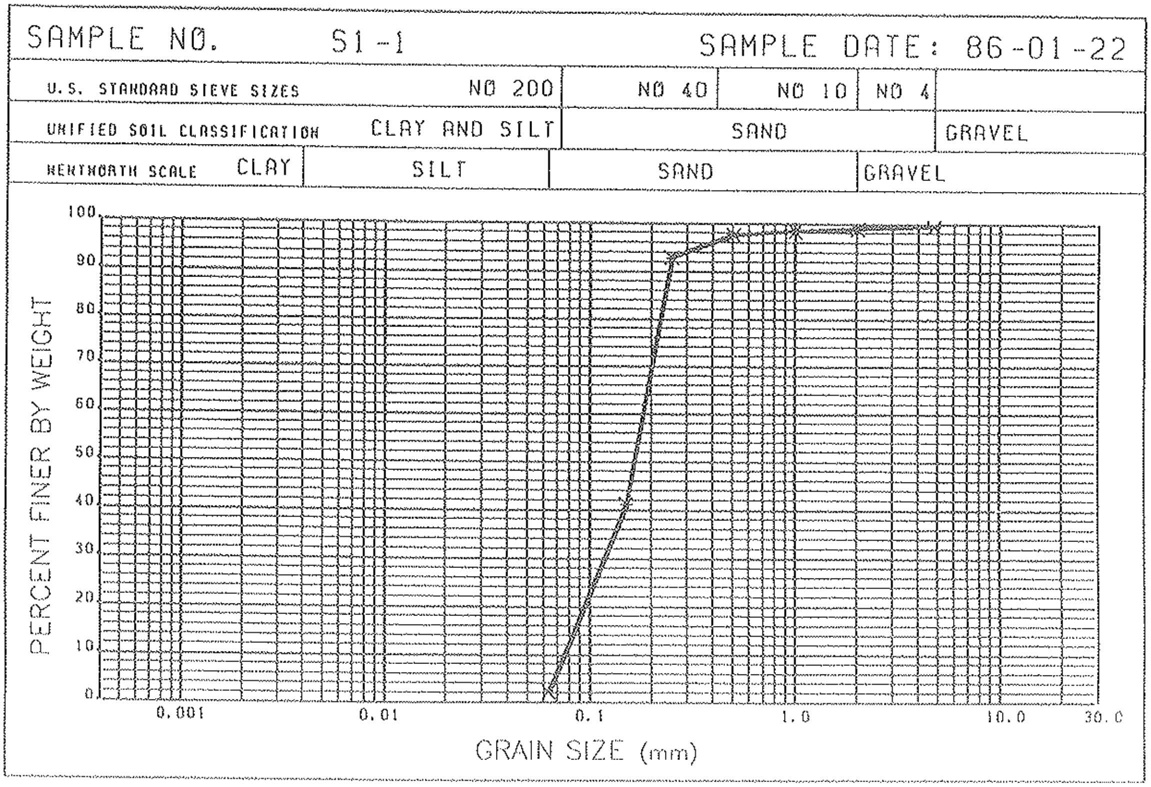
Sediment samples collected during the cruises are listed in Table C-1. The locations at which the grab samples were taken are defined with reference to the site plans in Section 2.3.

Grain size analysis of the sand samples was performed by Seatech, except for samples SD-1, SD-2, and SD-3 which were analyzed by D. Clattenburg, Atlantic Geoscience Centre, Bedford Institute of Oceanography. Gravel samples were analyzed by Nolan Davis and Associates. The grain size plots are presented in Figures C-1 to C-45.

TABLE C-1

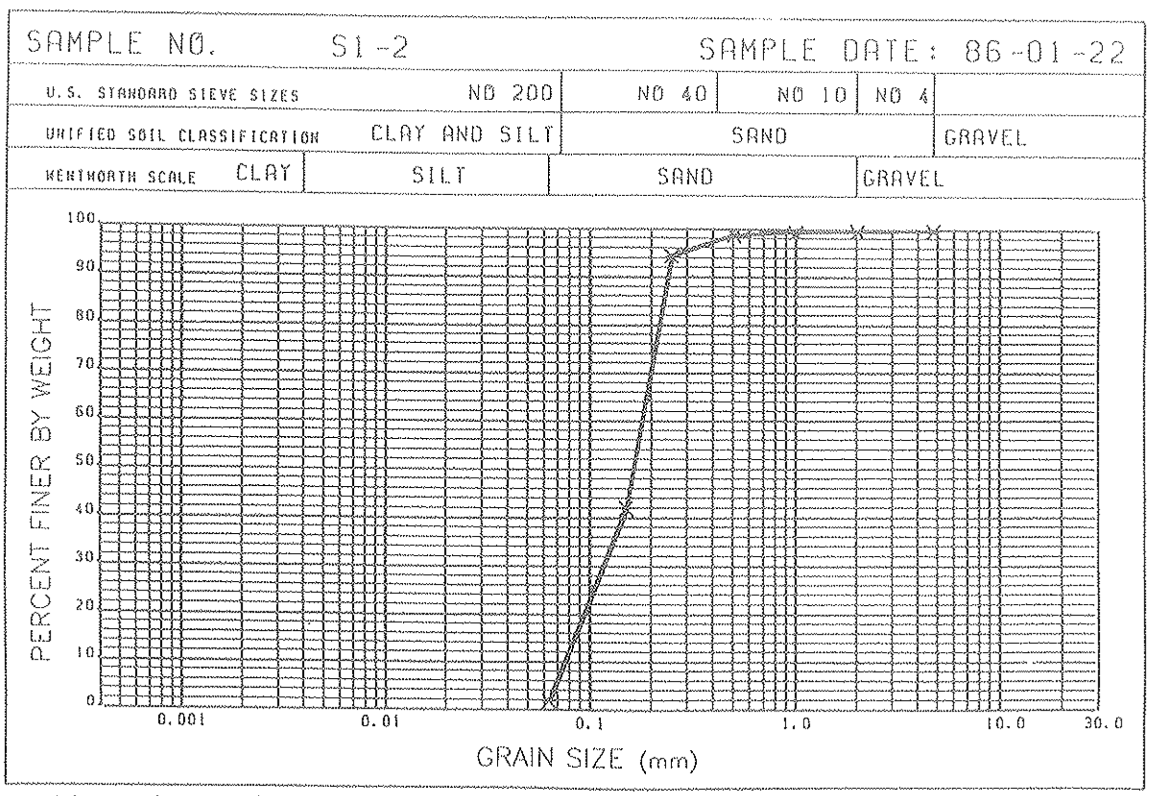
LIST OF GRAB SAMPLES

Martec ID	Date	Cruise	Site and Location*	Seatech ID	Figure No.
S1-1	86/01/25	3	S-1, G10	LG016-1	C-1
S1-2			S-1, G-0	-2	C-2
S1-3			S-1, G-19	-3	C-3
S1-4			S-1, G-25	-4	C-4
S2-1			S-2, G at highfly	-5	C-5
S3-1			S-3, G by mooring**	-6	C-6
S4-1			S-4, G at highfly	-7	C-7
S1-5	86/02/01	5	S-1, near rod #5	-8	C-8
S1-6			S-1, near rod #2	-9	C-9
S3-2	86/02/04	6	S-3, G by mooring	-10	C-10
S3-3			S-3, 17 m E of highfly	-11	C-11
S3-4			S-3, G at highfly	-12	C-12
S2-2	86/02/08	7	S-2, between rods #23 and #24	-13	C-13
S2-3			S-2, between rods #30 and #31	-14	C-14
S3-5			S-3, near rod #16	-15	C-15
S3-6			S-3, near rod #17	-16	C-16
S4-2	86/02/11	8	S-4, 22.9 m SE mooring	-17	C-17
S4-3			S-4, by mooring	-18	C-18
S4-4	86/02/25	9	S-4, by current meter	LG029-1	C-19
S4-5			S-4, by rod #37 (grab #2)	-2	C-20
S4-6			S-4, by rod #37 (grab #1)	-3	C-21
S3-7			S-3, by dump	-4	C-22
S3-8			S-3, by current meter	-5	C-23
S1-7			S-1, S of rod #6	-6	C-24
S1-8			S-1, S of rod #5	-7	C-25
S2-4	86/03/04	10	S-2, by rod #26	-8	C-26
S1-9			S-1, by rod #5	-9	C-27
S3-9			S-3, bottom 10 cm of box core	-10	C-28
S3-10			S-3, 10-20 cm of box core	-11	C-29
S3-11			S-3, 0-10 cm of box core	-12	C-30
S3-12			S-3, disturbed top of box core	-13	C-31
S1-10	86/03/23	11	S-1, by rod #7	-14	C-32
S1-11			S-1, by rod #5	-15	C-33
S2-5			S-2, by rod #25	-16	C-34
S2-6			S-2, by rod #26	-17	C-35
S3-13			S-3, by rod #20	-18	C-36
S3-14			S-3, by rod #14	-19	C-37
SD-1	86/06/21	14	SD, edge of hole (AGC No. 3964)	N/A	C-38
SD-2			SD, inside of hole (AGC No. 3965)	N/A	C-39
SD-3			SD, outside of hole (AGC No. 3966)	N/A	C-40
S1-12	86/07/07	15	S-1, by rod #7	LG059-1	C-41
S1-13			S-1, by rod #5	-2	C-42
S4-7			S-4, by rod #36	-3	C-43
S2-7			S-2, by rod #29	-4	C-44
S2-8			S-2, by rod #31	-5	C-45



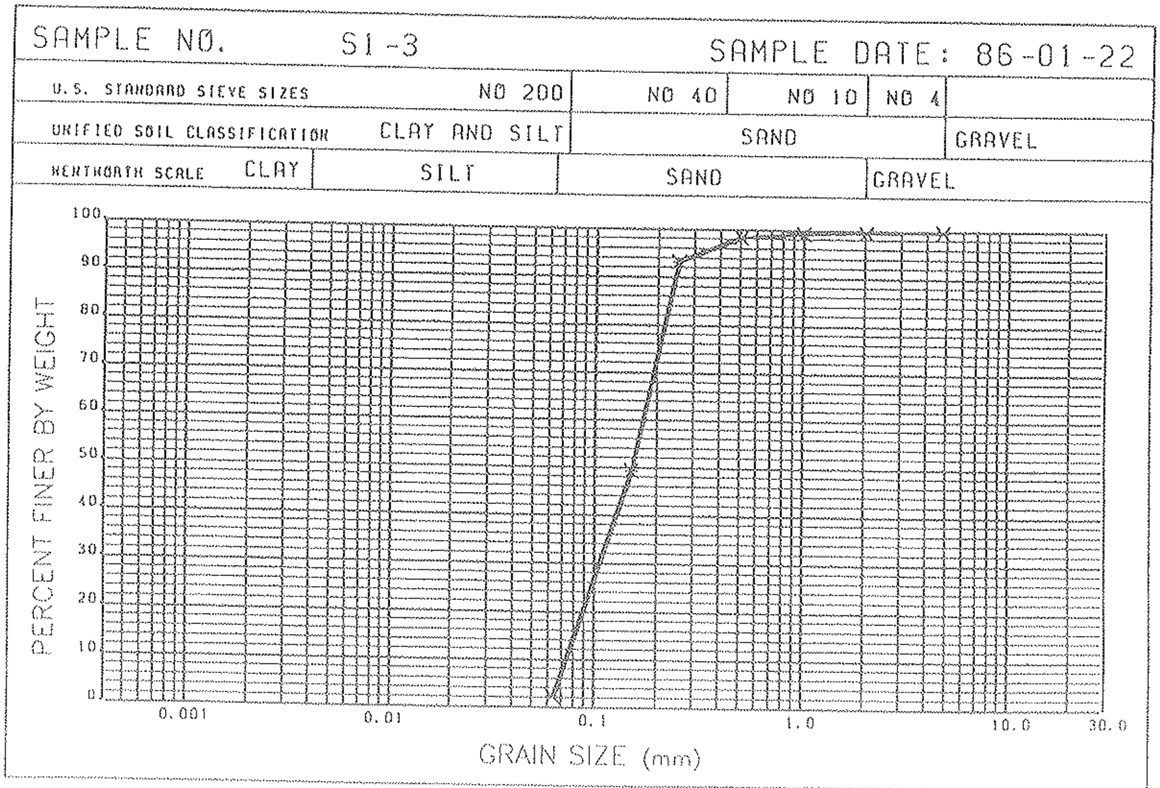
Martec Limited

FIGURE NO. C-1



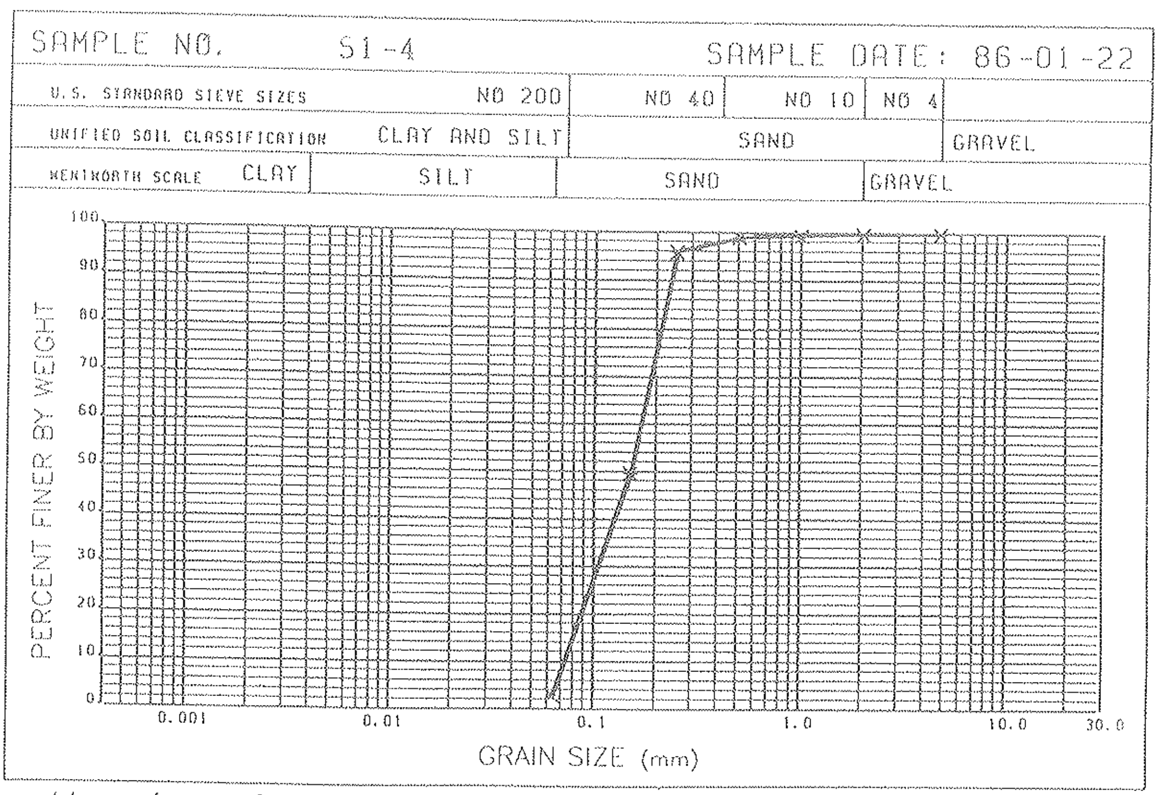
Martec Limited

FIGURE NO. C-2



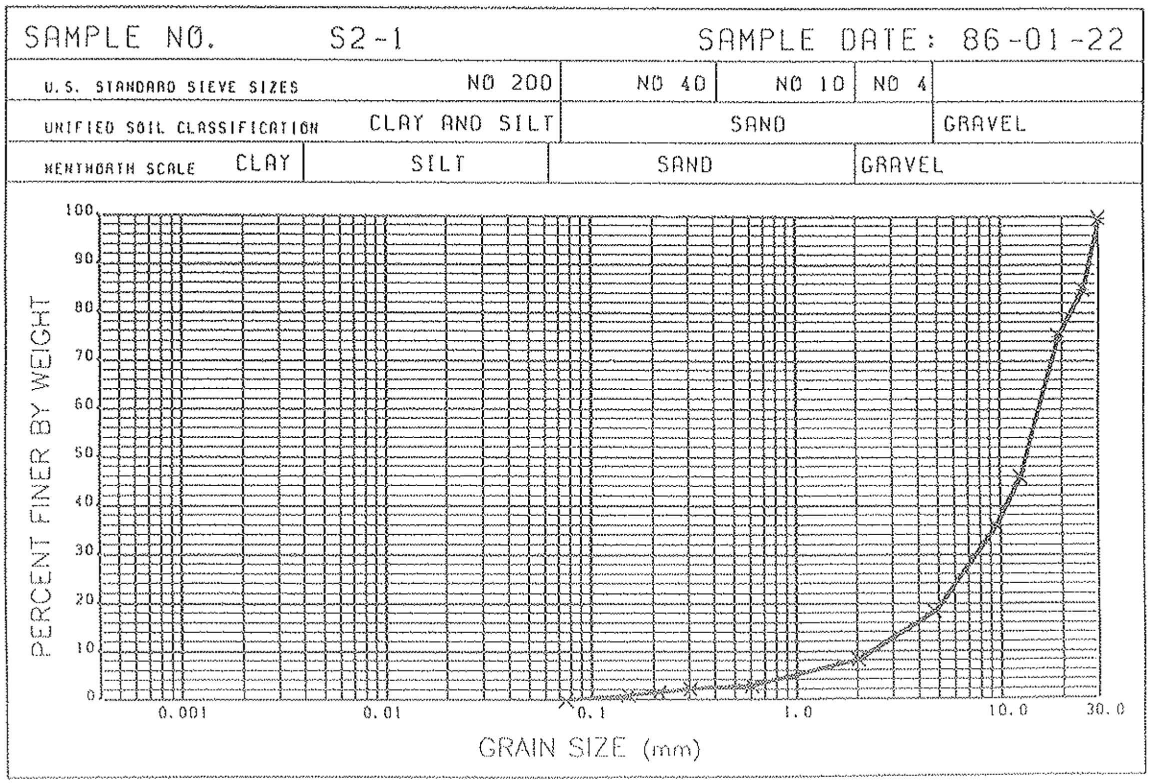
Martec Limited

FIGURE NO. C-3

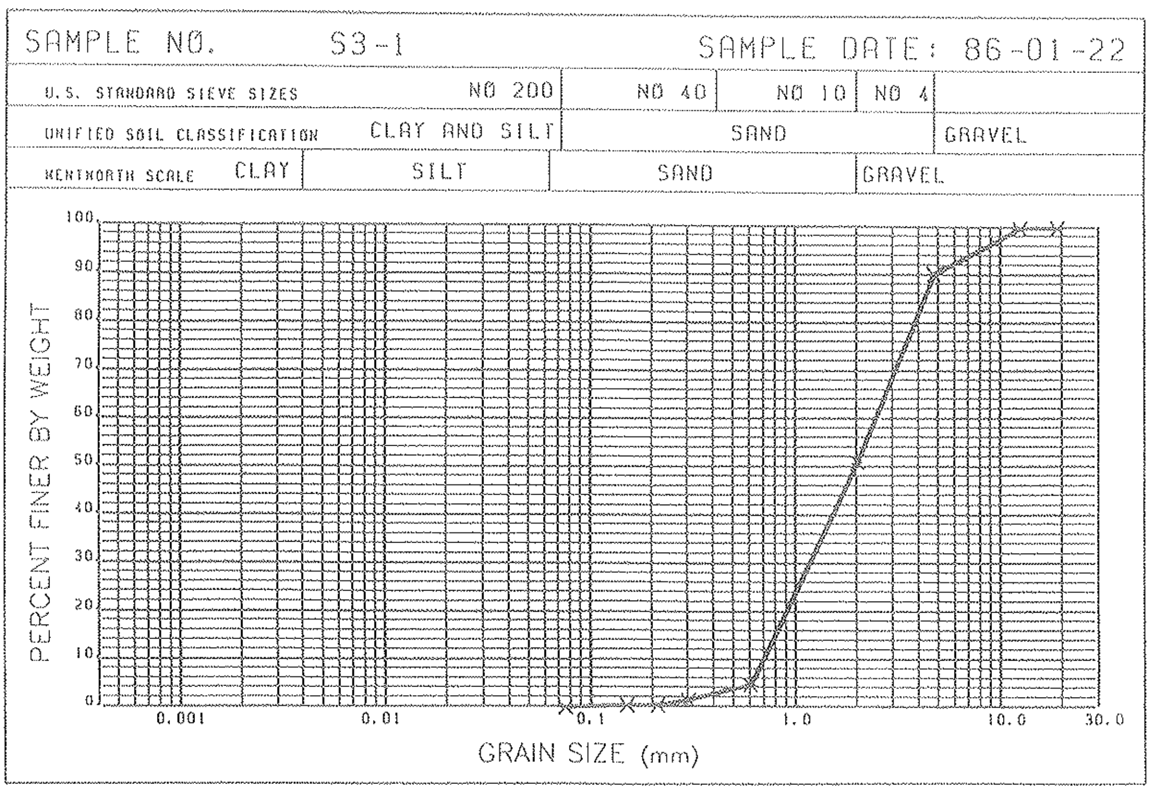


Martec Limited

FIGURE NO. C-4



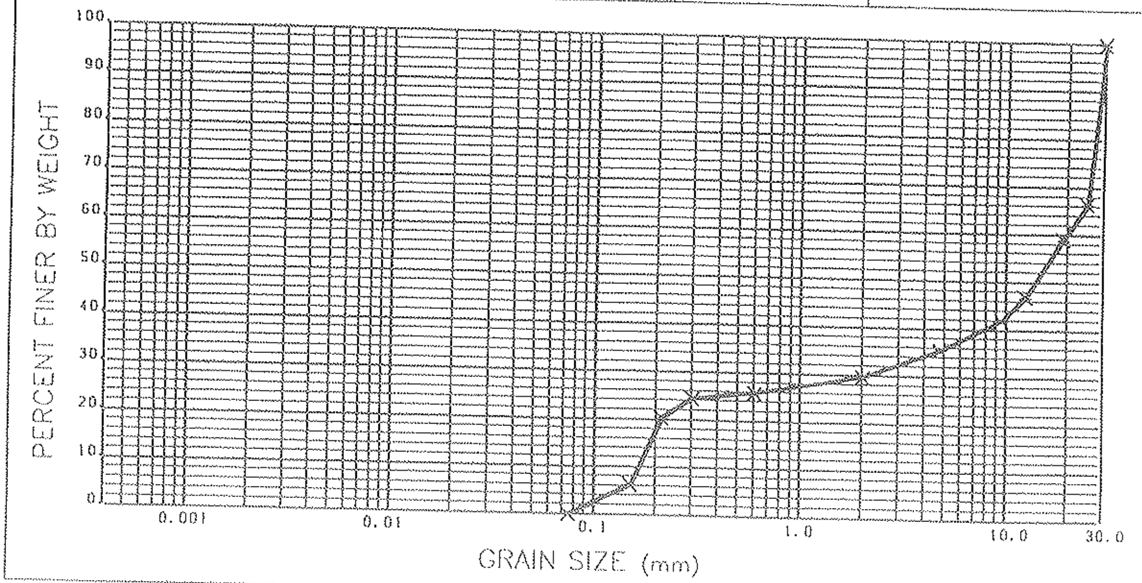
Martec Limited FIGURE NO. C-5



Martec Limited FIGURE NO. C-6

SAMPLE NO. S4-1 SAMPLE DATE: 86-01-22

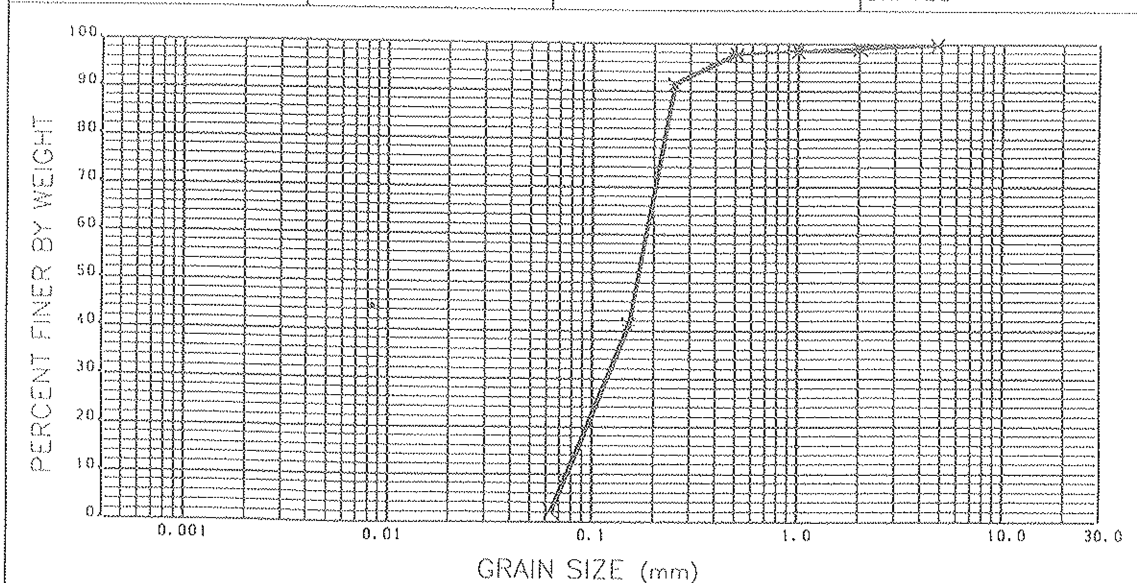
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



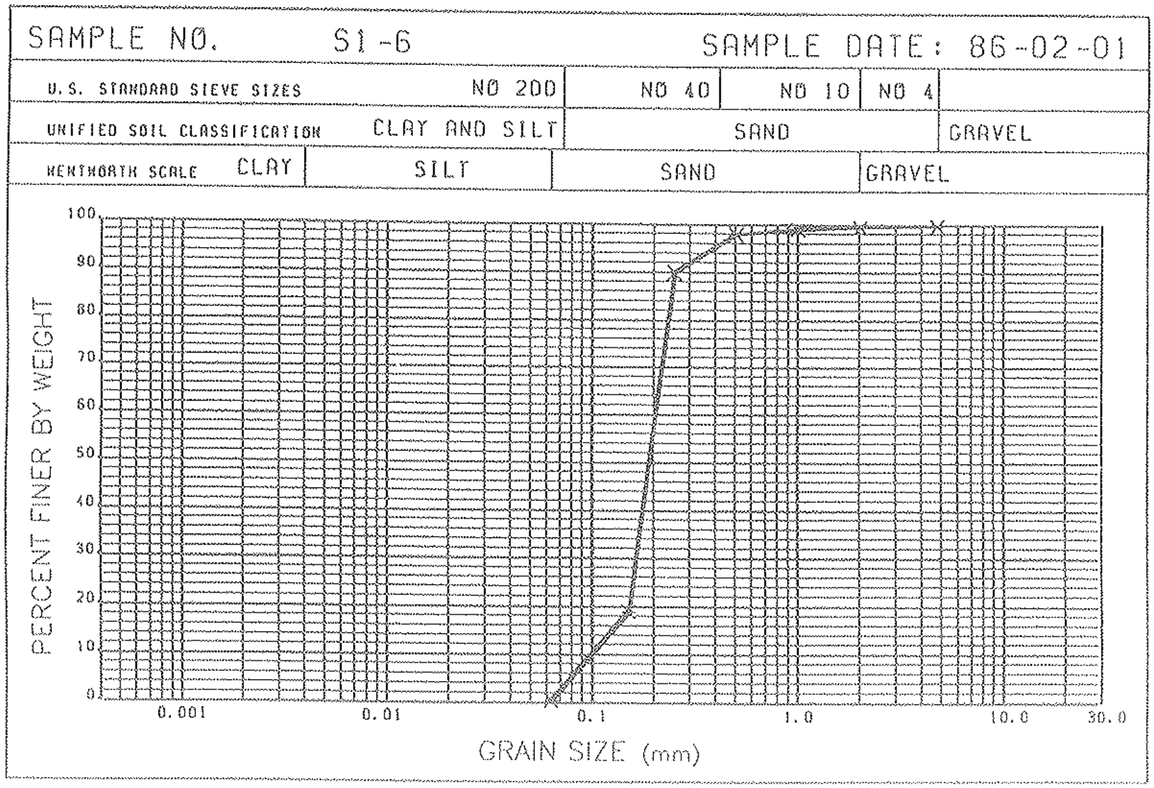
Martec Limited FIGURE NO. C-7

SAMPLE NO. S1-5 SAMPLE DATE: 86-02-01

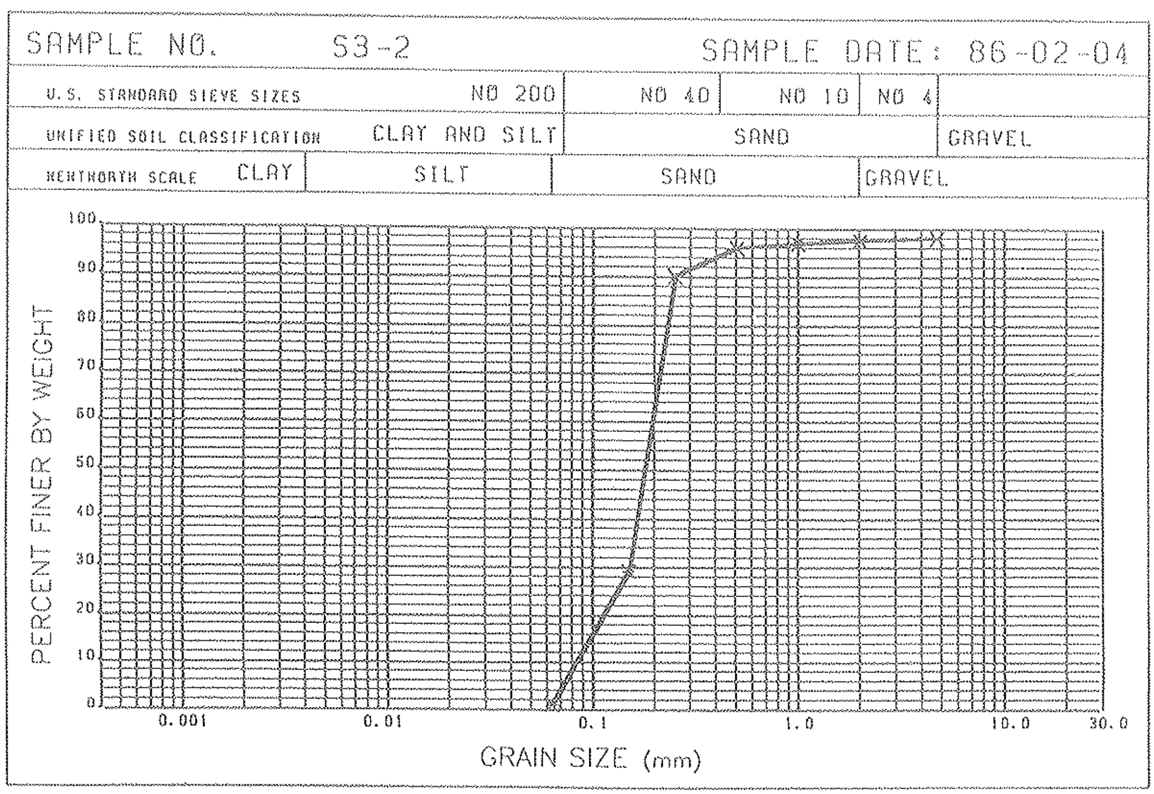
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



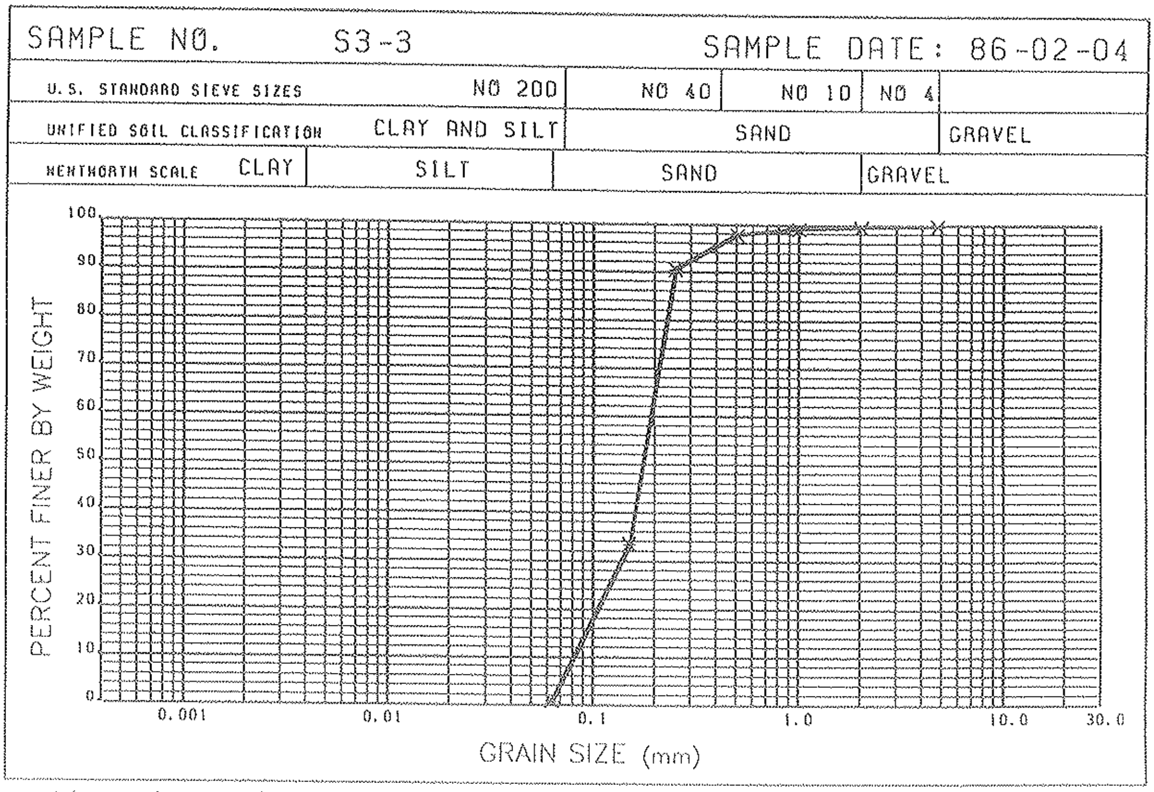
Martec Limited FIGURE NO. C-8



Martec Limited FIGURE NO. C-9

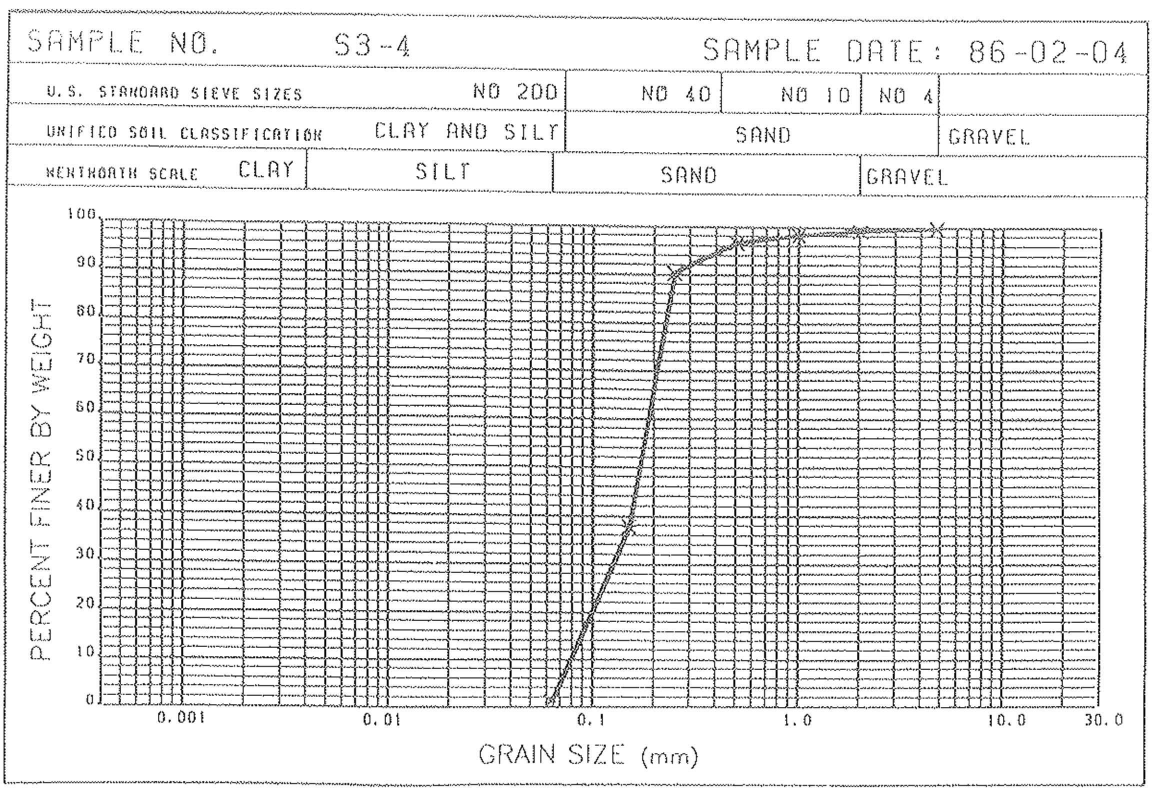


Martec Limited FIGURE NO. C-10



Martec Limited

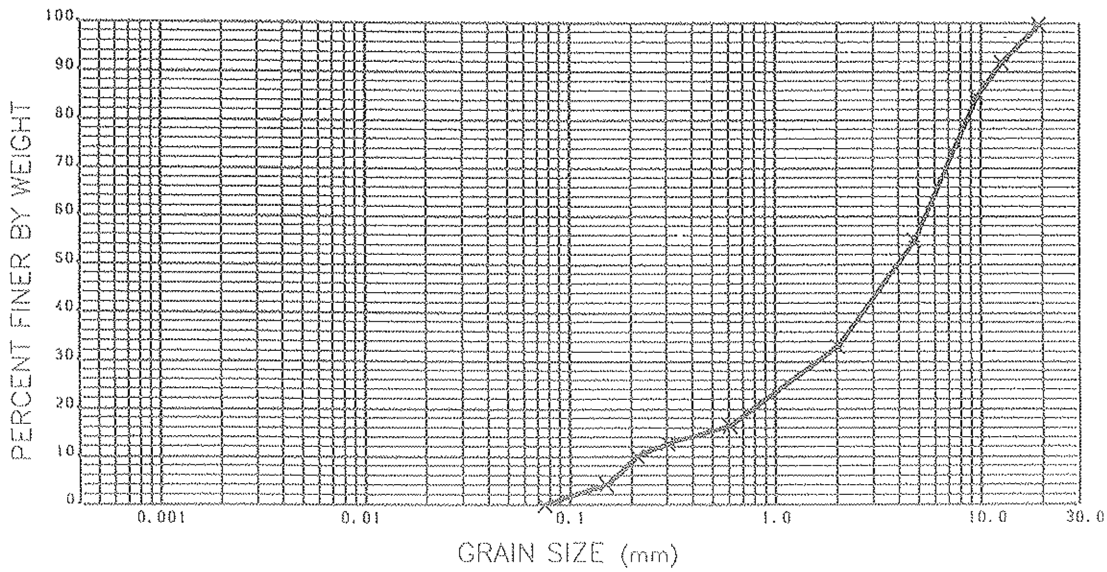
FIGURE NO. C-11



Martec Limited

FIGURE NO. C-12

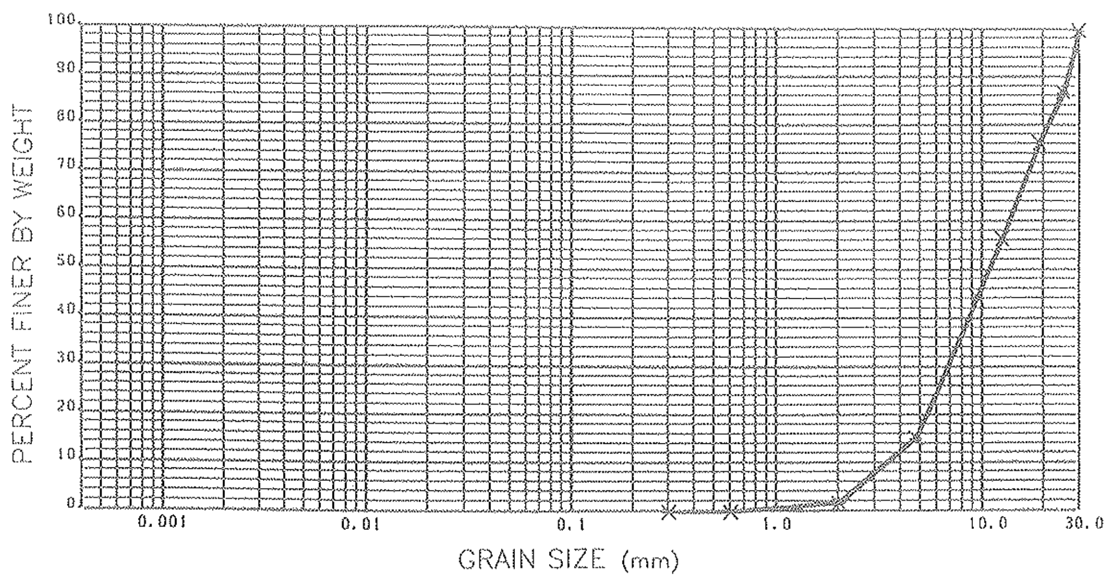
SAMPLE NO. S2-2	SAMPLE DATE: 86-02-08					
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4		
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL	
WENTWORTH SCALE	CLAY	SILT	SAND		GRAVEL	



Martec Limited

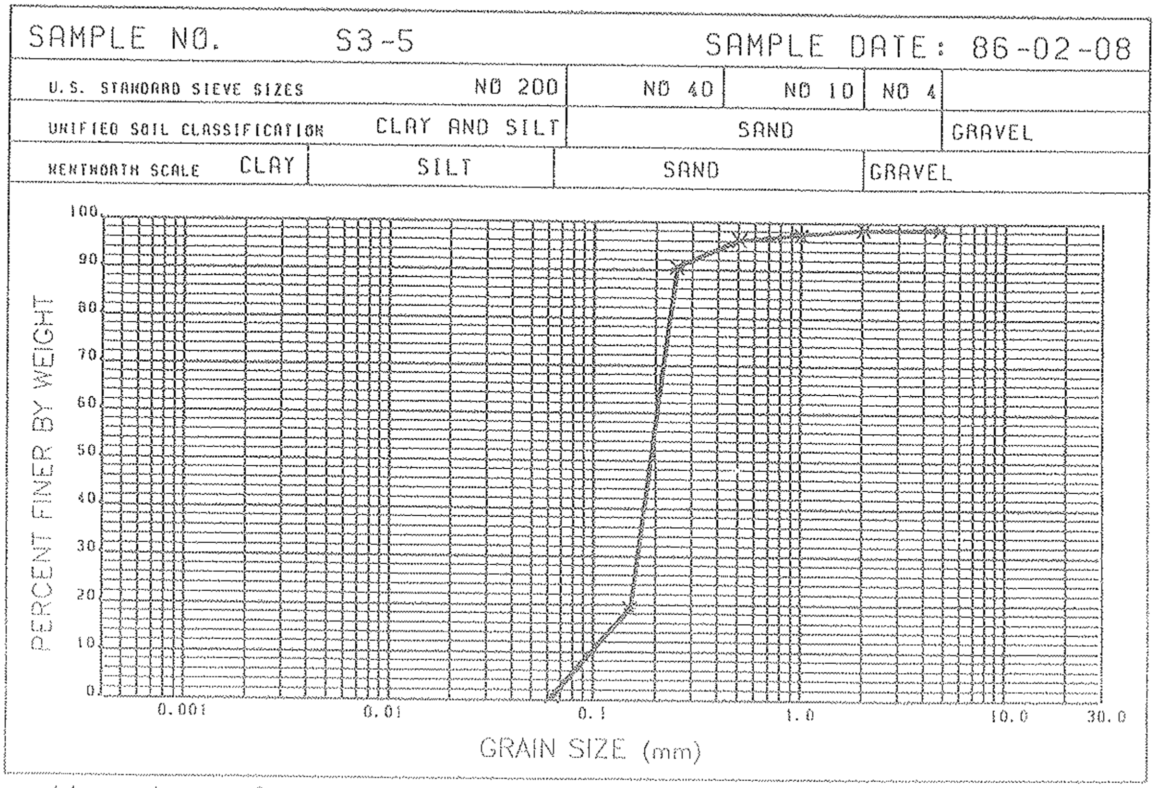
FIGURE NO. C-13

SAMPLE NO. S2-3	SAMPLE DATE: 86-02-08					
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4		
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL	
WENTWORTH SCALE	CLAY	SILT	SAND		GRAVEL	



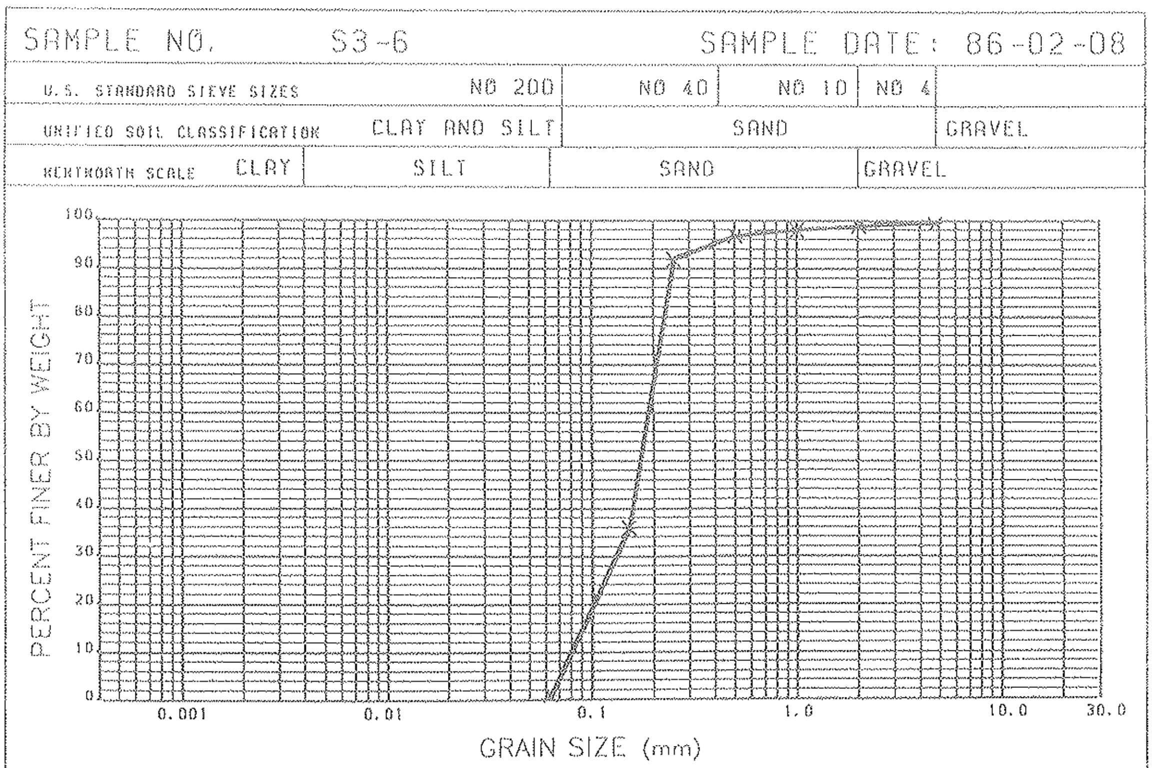
Martec Limited

FIGURE NO. C-14



Martec Limited

FIGURE NO. C-15

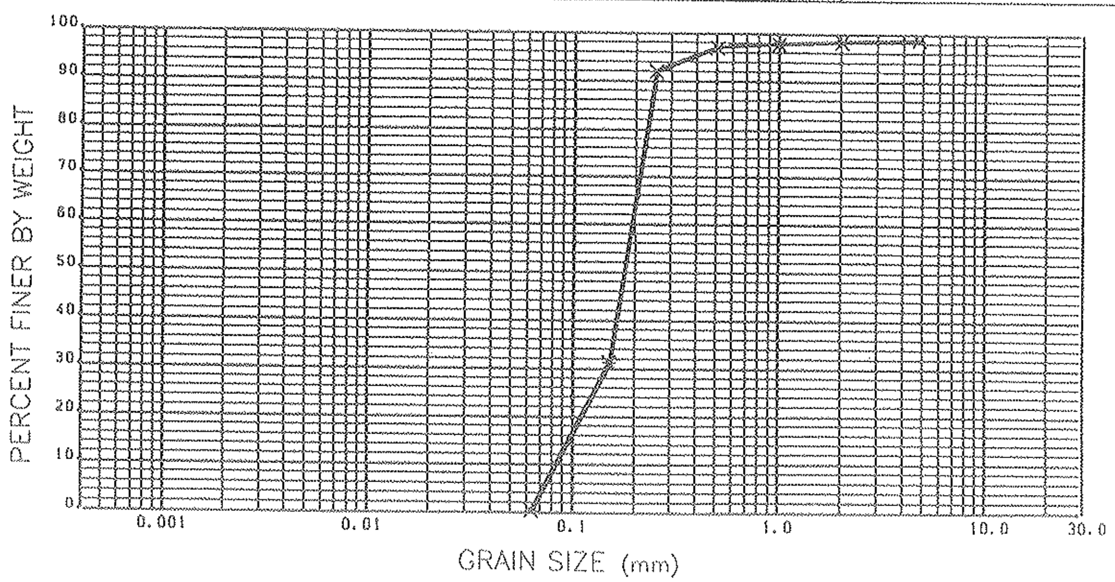


Martec Limited

FIGURE NO. C-16

SAMPLE NO.	S4-2	SAMPLE DATE: 86-02-11

U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	

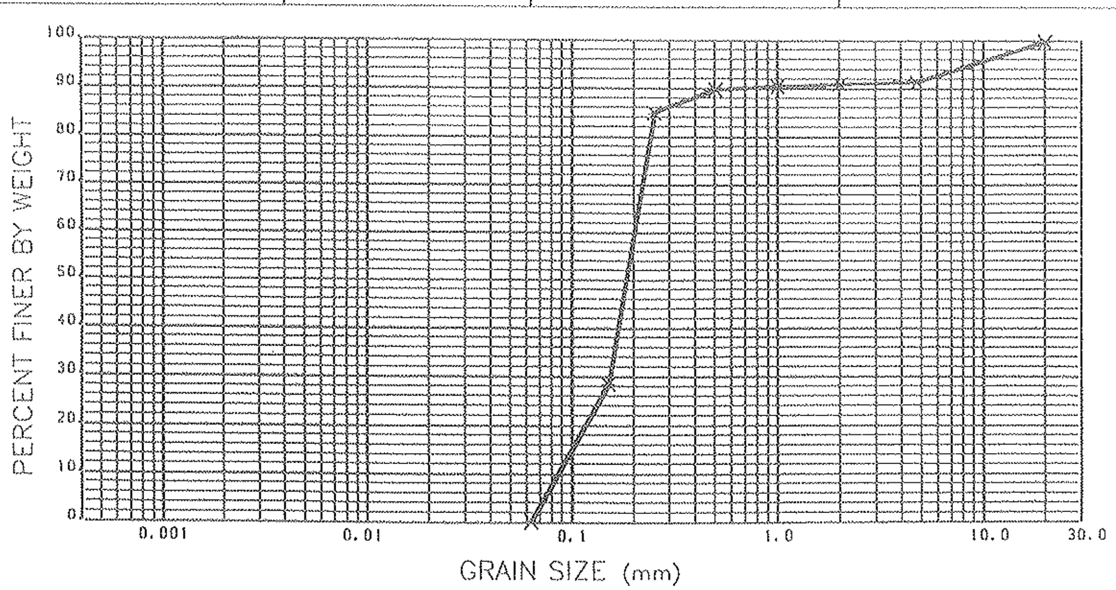


Martec Limited

FIGURE NO. C-17

SAMPLE NO.	S4-3	SAMPLE DATE: 86-02-11

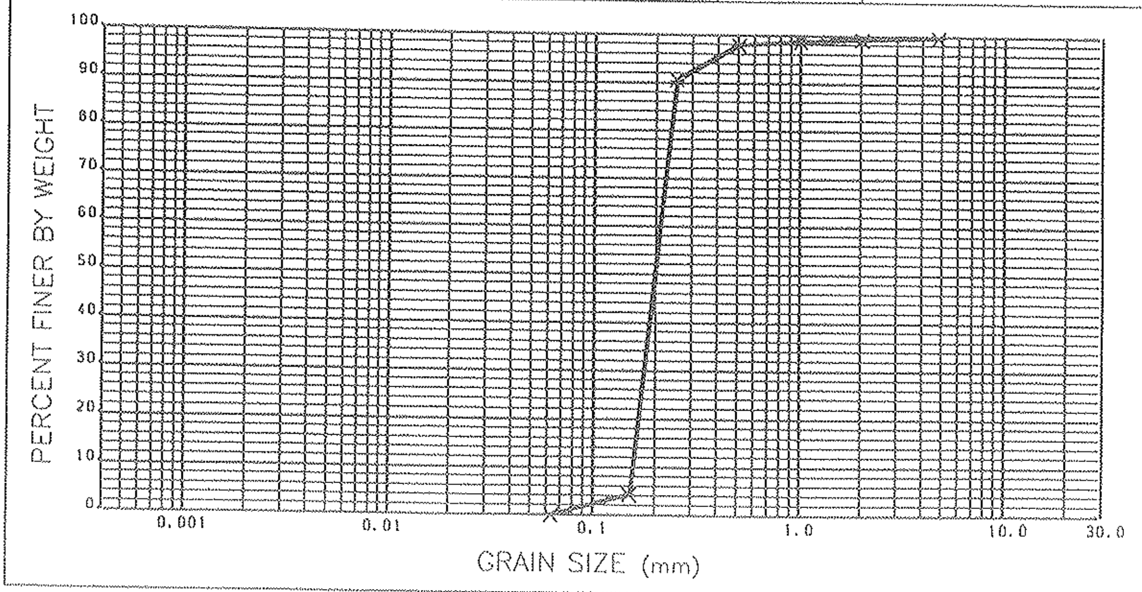
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



Martec Limited

FIGURE NO. C-18

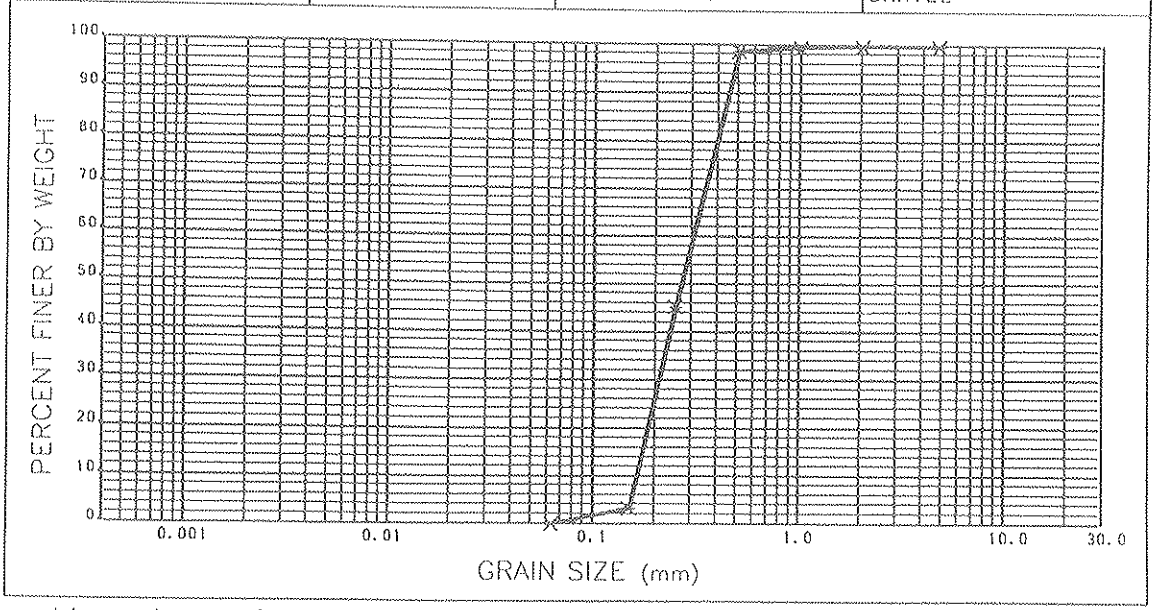
SAMPLE NO. S4-4					SAMPLE DATE: 86-02-25
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



Martec Limited

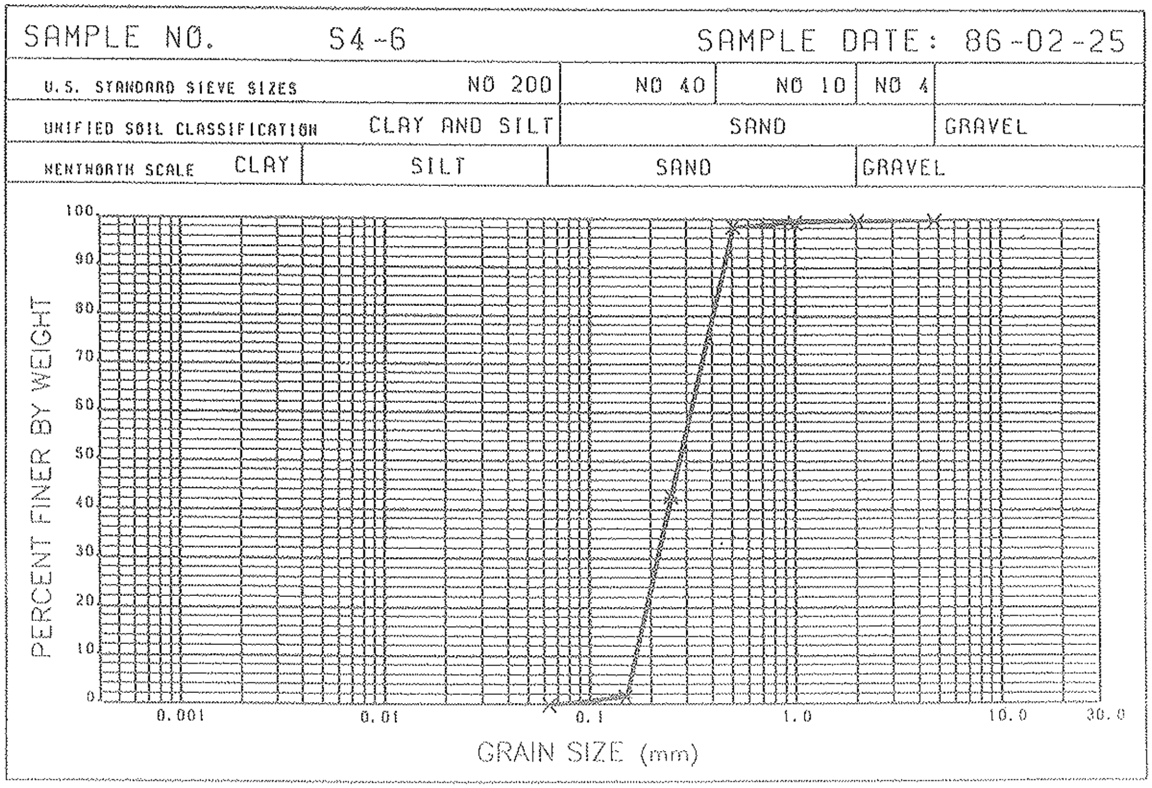
FIGURE NO. C-19

SAMPLE NO. S4-5					SAMPLE DATE: 86-02-25
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	

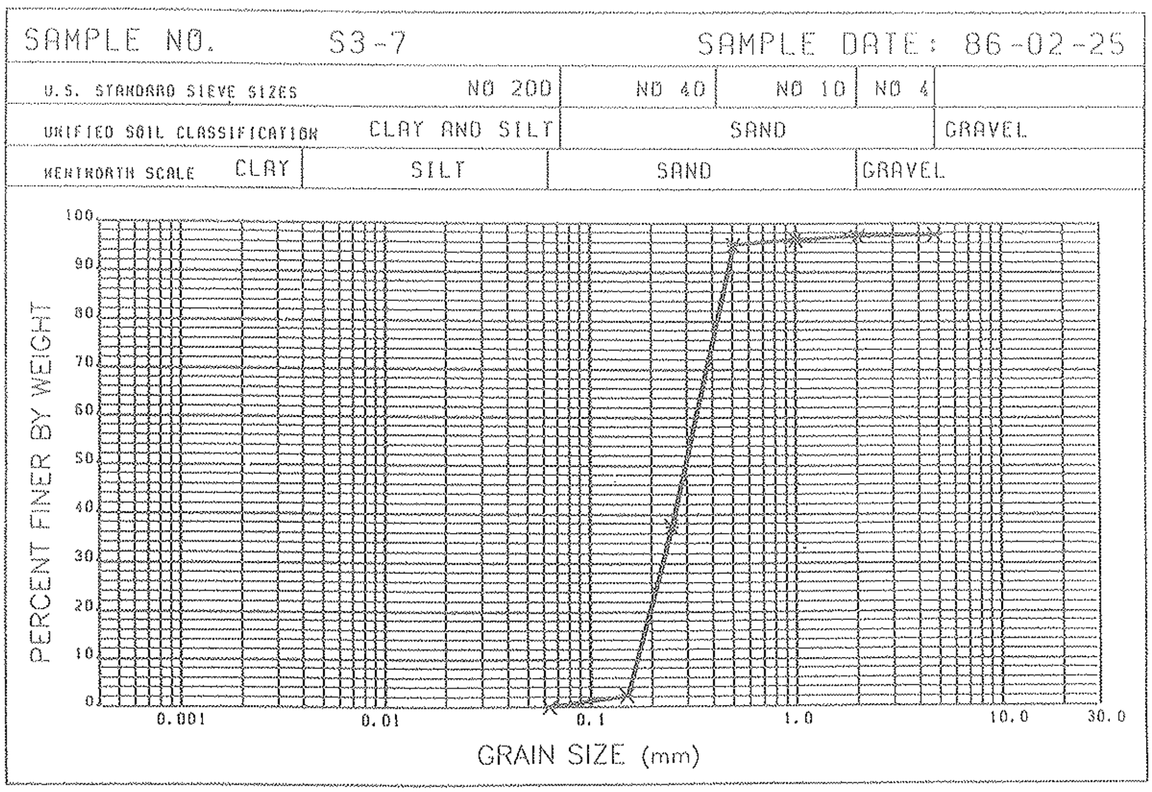


Martec Limited

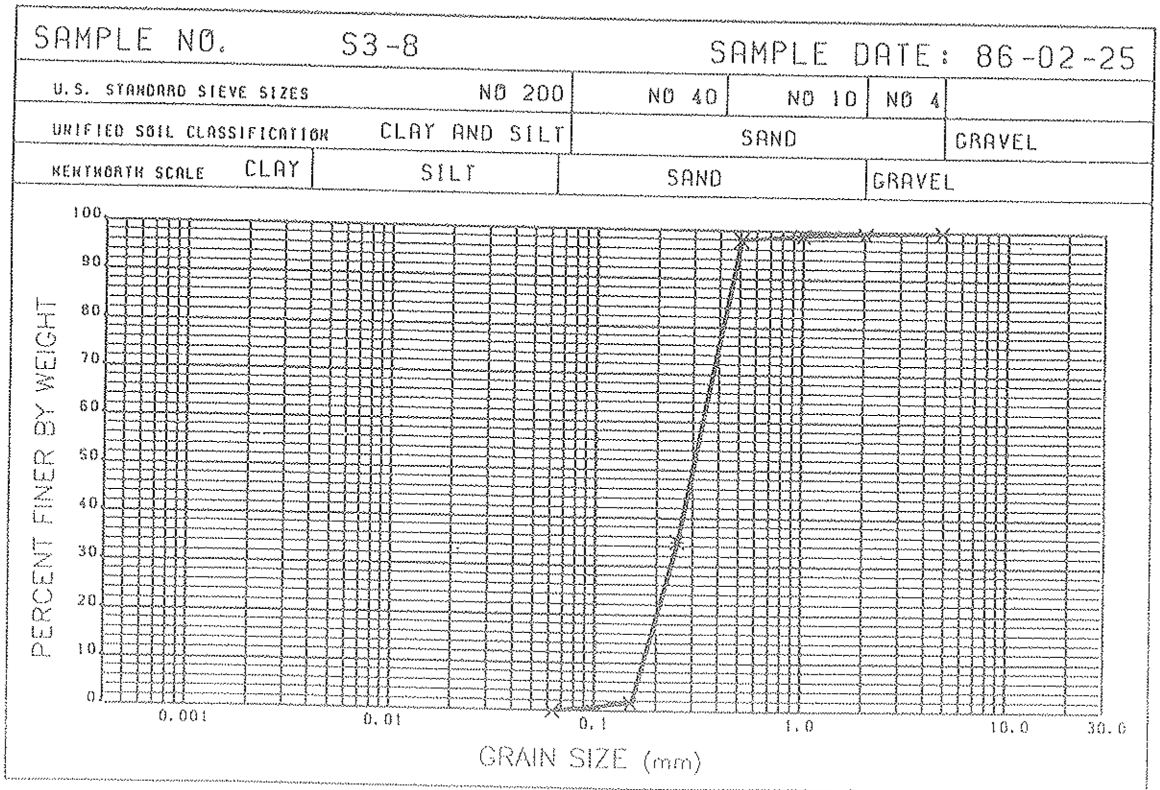
FIGURE NO. C-20



Martec Limited FIGURE NO. C-21

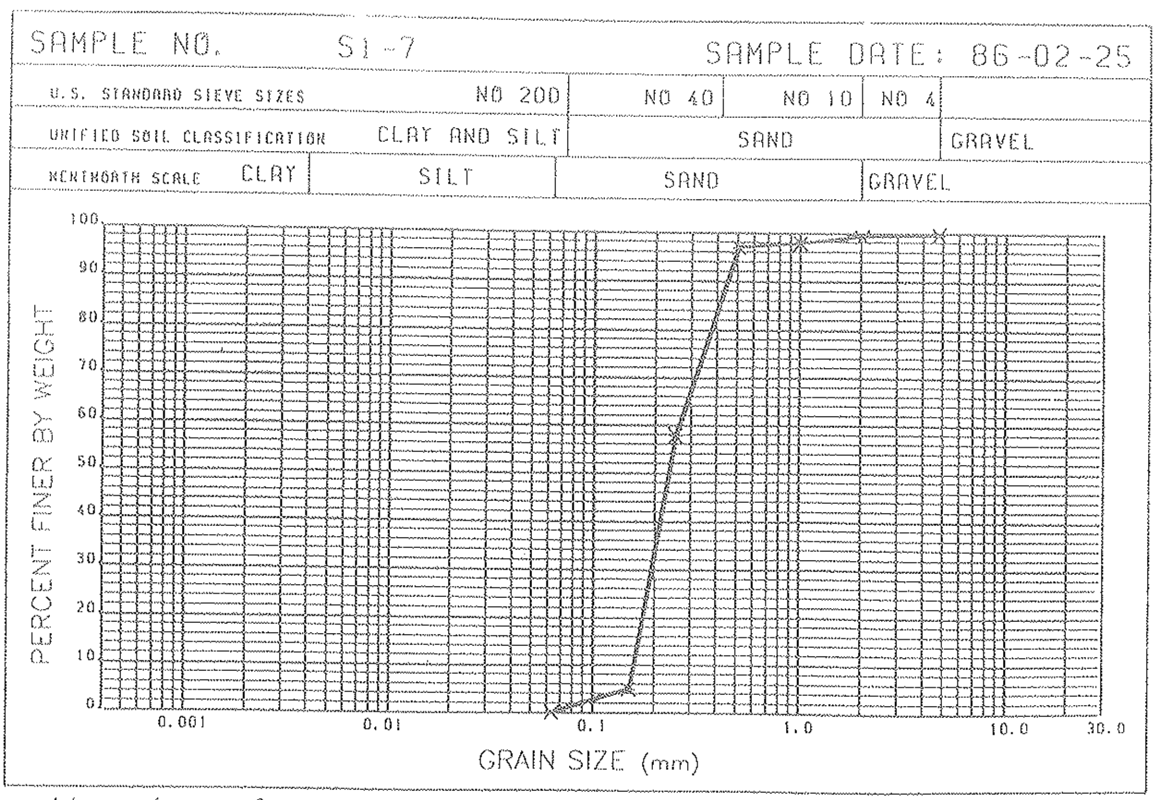


Martec Limited FIGURE NO. C-22



Martec Limited

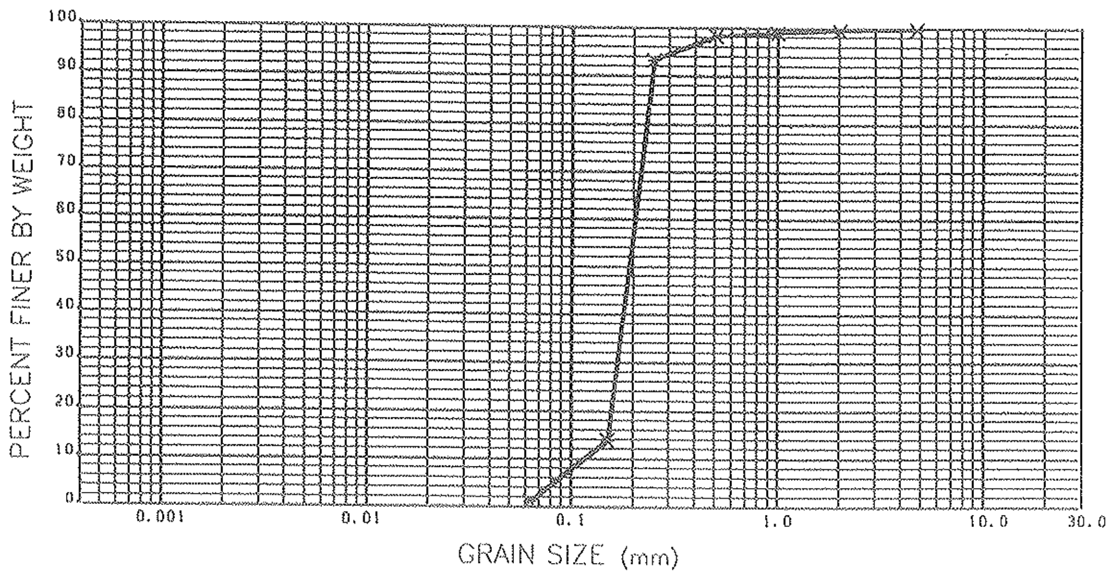
FIGURE NO. C-23



Martec Limited

FIGURE NO. C-24

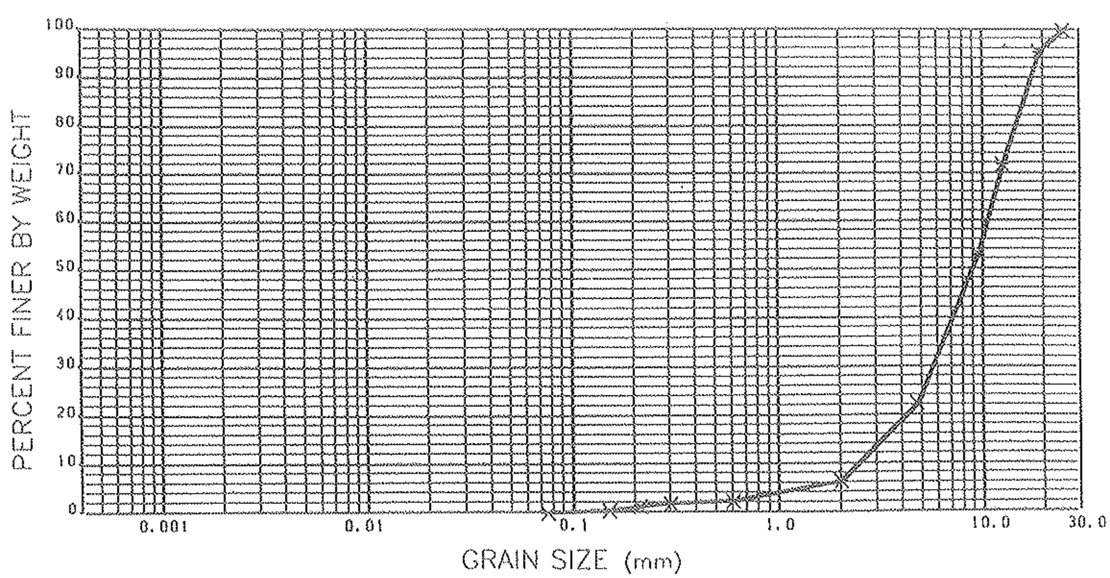
SAMPLE NO. S1-8				SAMPLE DATE: 86-02-25	
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



Martec Limited

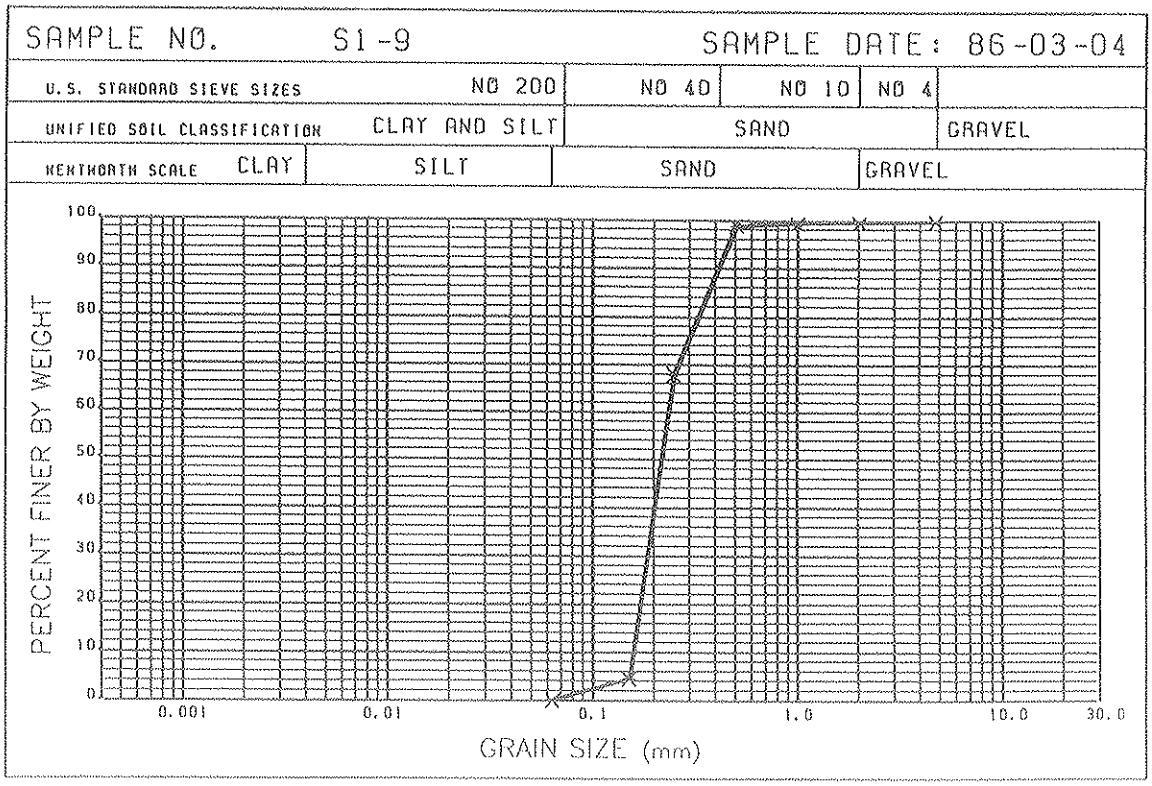
FIGURE NO. C-25

SAMPLE NO. S2-4				SAMPLE DATE: 86-03-04	
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



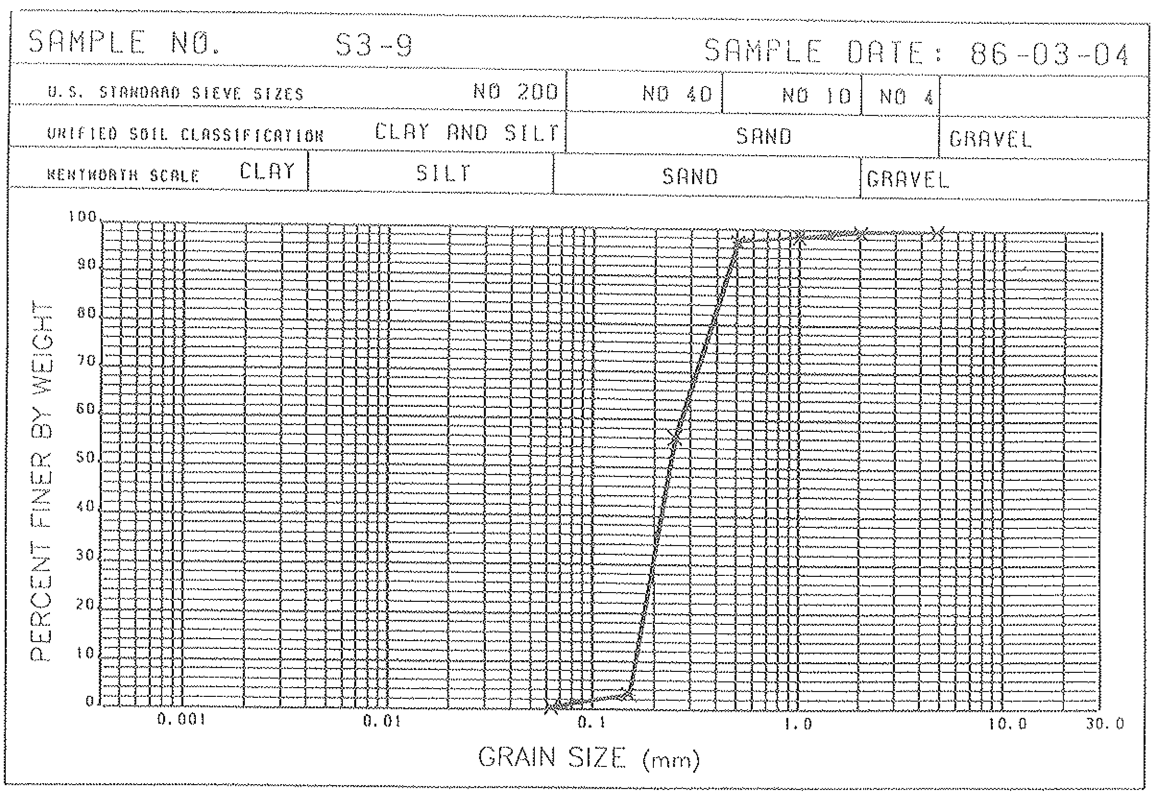
Martec Limited

FIGURE NO. C-26



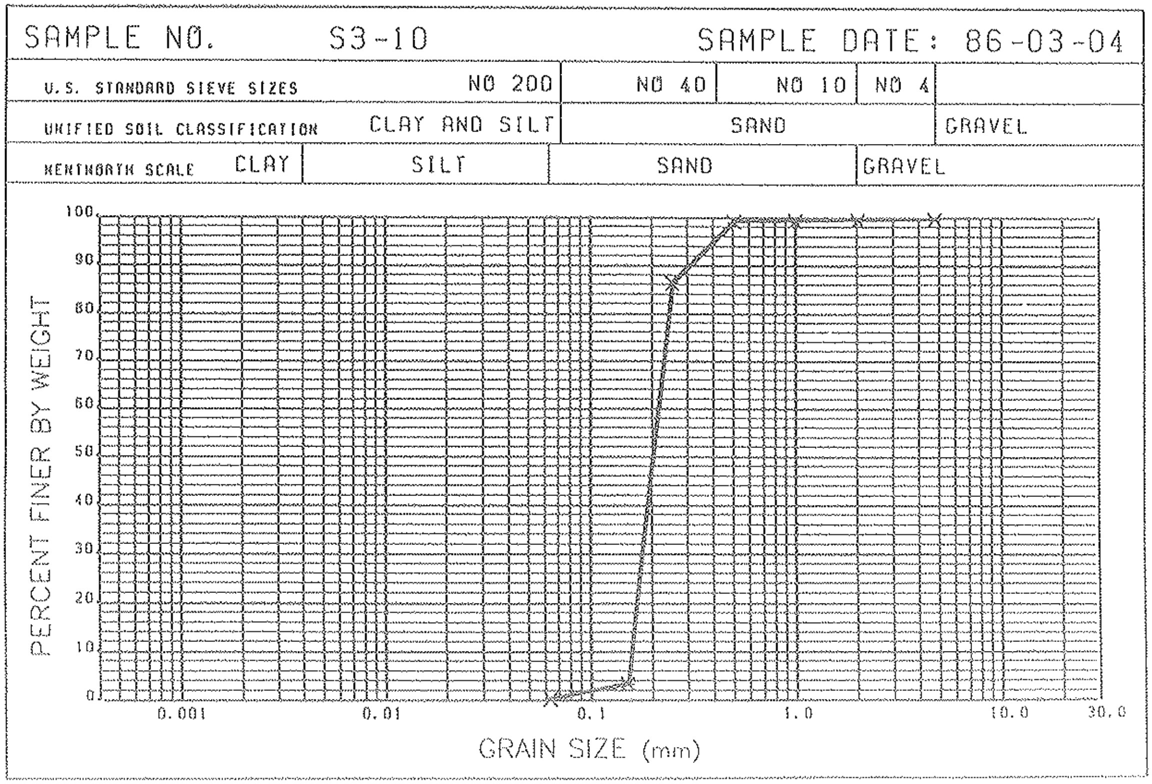
Martec Limited

FIGURE NO. C-27



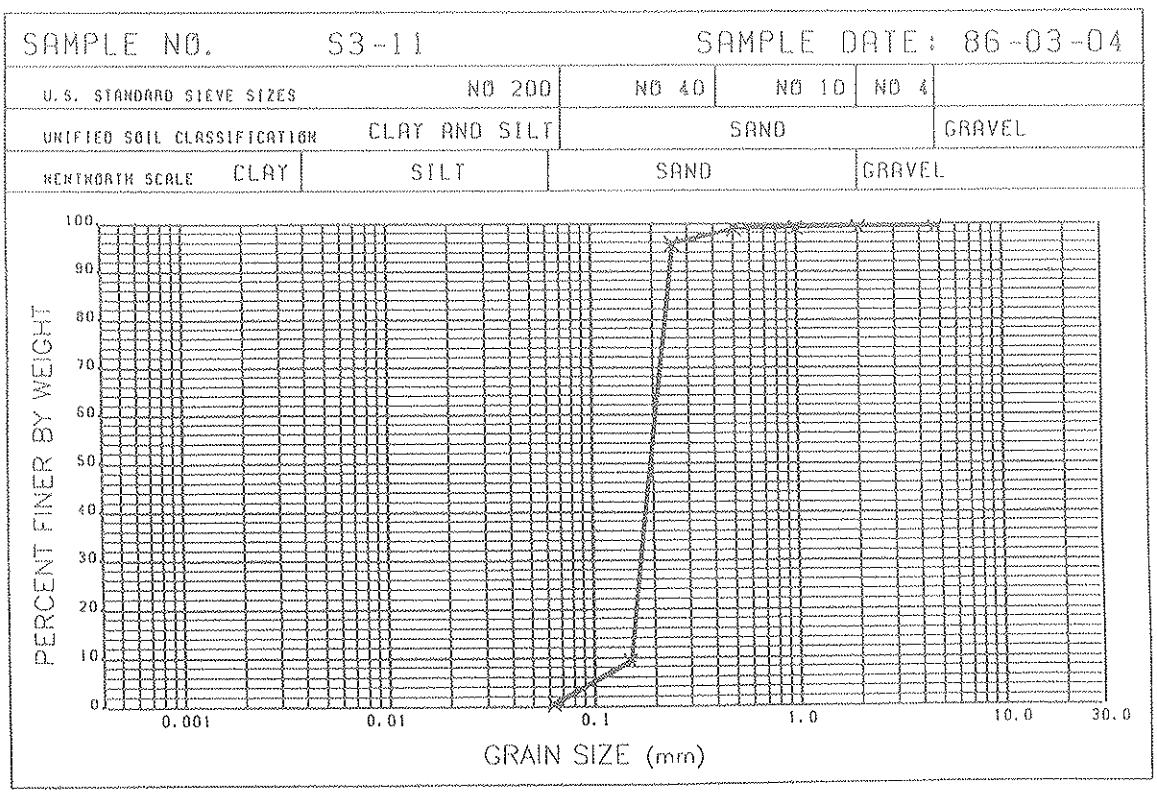
Martec Limited

FIGURE NO. C-28



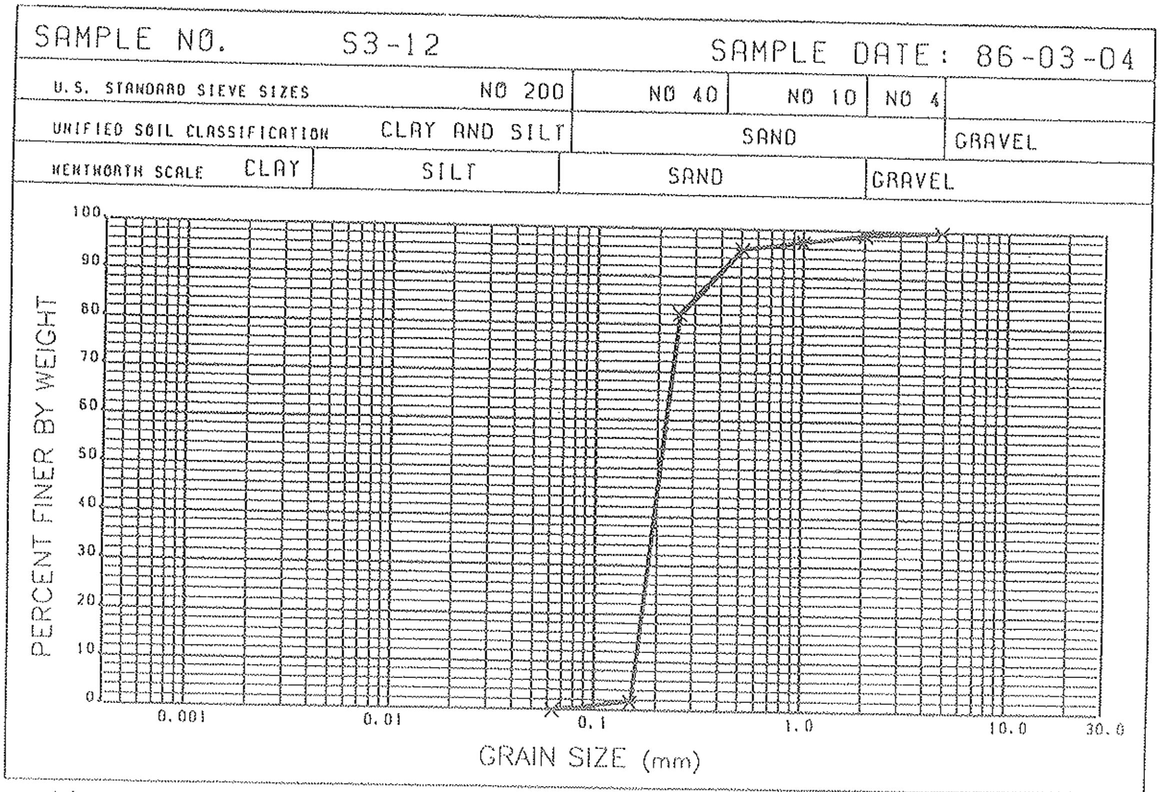
Martec Limited

FIGURE NO. C-29



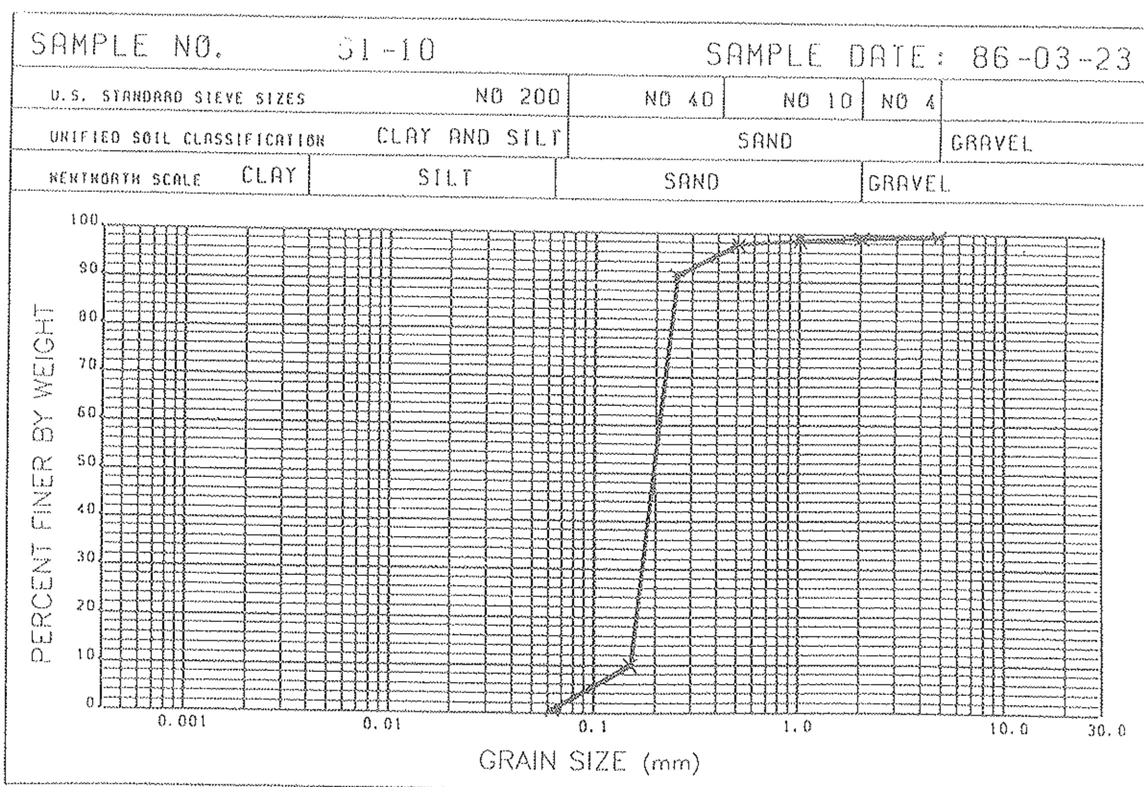
Martec Limited

FIGURE NO. C-30



Martec Limited

FIGURE NO. C-31

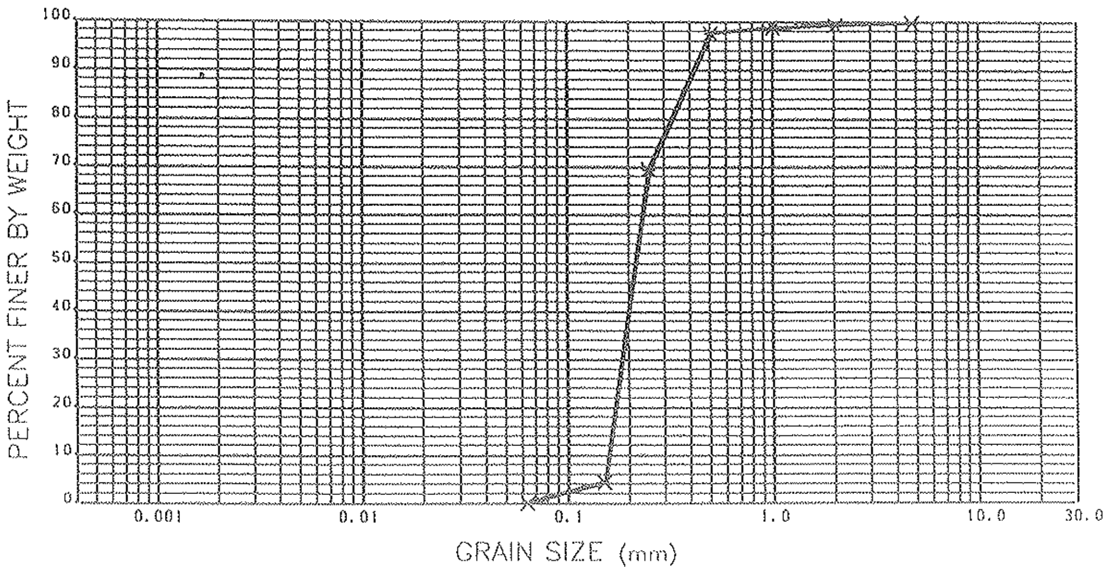


Martec Limit !

FIC JRE NO. C-32

SAMPLE NO. S1-11 SAMPLE DATE: 86-03-23

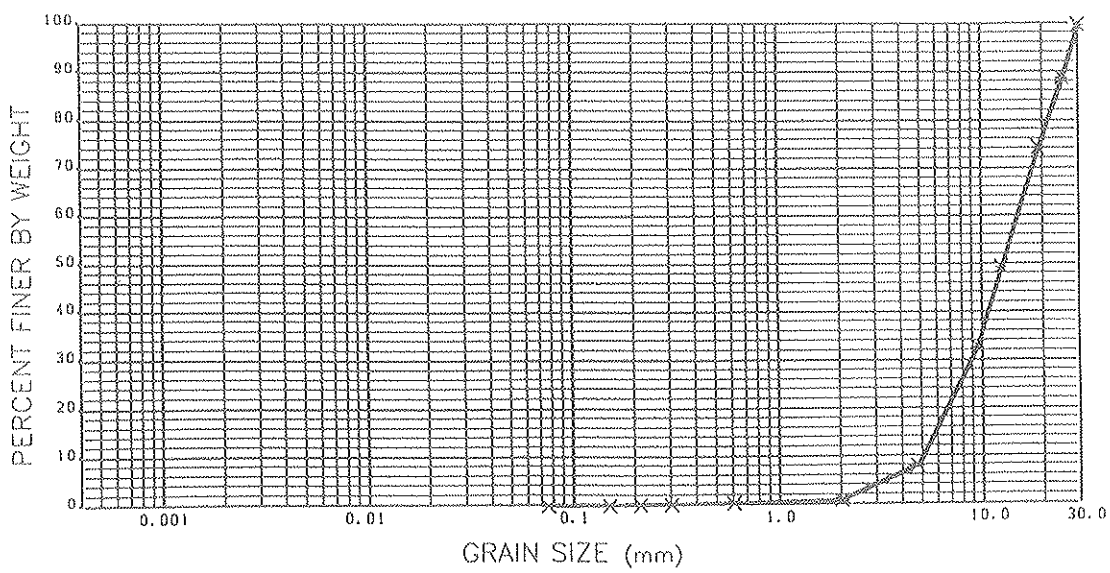
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



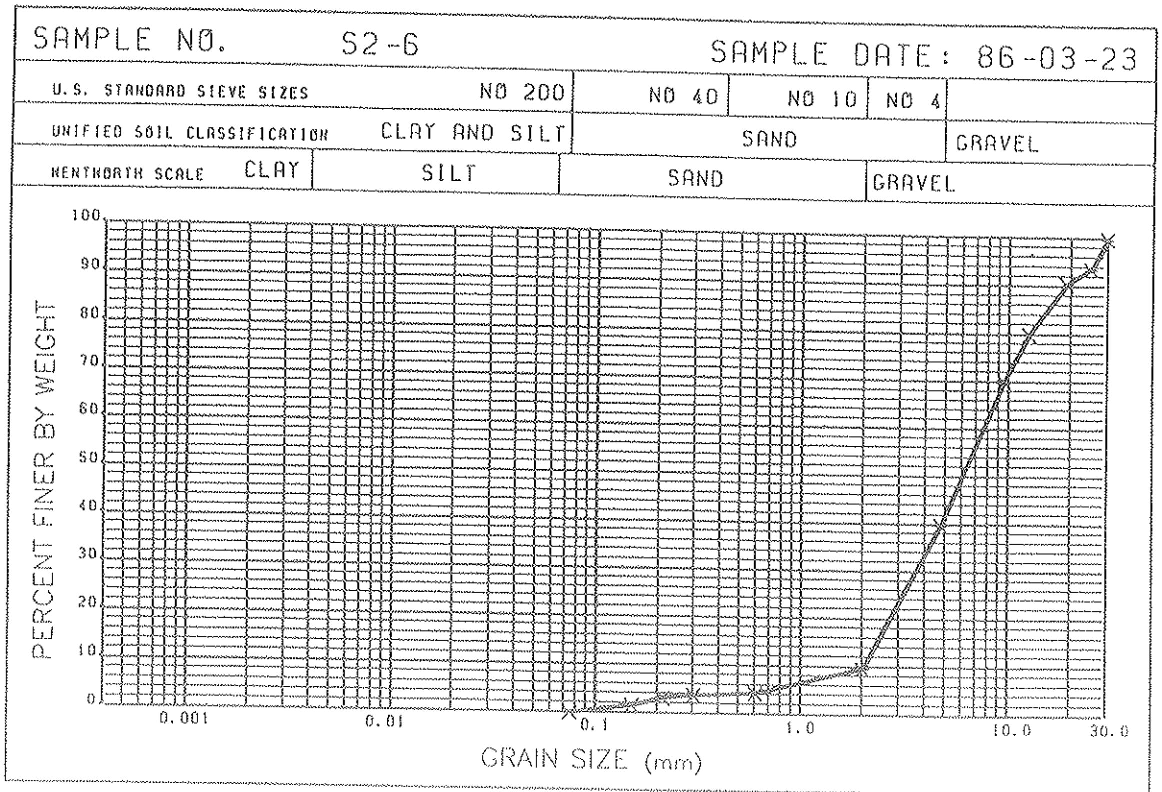
Martec Limited FIGURE NO. C-33

SAMPLE NO. S2-5 SAMPLE DATE: 86-03-23

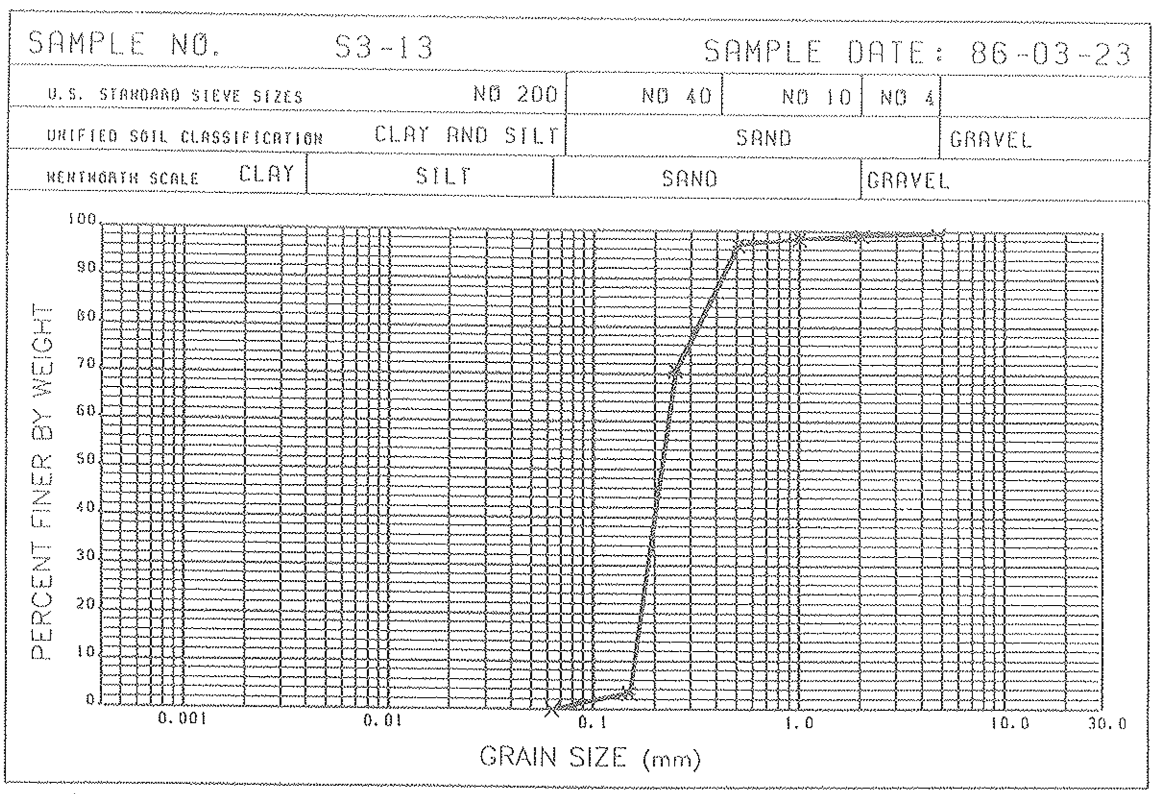
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



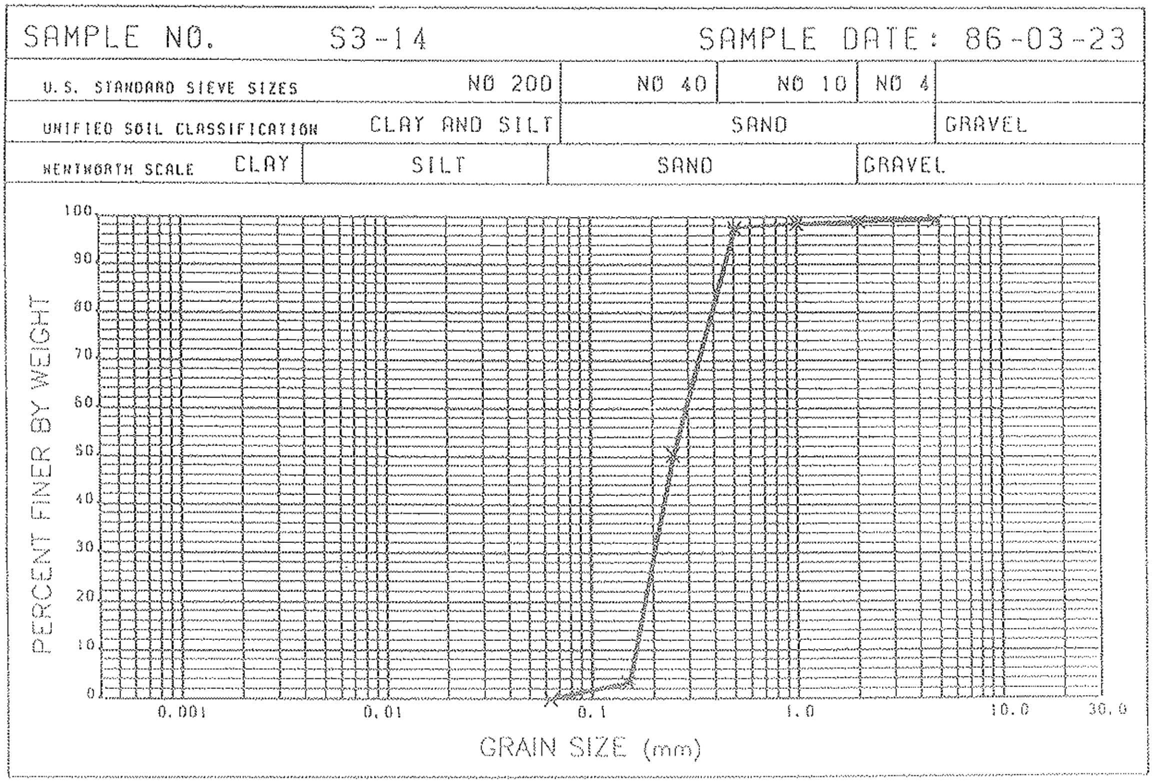
Martec Limited FIGURE NO. C-34



Martec Limited FIGURE NO. C-35

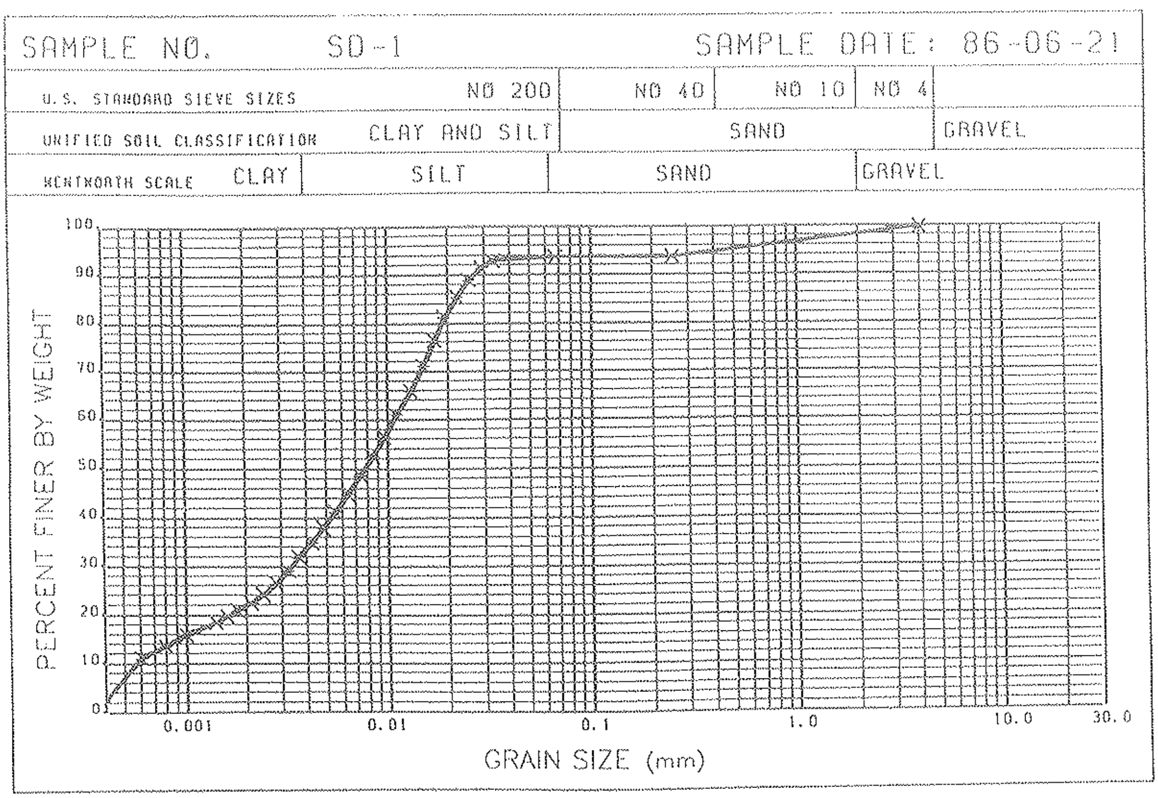


Martec Limited FIGURE NO. C-36



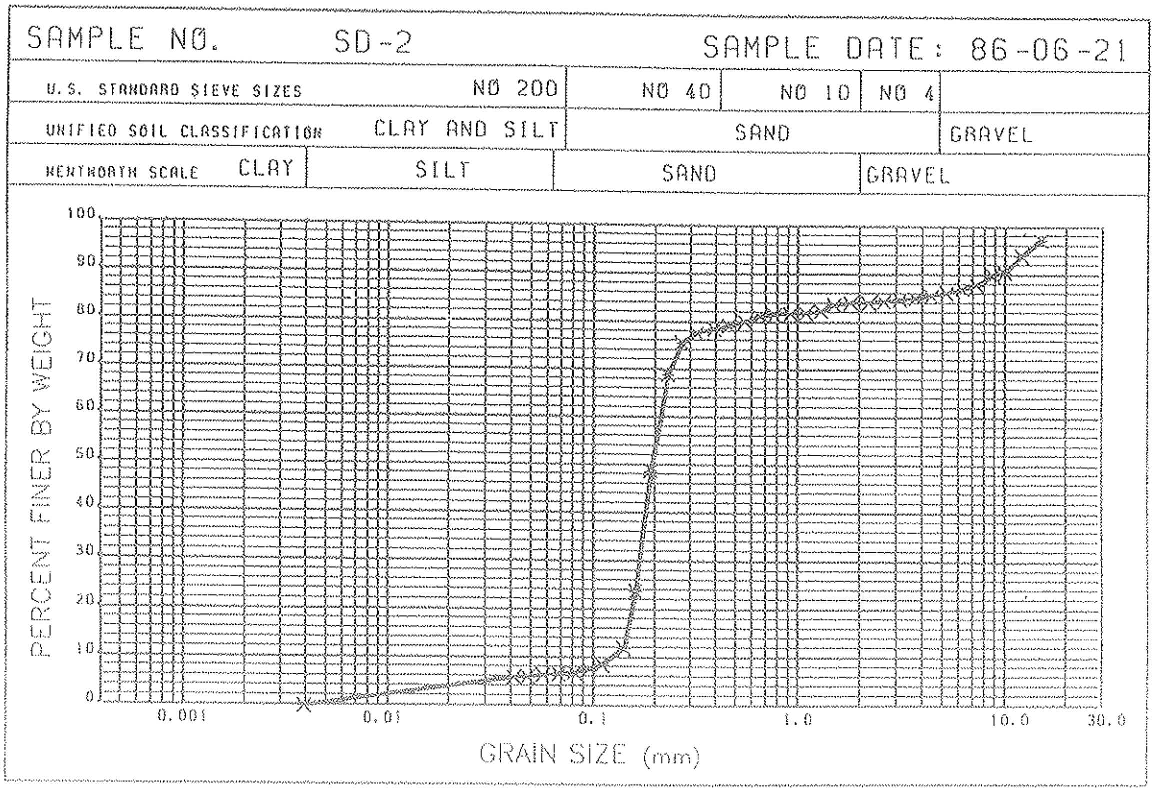
Martec Limited

FIGURE NO. C-37

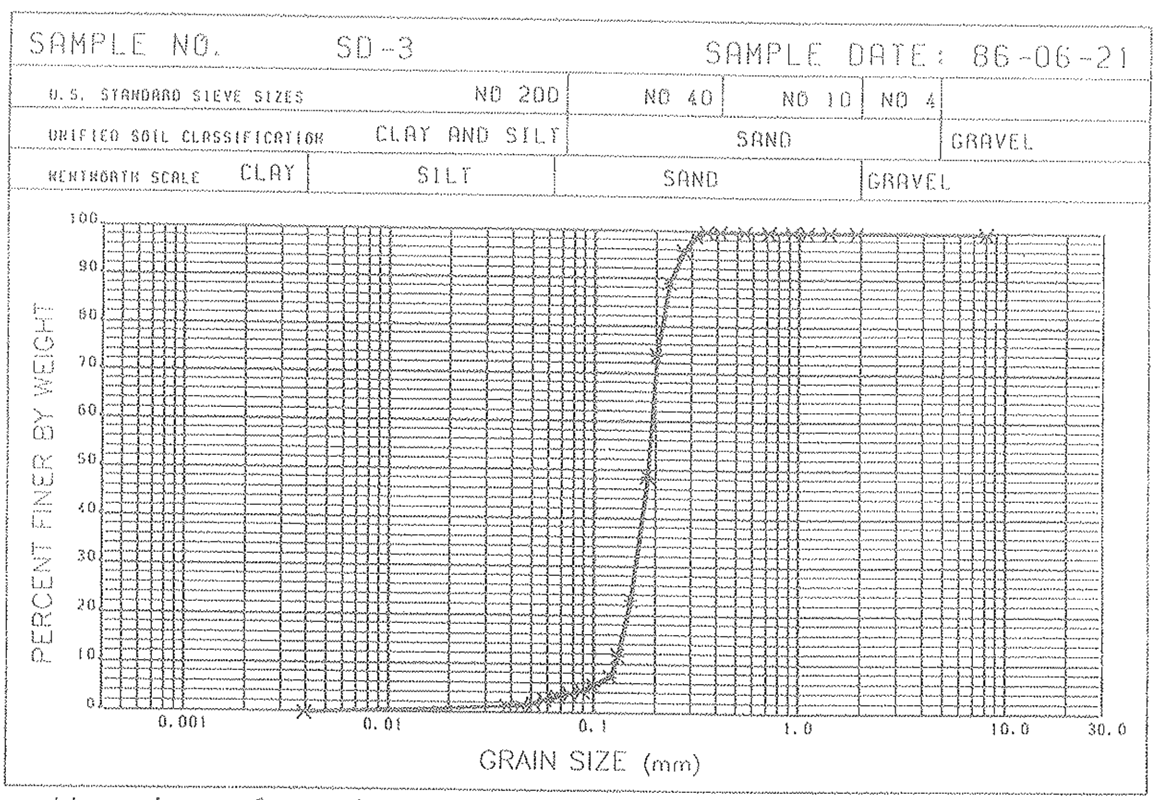


Martec Limited

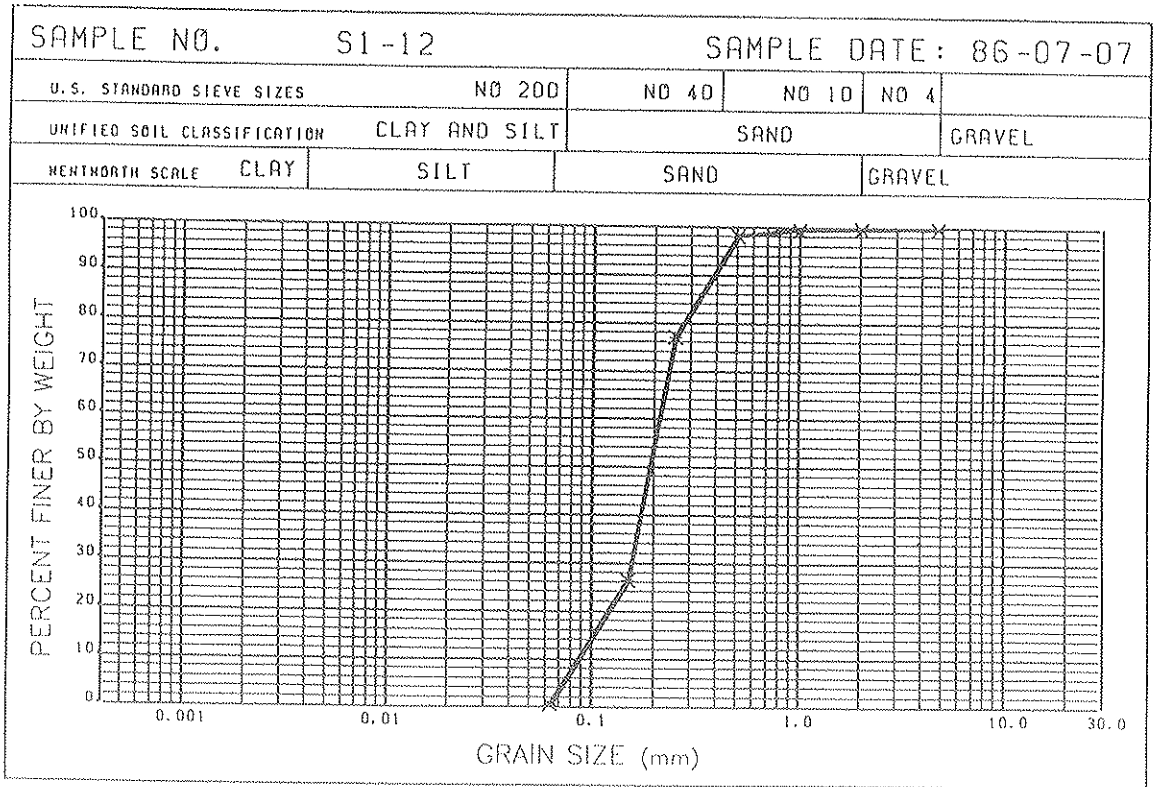
FIGURE NO. C-38



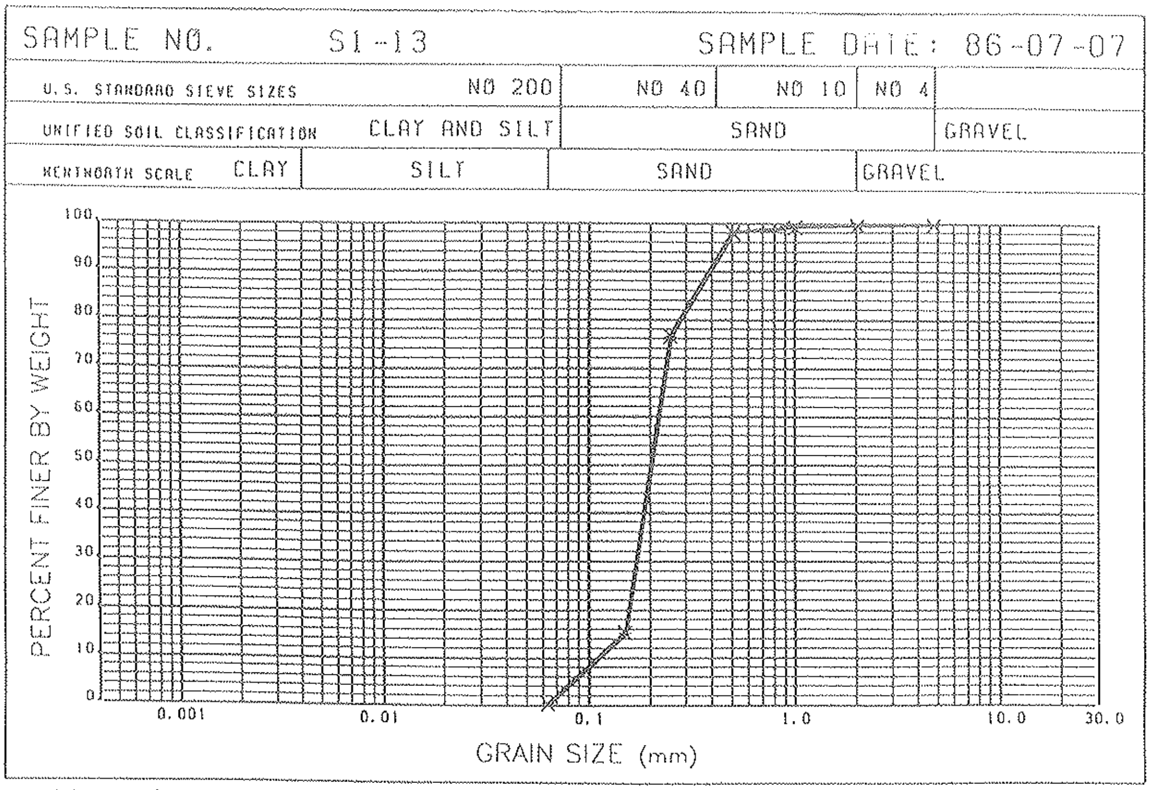
Martec Limited FIGURE NO. C-39



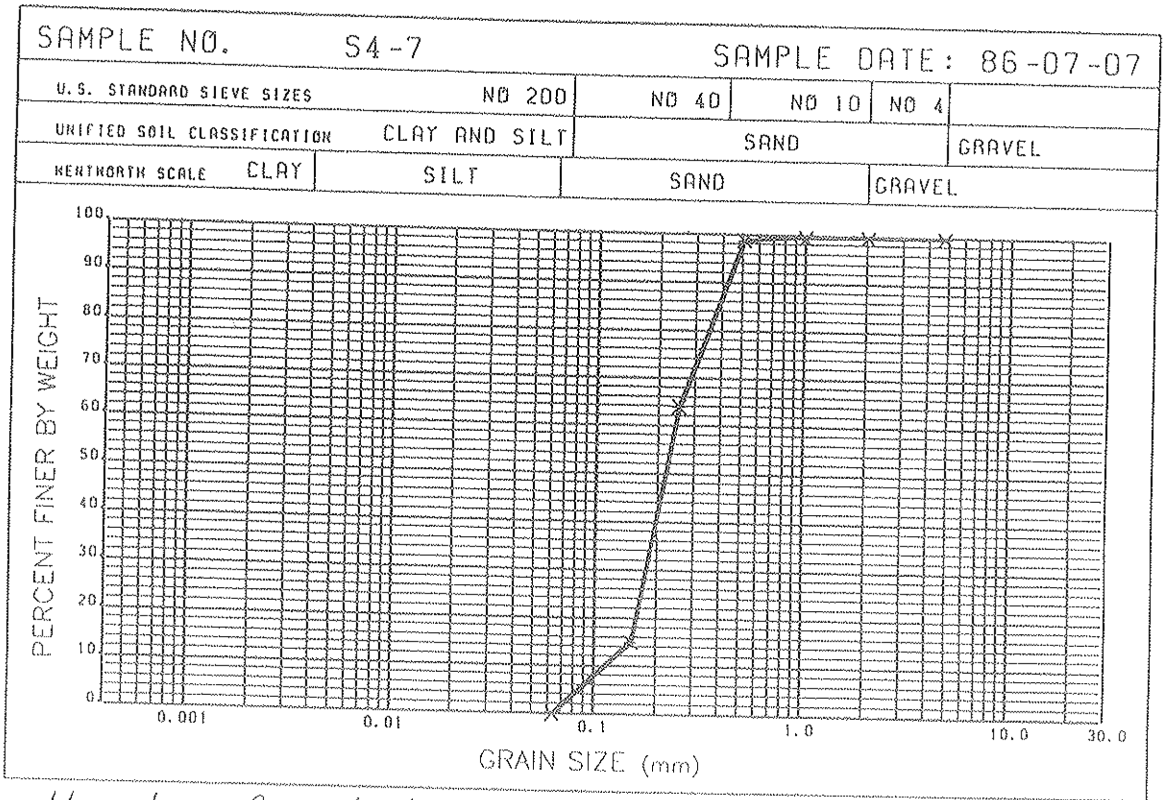
Martec Limited FIGURE NO. C-40



Martec Limited FIGURE NO. C-41

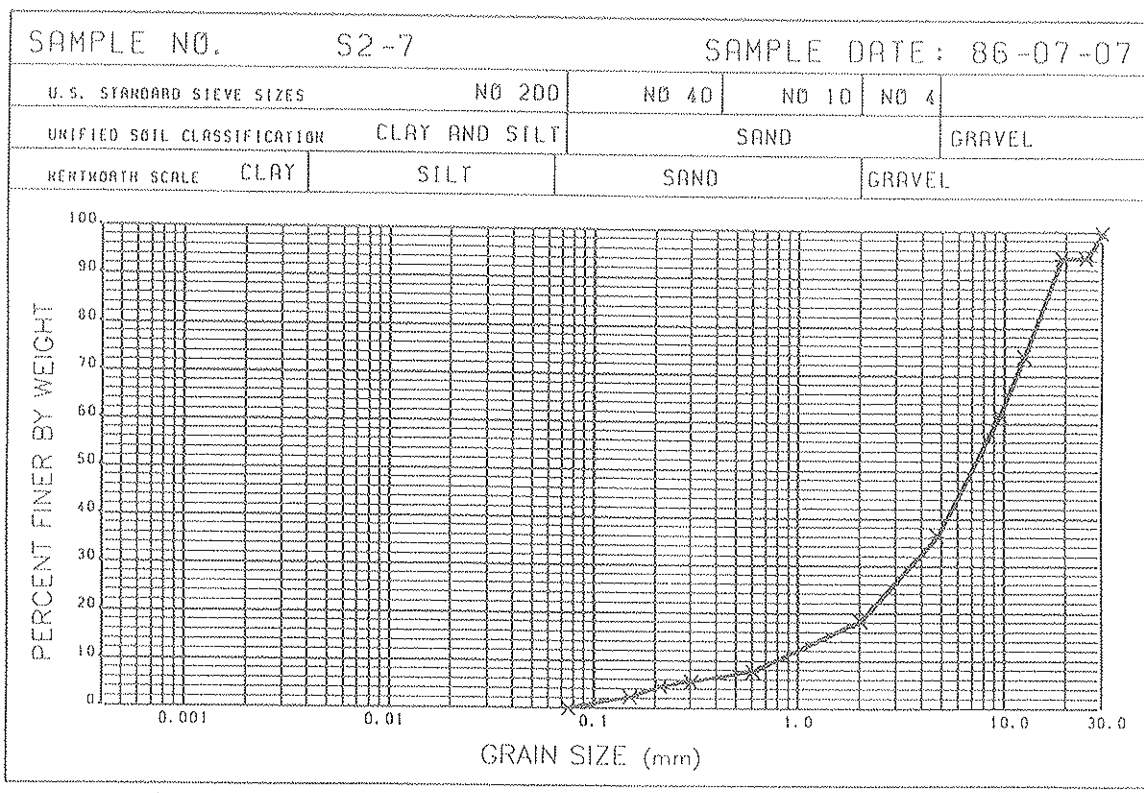


Martec Limited FIGURE NO. C-42



Martec Limited

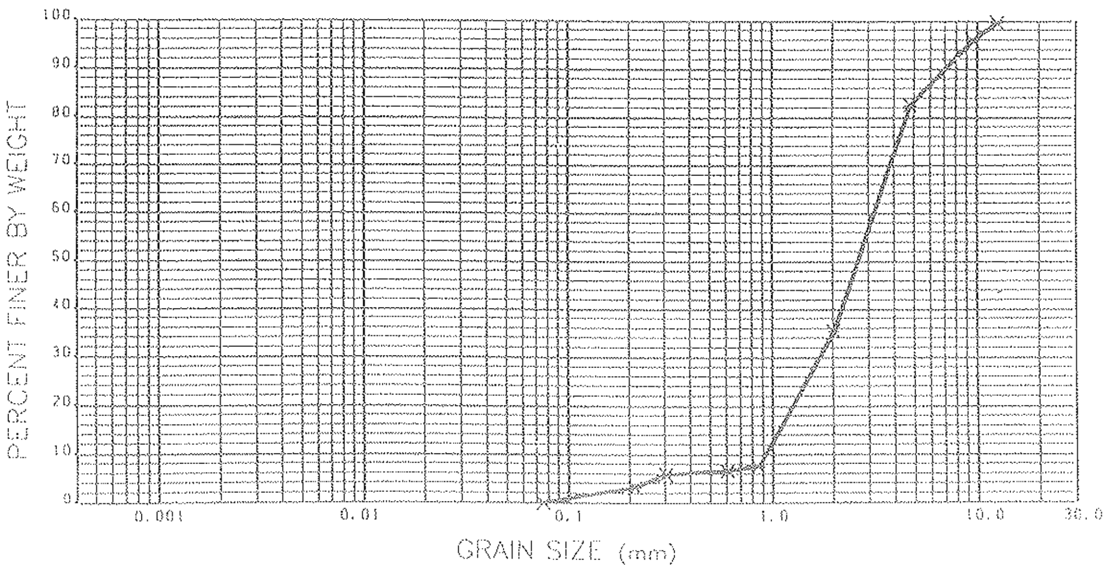
FIGURE NO. C-43



Martec Limited

FIGURE NO. C-44

SAMPLE NO.	S2-8	SAMPLE DATE: 86-07-07			
U.S. STANDARD SIEVE SIZES	NO 200	NO 40	NO 10	NO 4	
UNIFIED SOIL CLASSIFICATION	CLAY AND SILT	SAND			GRAVEL
WENTWORTH SCALE CLAY	SILT	SAND		GRAVEL	



Martec Limited

FIGURE NO. C-45