UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

[Reports Open file series]

MARINE GEOTECHNICAL DATA FOR NORTH PACIFIC SEDIMENTS

By

Adrian F. Richards

Marine Geotechnical Laboratory

Lehigh University, #17

Bethlehem, PA. 18015

1978

Open-file report

78-231

This report is preliminary and has not been edited or reviewed for conformity with Geologial Survey standards

LAYMAN'S SUMMARY

Marine geotechnical data for North Pacific sediments

By A. F. Richards

This compilation of the geotechnical properties of pelagic sediment from the North Pacific represents the most complete set of such data for this area of the world's ocean. The area between 5° and 16°N and east of 155°W has been examined in greatest detail. This area is of great interest to mining companies that are considering exploration of deep-ocean ferromanganese nodules. The data should be useful in ascertaining the extent to which the sea floor may be disturbed during mining.

Table Of Contents

CHAPTER 1

Marine Geotechnical Data Compilation, Presentation, and Synthesis for the Pelagic Nodule Area, Central Northeast Pacific Ocean

Final Report

Grant No. 14-08-0001-G-258

to the U.S. Geological Survey

by

Adrian F. Richards

Marine Geotechnical Laboratory

Lehigh University, #17

Bethlehem, PA 18015

June 1977

ABSTRACT

Geotechnical data from the published and unpublished literature are compiled in SI units and tabulated in a standardized format. Eight data sets are presented from a geographic area approximately bounded by 5° and 32° north latitude and 120° and 170° west longitude. The data exist in machine-readable form in the data bank of the Marine Geotechnical Laboratory, Lehigh University.

Individual geotechnical property data from cores collected from DOMES sites A, B, and C--including cores collected from the Deepsea Ventures mine site, are grouped and plotted against depth below the seafloor. A least-squares regression predictor equation for each grouped property related to depth is presented together with related statistical data for the equations. Low correlation coeficients for each of the predictor equations, except for "undisturbed" and remolded shear strength, suggest that improved predictor equations may result by grouping geotechnical data only for similar sediment types, rather than considering data from several large geographical areas grouped together without regard to differing sediment types within the areas.

INTRODUCTION

The objective of this investigation was to compile existing published, and unpublished marine geotechnical data in a standardized format, keypunched, and entered in the Marine Geotechnical Laboratory (MGL) data bank at Lehigh University. In addition, results of geotechnical analyses of DOMES and Deepsea Ventures cores performed in the MGL were synthesized by developing predictor equations for geotechnical properties of cores, related to a maximum depth below the seafloor of one meter, collected from DOMES sites A, B, and C, and from the Deepsea Ventures mine claim, which includes site C.

Geotechnical property data from cores collected on DOMES cruises RP-6-OC-75 and RP-8-OC-76 and from cores provided by Deepsea Ventures, Inc. are presented in separate chapters in this open file report. Data from eight other sources are tabulated in this report. They are from analyses of cores collected in an area of the deep seafloor approximately bounded by 5° and 32° north latitude and 120° and 170° west longitude. This large area includes pelagic clay, calcareous ooze, and siliceous ooze (Frazer et al., 1972). More specific sediment data, which are related to metal content of pelagic nodules for the area, are summarized by Hartmann et al., (1973).

Keller and Bennett (1968) and Keller (1969) have reviewed the distribution of sediments, shear strength, water content, and bulk density for the entire North Pacific Ocean basin. These studies provide a regional review that is useful for orientation before considering the geotechnical properties of the more limited area reported in this paper.

DATA SOURCES

Locations of cores from the eight sources of data are given in Table 1. Some geotechnical properties were calculated in the Lehigh MGL (Table 2) from the basic data that will be presented later. Original data, to a depth of one meter below the seafloor, were converted into the international system of units (SI) and key punched to be included in the machine-readable data bank of the MGL. Richards (1974) discusses the use of SI units and symbols in marine geotechnology.

Geotechnical data from cores raised by the DOMES and Deepsea Ventures cruises that were used in developing the regional predictor equations (Table 3), which will be discussed later, are from Richards (this report). Data from the eight other sources are presented in Tables 4-11. Methods of core collection, core storage, time elasping between collection and testing, and data presentation may vary, sometimes significantly,

from one data source to the next.

Arrhenius (1952) published geotechnical data resulting from the Swedish Deep Sea Expedition (Table 4). His relative strength measurements made by the Swedish fall cone were converted into convention shear strength using the formula presented by Moore and Richards (1962). Water content values were calculated from salinity (chlorinity) measurements by Arrhenius (1952) from the equation

$$w = 3.1\ (S-26)$$

in which w is the water content in percent dry salt-free weight for East Pacific eupelagic sediments and S is the salinity.

Cropper (1968) compiled geotechnical data from cores collected from the vicinity of the Hawaiian Islands (Table 5). Shear strength was measured using a motorized Farnell laboratory vane rotated at 35°/min. Bulk density was calculated by Cropper from the measured water content. The geotechnical data reported by Belshé (1968) are included in Cropper's (1968) thesis as well as in Table 5.

Lair and Sanko (1968) summarize data from cores raised west of the Hawaiian Islands (Table 6). Shear strength was measured using the Geonor fall cone. Cone penetration values were converted into shear strength using the Hansbo (1957) tables. Bulk density was calculated from the water content and specific gravity measurements. Both void ratio and porosity were

calculated by Lair and Sanko (1968).

Lee (1973) performed triaxial tests on two box core samples (Table 7). The core locations, which were not published, were subsequently provided in a personal communication.

Moore (1962) published vane shear strengths and sensitivity values from which the remolded strength was calculated in the MGL (Table 8). The vane speed, and other parameters, was not cited but assumed to be 6°/min.

Navy strength data obtained from the original National Oceanographic Data Center (NODC) was presumably acquired using a Wykeham Farrance laboratory vane rotated at 6°/min; this and other geotechnical tests are believed to follow procedures described by Richards (1961, 1962). Data from the tests is presented in Table 9. Additional marine geotechnical data may exist in the National Geophysical and Solar-Terrestrial Data Center of the NOAA Environmental Data Service; however, they are not yet available in a machine-readable form.

Noorany (1972) made triaxial tests on several box core samples collected for Kennecott Exploration, Inc. (Table 10). Two other cores raised about 2° north latitude (Noorany, 1971) were not included because their low latitude placed them outside of the area of maximum interest. Additional geotechnical analyses of box cores collected from the area covered in this report are understood to exist (Noorany, 1977, personal communication).

Simpson (1975) summarized results of hand-held vane-shear tests made at sea on box cores raised during the October-November 1975 DOMES cruise (Table 11).

Several other published data sources exist that have not been utilized. Hagerty (1974) cites data from the study area, but provides no locations. Hartmann et al. (1973) summarize geotechnical properties from cores raised with the study area, but neither core locations nor specific properties related to depth are presented. Horn et al. (1974) tabulate average grain size, bulk density, and water content data, for different sediment types, but do not list either properties from individual cores or shear strength data. Geotechnical data reported by Tsurusaki and Hirota (1976) exist for cores collected west of 170° west longitude.

PREDICTOR EQUATIONS

Individual geotechnical property data for each core were graphed by a Calcomp plotter with respect to depth below the mudline, and data from 40 cores were grouped on one graph for each property (Figs. 1-9). The 40 cores were collected from DOMES sites A, B, and C (this report) and included data from Deepsea Ventures mine claim cores (this report).

A least-squares regression line was machine-fitted to the data in each graph. The equation of the line, and related statistical data, is summarized in Table 3 for key geotechnical properties. In this table, the median grain size, ϕ, is given in phi units, which are related to SI units by the equation:

$$\phi = -\log_2 \text{(diam. in mm)}$$

The low correlation coefficient for all of the properties, except "undisturbed" and remolded shear strength, indicates that this method of analysis is not very satisfactory for most geotechnical properties. This is probably because the properties within large geographic areas are considered together without regard to the probable different sediment types within each area. The next logical step in this method of analysis would be to group together sediments having similar geological properties and then determine geotechnical predictor equations for each similar sediment type. It is noteworthy, however, that apparently there is a higher degree of uniformity of shear strength within areas A, B, and C than for the other measured and computed properties given in Table 3. At the seafloor surface, the sensitivity (ratio of "undisturbed to remolded shear strength) computed from the predictor equations is 3.4, which is a lower value than occurs in Area A alone but about the same as in Areas B and C (Richards, 1977a and 1977b).

ACKNOWLEDGEMENTS

I would like to thank G. Abdelnour, J. Andrews, M. McGrath, B. Young, and D. Volk for assistence in data reduction and computer programing. Dr. J. Parks developed the computer programs. This research was sponsored by the U.S. Geological Survey, Department of Interior, under Grant No. 14-08-0001-G-258.

REFERENCES

Arrhenius, G., 1952, Sediment cores from the East Pacific: Reports of the Swedish Deep-Sea Expedition 1947-1948: v. 5, fasc. 1, 227 p.

Belshé, J. C., 1967, Ocean sediments sampled during 1964-1967 in the Hawaiian archipelago: Univ. Hawaii, Hawaii Inst. Geophysics, Applied Oceanog. Series No. 6, HIG-68-7, 52 p.

Cropper, A. G., 1968, Mass physical properties of deep-sea sediments in the Hawaiian area: Unpub. M.S. thesis, Univ. of Hawaii, 74 p. + 3 appendices.

Frazer, J. Z., Hawkins, D. L., Hydock, L., Crocker, W. L., Schoenbechler, M., Newhouse, D. A., and Chase, T. E., 1972, Surface sediments and topography of the North Pacific: La Jolla, CA, Scripps Inst. Oceanography, charts 8 and 9.

Hagerty, R., 1974, Usefulness of spade cores for geotechnical studies and some results from the northeast Pacific, in Inderbitzen, A. L., ed., Deep-sea sediments, physical and mechanical properties: New York, Plenum Press, p. 169-186.

Hansbo, S., 1957, A new approach to the determination of the shear strength of clay by the fall-cone test: Royal Swedish Geotech. Inst. Proc., No. 14, 47 p.

Hartmann, M., Kögler, F.-C., Müller, P., and Suess, E., 1973, Preliminary results of geochemical and soil mechanical investigations on Pacific Ocean sediments, in Morgenstein,

M., ed., Papers on the origin and distribution of manganese nodules in the Pacific and prospects for exploration: Honolulu, Univ. of Hawaii, p. 71-76.

Horn, D. R., Delach, M. N., and Horn, B. M., 1974, Physical properties of sedimentary provinces, North Pacific and North Atlantic Oceans, in Inderbitzen, A. L., ed., Deep-sea sediments physical and mechanical properties: New York, Plenum Press, p. 417-441.

Keller, G. H., 1969, Engineering properties of some sea-floor deposits: Jour. Soil Mech. Eng. Div., Proc. American Soc. Civil Eng., v. 95, No. SM 6, p. 1379-1392.

Keller, G. H., and Bennett, R. H., 1968, Mass physical properties of submarine sediments in the Atlantic and Pacific basins: 9th Intern. Geol. Cong., v. 8, p. 33-50.

Lair, C., and Sanko, P., 1968, Core, sound velocimeter, hydrographic and bottom photographic stations, cores and bottom photographic stations: Marine geophysical survey program 65-67 western north Atlantic and eastern and central North Pacific Oceans, area 6, v. 8, Norwood, NJ, Alpine Geophysical Assoc., 82 p. (AD-851974)

Lee, H. J., 1973, Engineering properties of a pelagic clay: U.S. Naval Civil Eng. Lab. Tech. Note N-1296, 28 p.

Moore, D. G., 1962, Bearing strength and other physical properties of some shallow and deep-sea sediments from the North Pacific:

Geol. Soc. America Bull., v. 73, p. 1163-1166.

Moore, D. G., and Richards, A. F., 1962, Conversion of "relative" shear strength" measurements by Arrhenius on east Pacific cores to conventional units of shear strength: Géotechnique, v. 12, p. 55-59.

Noorany, I., 1971, Engineering properties of submarine calcareous soils from the Pacific, in Proceedings: the international symposium on the engineering properties of sea-floor soils and their geophysical identification: Seattle, Washington (sponsored by Unesco, Natl. Sci. Found., and Univ. of Washington), p. 130-139.

Noorany, I., 1972, Engineering properties of submarine clays from the Pacific, in First International Conference on Port and Ocean Engineering under Arctic Conditions: Trondiem, Norway, Technical Univ. of Norway, p. 255-270.

Richards, A. F., 1961, Investigations of deep-sea sediment cores, I, shear strength, bearing capacity, and consolidation: U.S. Navy Hydrographic Office, Tech. Rept. 63, 70 p.

Richards, A. F., 1962, Investigations of deep-sea sediment cores, II, mass physical properties: U.S. Navy Hydrographic Office, Tech. Rept. 106, 146 p.

Richards, A. F., 1974, Standardization of marine geotechnics symbols, definitions, units, and test procedures, in Inderbitzen, A. L., ed., Deep-sea sediments, physical and

mechanical properties: New York, Plenum Press, p. 271-292.

Richards, A. F., 1977a, Geotechnical testing of U.S. Geological Survey cores collected from the pelagic nodule area, central northeast Pacific Ocean: unpub. Final Rept., U.S. Geol. Survey Grant No. 14-08-0001-G-257.

Richards, A. F., 1977b, Geotechnical testing of Deepsea Ventures box cores collected from pelagic nodule area, central northeast Pacific Ocean: unpub. Final Rept., U.S. Geol. Survey Grant No. 14-08-0001-G-256.

Simpson, F., 1975, Results of vane shear tests conducted at-sea on DOMES cruise RP-8-OC-75: unpub. Prog. Rept., San Diego, Lockheed Ocean Lab., 11 p.

Tsurusaki, K., and Hirota, T., 1976, Studies of the investigation techniques and instruments for deep sea floor mineral resources during the Hakurei-maru cruise GH 761 to the Pacific, southwest of Hawaii, January 10 to March 9, 1976: Mining and Safety, v. 22, p. 505-522 (in Japanese, with an English summary)

Table 1. Location of Geotechnical Property Cores

Core No.	N. Lat.	W. Long.	Water Depth, m (uncorrected)	Domes Site Vicinity	Reference
51	15° 40'	123° 21'	4300	C	Arrhenius, 1952
53	15° 34'	127° 11'	4725	C	" "
54	13° 17'	127° 25'	4800	C	" "
55	11° 30'	127° 37'	4916		" "
661003-1	21° 59'	156° 59.5'	4750		Cropper, 1968
661003-2	21° 52.5'	156' 56'	4825		" "
661003-8	22° 21'	155° 43'	4440		" "
661003-10	23° 43.5'	155° 25'	4133		" "
660622-1	23° 16'	155° 30'	4425		" "
670123-3	18° 00'	156° 41'	4585		" "
670224-1	21° 40'	156° 27'	5375		" "
670224-2	21° 29'	155° 54.5'	5700		" "
670224-3	20° 55'	155° 02'	5750		" "
670313-5	20° 34.5'	157° 27'	3980		" "

Core No.	N. Lat.	W. Long.	Water Depth, m (uncorrected)	Domes Site Vicinity	Reference
670504-1	22° 30.4'	160° 07'	4435		Cropper, 1968
MR-1	22° 23'	155° 24'	4428		" "
MR-2	22° 31'	155° 23'	4371		" "
MR-3	22° 31'	155° 31'	4390		" "
MR-4	22° 28'	155° 28'	4390		" "
MR-5	22° 28'	155° 18'	4390		" "
MR-6	22° 31'	155° 13'	4393		" "
MR-7	22° 35'	155° 09'	4313		" "
11-1	15° 51'	160° 37'	5550		Lair & Sanko, 1968
11-2	17° 13.5'	163° 40'	5515		" "
11-3	17° 42'	169° 39'	5266		" "
16-4	20° 10'	161° 28'	4640		" "
16-5	22° 10.5'	163° 50'	4720		" "
16-6	22° 05.8'	169° 27.5'	4420		" "
17-7	25° 05.5'	160° 20'	4775		" "

Core No.	N. Lat.	W. Long.	Water Depth, m (uncorrected)	Domes Site Vicinity	Reference
17-8	25° 53'	161° 33'	4960		Lair & Sanko, 1968
17-9	31° 28'	160° 14'	5600		" "
A	15° 32'	126° 32'	4362	C	Lee, 1973
B	15° 30'	126° 00'	4389	C	" "
PO6 a, b, c, d, e	32° 27'	120° 41'	3680		Moore, 1962
CK-1a	29° 24'	153° 06'	5660		" "
N-3 (266702)	29° 55'	157° 59'	5681		NODC, unpublished
N-4 (266702)	30° 02'	160° 26'	5542		" "
N-5 (266704)	30° 06'	149° 00'	5362		" "
N-6 (266704)	29° 58.5'	158° 47.5'	5667		" "
N-19 (31685)	13° 55'	139° 56'	4758	B	" "
9-4B	2° 36'	158° 37.5'	3164		Noorany, 1971
9-4C	2° 11'	158° 57.5'	4481		" "
9-5A	8° 36'	154° 37'	5066	A	Noorany, 1972
10-1	23° 50.4'	143° 58'	5514		" "
10-1c	23" 25'	144° 04.7'	5505		" "

Core No.	N. Lat.	W. Long.	Water Depth, m (uncorrected)	Domes Site Vicinity	Reference
46-1	9° 20.7'	150° 50.7'	5009	A	Simpson, 1975
46-2	9° 21.3'	150° 49.5'	5038	A	" "
46-4	9° 23.8'	150° 52.8'	5004	A	" "
46-5	9° 21.3'	150° 51.4'	4952	A	" "
46-6	9° 24.0'	150° 49.9'	5073	A	" "
46-7	9° 19.6'	150° 50.7'	4965	A	" "
46-9	9° 20.0'	150° 48.4'	4700	A	" "
47-10	9° 0.3'	151° 10.9'	4958	A	" "
47-11	9° 2.5'	151° 10.6'	4905	A	" "
47-13	9° 2.3'	151° 11.2'	4892	A	" "
47-12	9° 3.5'	151° 11.1'	4861	A	" "
47-14	9° 4.0'	151° 14.2'	4960	A	" "
47-15	9° 4.8'	151° 11.1'	4965	A	" "
47-18	9° 4.8'	151° 9.4'	4978	A	" "
48-19	8° 16.5'	151° 7.3'	4896	A	" "
48-20	8° 14.3'	151° 14.3'	3637	A	" "

Core No.	N. Lat.	W. Long.	Water Depth, m (uncorrected)	Domes Site Vicinity	Reference
48-22	8° 16.0'	151° 11.3'	4967	A	Simpson, 1975
48-23	8° 18.1'	151° 9.5'	4993	A	" "
49-24	8° 27.5'	150° 46.7'	4881	A	" "
49-25	8° 28.5'	150° 44.5'	4859	A	" "
49-26	8° 27.4'	150° 50.2'	4826	A	" "
49-27	8° 30.2'	150° 47.8'	4892	A	" "
50-28	8° 41.7'	150° 18.7'	3637	A	" "
50-29	8° 43.8'	150° 18.7'	4887	A	" "
50-30	8° 41.1'	150° 15.1'	4786	A	" "
50-31	8° 41.4'	150° 15.0'	4824	A	" "
50-32	8° 43.1'	150° 14.1'	4806	A	" "
51-33	11° 41.6'	139° 11.0'	4740	B	" "
51-34	11° 42.4'	139° 10.8'	4782	B	" "
51-35	11° 43.1'	139° 8.9'	4771	B	" "
51-36	11° 43.7'	139° 8.2'	4771	B	" "
52-37	11° 13.7'	139° 9.9'	4733	B	" "
52-38	11° 14.9'	139° 5.4'	4790	B	" "

Core No.	N. Lat.	W. Long.	Water Depth, m (uncorrected)	Domes Site Vicinity	Reference
52-40	11° 16.3'	139° 4.2'	4720	B	Simpson, 1975
52-41	11° 13.5'	139° 7.7'	4711	B	" "
52-42	11° 15.5'	139° 3.3'	4731	B	" "
53-43	11° 42.2'	138° 23.4'	4852	B	" "
53-44	11° 43.3'	138° 22.4'	4855	B	" "
53-45	11° 43.9'	138° 22.2'	4841	B	" "
53-46	11° 44.3'	138° 21.2'	4788	B	" "
54-47	12° 10.4'	137° 44.1'	4788	B	" "
54-48	12° 11.0'	137° 41.0'	4788	B	" "
54-51	12° 8.9'	137° 44.6'	4791	B	" "
54-52	12° 9.6'	137° 42.4'	4810	B	" "
55-53	11° 48.6'	137° 28.3'	3637	B	" "
55-54	11° 50.8'	137° 26.7'	4693	B	" "
55-55	11° 48.2'	137° 26.3'	4715	B	" "
55-56	11° 48.6'	137° 24.3'	3637	B	" "

Table 2. Calculated Geotechnical Properties

Property	Symbol	Calculation	Notes
Void ratio	e	$e = \frac{Gw}{100}$	Assumed 100% saturation
Porosity	n	$n = \frac{e}{1+e}\ (100)$	
Liquidity index	I_L	$I_L = \frac{w - w_p}{I_p}$	
Plasticity index	I_p	$I_p = w_L - w_p$	

Table 3. Geotechnical Predictor Equations: Sites A, B, and C Combined (40 Cores)

Parameter	Predictor Equation[1]	Standard Error of Estimate	Correlation Coefficient	Number of Data
Grain Size, % >62μm	8.370 - 6.228 x z	11.043	-.083	68
Grain Size, % <2μm	18.922 - 10.243 x z	8.514	-.175	68
Median Grain Size, ϕ	8.119 - 0.159 x z	0.319	-.073	68
Bulk Density, Mg/m^3	1.263 + 0.044 x z	0.061	.089	120
Water Content, % dry weight	219.249 - 57.682 x z	56.694	-.139	520
Liquid Limit, %	146.334 + 27.059 x z	36.348	.112	78
Plastic Limit, %	79.935 - 10.857 x z	27.502	-.059	78
Shear Strength, undist., kPa	4.432 + 13.215 x z	4.840	.346	132
Shear Strength, remold., kPa	1.313 + 3.010 x z	1.554	.253	132

[1] z = depth below seafloor in meters.

Table 4. Geotechnical Properties of Arrhenius (1952) Cores

Arrhenius, 1952

Core 51

Specific Gravity = -

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
0				1.33	150							4.64			47	2
110				1.26	191							6.42			58	2
170				1.28	187							5.89			57	1
230				1.28	187							4.31			57	1
330				1.28	187							3.93			57	
440				1.28	183							5.08			56	
530				1.28	180							5.89			55	1
630				1.28	183							6.89			56	1
730				1.28	187							5.55			55	1
830				1.28	180							5.84				1
920				1.30	172							8.43			53	1

Arrhenius, 1952

Core 53

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
100				1.28	187							20.68			57	60
200				1.25	217							43.24			65	52
300				1.26	202							32.80			61	48
400				1.25	213							26.05			64	57
510				1.28	187							27.91			57	54
620				1.26	191							23.22			58	54
720				1.23	272							24.90			80	38
780				1.23	283							24.32			83	32
900				1.23	239							27.29			71	49
1000				1.25	224							23.22			67	53

Core 54

Specific Gravity = -

0				1.26	209							4.64			63	1
100				1.23	254							8.81			75	1
200				1.23	250							4.98			74	0
390				1.23	272							5.55			80	1
500				1.23	242							4.64			72	0
580				1.23	276							5.84			81	1
690				1.23	246							3.93			73	1
790				1.23	235							5.55			70	1
900				1.23	246							9.91			73	1
980				1.23	257							9.24			76	1

Arrhenius, 1952

Core 55

Specific Gravity = -

Depth, µm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
0				1.23	254							11.63			75	1
20				1.23	279							5.84			82	1
70				1.23	283							1.48			83	1
170				1.23	291							2.92			85	1
190				1.23	346							1.15			99	0
300				1.23	276							2.06			81	1
380				1.23	279							2.92			82	1
450				1.23	283							2.78			83	0
530				1.23	302							4.40			88	0
600				1.23	298							4.84			87	0
700				1.23	235							4.12			70	1
800				1.23	261							4.64			77	1
900				1.23	239							7.32			71	1
1000				1.23	246							4.64			73	1

Table 5. Geotechnical Properties of Cropper (1968) Cores

Cropper, 1968

Core MR-3

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13			7.2													
38				1.43								1.93				
114	9		6.5	1.60								4.55				
190				1.57								6.48				
267	16		7.0	1.56								7.72				
336				1.54								13.65				
362			7.1													
400				1.54				92	46	46		15.58				
419	40	11	7.4													
457				1.48				109	46	63		20.89				
483	32	18	6.8													
502				1.35	156			153	87	66	1.0	38.68				
540	17	31	5.5													
572				1.33	168			178	100	78	0.9	99.99				
578			4.1													
654				1.31	177			174	117	57	1.0					

Cropper, 1968

Core MR-1

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13			8.0													
38				1.44	139							.83				
114				1.46	119							1.42				
190				1.51	101							2.50				
267	37		7.4	1.61	90							5.87				
387			7.8	1.55	84			70	34	36	1.4	6.90				
559	9	1	6.4	1.57	77			82	36	46	2.0	7.29				
590	47	6														
718			8.3													
762				1.44	114			92	37	55	1.4	9.01				
794			7.4													
914				1.42	110			89	35	54	1.4	16.27				
946	40	10	7.2													
991				1.49	103							18.75				

Cropper, 1968

Core MR-6

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13			7.6													
38				1.43	131							2.21				
114				1.49	112							4.34				
190	7		6.4	1.53	97							4.96				
267				1.55	94							5.52				
356	14	5	7.3	1.63	78			83	40	43	0.9	7.80				
470	20	11	7.2	1.48	95			89	39	50	1.1	7.38				
559	30	10	6.9	1.51	100			102	43	59	1.0	11.10				
619	24	6	6.5						67							
667				1.32	185			191				32.89				
724				1.34	171			174	172	2	-0.5	85.15				

Cropper, 1968

Core MR-5

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13			7.5													
51				1.50	121							3.72				
114				1.53	115							4.96				
190				1.55	91							5.93				
203	21		7.3													
267				1.53	92							8.62				
318	5	5														
356			6.5	1.38	71			88	28	60	0.7	9.79				
457			7.2	1.68	104			86	35	51	1.4	12.06				
495	13	3														
559	19	3	6.4	1.50	94			93	36	57	1.0	12.89				
610	24	9	6.5	1.50	103			102	33	69	1.0	16.41				
673	24	5	5.8	1.40	134			54				69.77				
762				1.33	228			180	90	90	1.5					

Cropper, 1968

Core MR-4

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13			7.6													
64				1.47	116							3.17				
114				1.50	103							6.55				
190				1.56	91							7.31				
267				1.56	95							11.58				
336				1.63	71			75	27	48	0.9	10.55				
371	31	1	7.5													
381	92		6.3													
464				1.72	87				37			13.10				
498	10	8	7.0													
590				1.52	91			91	39	52	1.0	15.86				
625	12	6	7.2													
679	16	10	7.1													
718				1.49	108			116	41	75	0.9	17.37				
772				1.44	146			156	48	108	0.9	33.99				
784	20	31	5.9													
832				1.33	181			182	163	19	1.0	52.33				

Cropper, 1968

Core MR-2

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13			7.4													
38				1.50	114							2.55				
114				1.55	96							5.10				
190	13		6.5	1.57	100							6.14				
267				1.54	96							7.45				
336			7.0						48			11.72				
406			7.2					90	45	45		13.17				
508			6.8					133	65	68		30.06				
590			6.2					187	135	52		42.06				
648			5.8					168	160	8						

Cropper, 1968

Core 661003-10

Specific Gravity =

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
38			7.8	1.57	98							1.10				
114				1.55	91							2.48				
190	54	1	8.3	1.53	99							5.24				
267			6.7	1.40	149							5.31				
343	31	1	7.2	1.36	164							6.34				
419				1.43	125							6.20				
495			8.0	1.47	108							7.79				
572	50		8.0	1.52	106							7.93				
648	29	1	6.9	1.30	212							11.17				
724				1.32	214							9.38				
749												10.07				
800	24	1	6.6	1.31	195							13.58				
876												16.13				
927			6.2													

Cropper, 1968

Core 670123-3

Specific Gravity =

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
38			5.8	1.30	228							.96				
114	37	17	6.5	1.27	269							.83				
190	22	15	6.5	1.27	260							1.38				
267	25	14	5.6	1.37	157							1.58				
343				1.42	146							4.55				
419	19	9	5.8	1.51	177							4.69				
495				1.47	111							3.45				
572	20	5	6.0	1.42	148							1.65				
648	20	5	6.0	1.38	158							1.93				
692												2.96				

Cropper, 1968

Core 670224-3

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
38			6.9	1.26	285											
114	29	7	6.6	1.31	300							.24				
190				1.26	359							.36				
267				1.18	462							.72				
305			7.1													
343				1.19	383							1.97				
419	5	53	2.8	1.14	478							1.43				
495	15	47	3.4	1.21	413							1.68				
572				1.16	473							1.02				
610			7.9	1.16	469							1.14				
660			8.1													

Cropper, 1968

Core 670224-2

Specific Gravity =

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
64			6.4	1.35	170							3.79				
114				1.30	206							3.52				
190	34	26	6.7	1.19	330							2.62				
267				1.27	333							1.17				
305	28	10	5.3	1.35	189											
343				1.24	335							3.86				
419	24	33	6.0	1.19	349							3.86				
495				1.19	333							3.52				
572	29	28	6.4	1.17	347							3.52				
648				1.18	396							3.86				
724	18	48	3.8	1.18	387							4.69				
800				1.14	283							4.96				
876				1.22	376							3.79				
952	32	32	5.9	1.18	365							3.58				

Cropper, 1968

Core 670224-1

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
38	22	20	5.1	1.44	134							3.03				
114	28	18	6.2	1.24	324							2.96				
190				1.23	322							2.48				
267	31	22	6.6	1.25	340							2.41				
343	30	36	5.4	1.19	282							2.62				
419				1.20	365							2.96				
495	37	17	6.8	1.24	274							2.62				
572				1.27	276							3.17				
648				1.31	240							3.72				
724				1.37	193							3.52				
800	32	16	6.7	1.49	125							4.90				
927	26	39	5.2	1.18	352							2.90				

Cropper, 1968

Core 661003-8

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13			6.9													
51												1.72				
70				1.52	100											
105												3.65				
121				1.56	95											
159												5.79				
178	53	1	7.8	1.63	79											
210												6.14				
229				1.57	94											
260												10.48				
283	44	1	7.6	1.57	92											
305												12.41				
336				1.52	99											
356												12.00				
400	34	1	7.1	1.40	150											
419												36.54				
470												99.99				
495	5	5	5.7	1.24	194											

Cropper, 1968

Core 661003-2 (continued)

Specific Gravity =

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
533	19	7	5.5	1.50	106											
565												6.62				
584				1.47	112											
597												4.69				
686	36	2	6.9									11.65				
698				1.46	98											
762												20.27				
775	36	1	7.0	1.59	87											
838												12.00				
864				1.52	103											
914												11.65				
940	32	1	6.4	1.49	108											
991												7.79				

Cropper, 1968

Core 661003-2

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
38												.62				
64			6.7	1.32	197											
102				1.32	207											
114												.55				
152	40	2	7.4	1.27	244											
190			7.4	1.30	247							.55				
229			7.4									1.31				
254				1.30	227											
267												2.07				
292			7.6													
305				1.34	189											
330	30	2	6.4		186											
343												1.72				
381				1.33												
419			7.2									1.79				
444				1.40	159											
470												3.38				

Cropper, 1968

Core 661003-1

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13			6.0													
38												.62				
60				1.48	129											
89												1.45				
108				1.47	130											
140												1.86				
159				1.48	113											
184												4.90				
210				1.56	96											
235												4.14				
248				1.57	97											
298			5.0													

Cropper, 1968

Core 660622-1

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13	51		8.0	1.44	126							.76				
64				1.52	106							2.14				
114				1.52	97							3.65				
190				1.58	87							4.76				
267	15		6.8	1.57	93							4.76				
343				1.54	95							4.55				
419				1.56	92							4.55				
495	17		6.8	1.52	89							6.69				
572				1.49	104							7.45				
660				1.50	106							8.82				
724				1.51	105							9.44				
800				1.50	115							8.89				
876	8		6.3	1.32	188							9.24				

Cropper, 1968

Core MR-7

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13			7.6													
38				1.43	131							.62				
114				1.49	107							1.58				
190	16	1	6.7	1.54	99							2.14				
267				1.55	94							4.69				
343	23		7.2	1.56	91							7.10				
419				1.54	92							9.65				
495				1.54	89							13.03				
572				1.51	97							11.17				
648	7		6.5	1.50	106							11.65				
724				1.50	106							13.24				
800	28	1	7.3	1.50	103							18.27				
876				1.56	109							11.65				
952												17.10				

Cropper, 1968

Core 670504-1

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
38	18	55	2.8	1.47	125							2.00				
102	41	19	6.2	1.55	78							27.16				
152				1.70	67							15.72				
197				1.68	70							12.27				
241	30	29	5.0	1.68	69							26.20				
279	32	19	5.9	1.52	88							30.61				
330	30	24	5.3	1.59	69							35.92				

Table 6. Geotechnical Properties of Lair and Sanko (1968) Cores

Lair & Sanko, 1968

Core 11-1

Specific Gravity = 2.56

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
50			5.6	1.62	68	1.74	64									
250				1.62	66	1.69	63									
350			9.2	1.34	141	3.61	78									
1000			9.2	1.37	125	3.20	76					9.02				

Core 11-2

Specific Gravity = 2.60

100			8.6	1.34	137	3.56	78					2.45				
500			8.8	1.32	165	4.29	81					3.04				
1000			8.7	1.35	145	3.77	79					4.90				

Lair & Sanko, 1968

Core 11-3

Specific Gravity = 2.62

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
50			8.3	1.47	97	2.54	72									5.4
500			8.1	1.48	92	2.41	69					27.56				0.0
Core 16-4																
Specific Gravity = 2.82																
400			9.1	1.38	136	3.84	79					4.22				
700			9.8	1.33	160	4.51	82					2.94				
Core 16-5																
Specific Gravity = 2.79																
100			7.3	1.48	100	2.79	74					5.59				
200			6.4	1.61	70	1.95	66					2.84				
600			8.2	1.38	136	3.79	79					13.73				
1000			8.9	1.40	126	3.52	78					8.04				

Lair & Sanko, 1968

Core 16-6

Specific Gravity = 2.76

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
250			10.4	1.43	115	3.17	76									
500			10.3	1.39	127	3.51	78					7.94				
1000			8.9	1.41	116	3.20	76					12.55				
Core 17-7																
Specific Gravity = 2.86																
30			7.9	1.41	127	5.81	85									
70			6.5	1.49	100	2.86	74									
130				1.51	95	2.72	73									
170				1.41	126	3.60	78									
220				1.42	118	3.37	77									
280			7.6	1.38	136	3.89	80									
320			8.5	1.25	221	6.32	86									

Lair & Sanko, 1968

Core 17-8

Specific Gravity = 2.83

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
50			8.6	1.26	213	6.03	86					38.25				
100			8.3	1.25	219	8.63	90					27.46				
140			8.5	1.25	224	6.34	86					55.90				
200			7.2	1.31	171	4.84	83					49.03				
240			7.4	1.38	137	3.88	79					81.40				
280			7.3	1.35	151	4.27	81									

Core 17-9

Specific Gravity = 2.49

100			10.8	1.47	95	2.37	70					7.26				
500			10.4	1.32	152	3.78	79					9.02				
1000			10.0	1.28	179	4.46	81					11.77				

Table 7. Geotechnical Properties of Lee (1973) Cores

Lee, 1973

Core A

Specific Gravity = 2.72

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
76	52	8						115	56	59		6.89	1.15	5.99		
229	56	6						124	55	69		6.89	1.15	5.99		

Core B

Specific Gravity = 2.71

76	57	5						105	56	49		6.89	1.15	5.99		
229	57	4						109	61	48		6.89	1.15	5.99		

Moore, 1962

Core P06 a, b, c, d, e

Specific Gravity = -

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
96												1.17	0.32	3.16		
287	66	0	9.0	1.31								2.22	0.82	2.71		
476												1.63	0.46	3.54		
668	63	0	9.0	1.32								2.32	0.68	3.41		
858												3.48	0.19	18.32		

Core CK-1A

Specific Gravity = -

75	76	2	9.1	1.45								1.54	0.50	3.08		
575	77	3	9.6	1.44								1.19	0.30	3.97		

Table 9. Geotechnical Properties of NODC (unpublished) Cores

NODC, unpublished

Core N-3 (266702)

Specific Gravity = -

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
95					107											
220					104											
300				1.42	104							3.24				
400					106											
500					99											
600				1.44	100							2.84				
700					105											
800					110											
900				1.42	106							4.31				
975					102											

Core N-4 (266702)

Specific Gravity = -

100				1.47	94							2.94				
200					47											
300					107											
400				1.44	99							3.42				
500					102											
600					104											
700				1.44	104							4.12				
800					101											
900					97											
1000				1.44	104											

NODC, unpublished

Core N-5 (266704)

Specific Gravity = -

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
45					121											
125				1.43	111							0.20				
205					108											
300					110											
400				1.43	114							0.20				
500					121											
600					105											
700				1.44	106							0.29				
800					100											
900					96											
1000				1.48	99							0.29				

Core N-6 (266704)

Specific Gravity = -

50					114											
135				1.46	99											
210					101											
300					103											
400				1.47	105							2.45				
500					80											
600					103											
700				1.44	105							3.92				
800					116											
900					108											
1000				1.44	110							1.67				

NODC, unpublished

Core N-19 (31685)

Specific Gravity = -

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
25				1.24	242							1.37				
125					224											
225				1.27	204							4.51				
330					202											
435					211											
485				1.27	196							4.22				
585					193											
700					197											
765				1.27	199							5.00				
865					211											
965					189											

Table 10. Geotechnical Properties of Noorany (1975) Cores

Noorany, 1975

Core 9-5A

Specific Gravity = 2.66

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
305					247	6.57	87	210				6.86	1.96	3.50		
Core 10-1																
Specific Gravity = 2.83																
305					123	3.48	78	118				3.92	1.96	2.0		
Core 10-1c																
Specific Gravity = 2.82																
305					118	3.33	77	102				3.92	1.57	2.50		

Noorany, 1975

Core 9-4B

Specific Gravity = 2.67

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
305					111	2.96	75	43				12.26	1.17	10.48		88

Core 9-4C

Specific Gravity = 2.76

305					88	2.43	71	56				13.73	2.11	6.51		93

Table 11. Geotechnical Properties of Simpson (1975) Cores

Simpson, 1975

Core 1

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	3.03	1.38	2.20
152	6.28	4.69	1.34
229	6.62	2.21	3.00
305	8.76	1.95	4.49
381	12.06	3.86	3.12
457	8.48	3.03	2.80

Core 2

76	2.76	0.98	2.82
152	6.07	2.48	2.45
229	7.10	2.48	2.86
305	7.10	2.48	2.86
305	7.93	2.48	3.20
381	9.58	2.48	3.86
457	11.24	3.31	3.40

Core 4

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	4.38	1.92	2.28
152	4.38	1.64	2.67
229	6.57	1.64	4.01
305	7.05	1.37	5.15
381	8.41	1.37	6.14

Core 5

76	19.58	4.55	4.30
152	13.17	3.72	3.54

Simpson, 1975

Core 6

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	3.09	1.22	2.53
152	7.10	2.21	3.21
229	7.93	1.93	4.11
305	13.44	2.76	4.88
381	11.51	2.48	4.64

Core 7

76	24.06	6.41	3.75
152	22.20	6.62	3.35

Core 9

76	4.69	2.21	2.12
152	6.62	2.48	2.67
229	7.38	1.65	4.47
305	9.31	1.65	5.64
381	10.69	2.48	4.31

Core 10

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.21	0.76	2.91
152	4.96	1.38	3.59
229	7.45	1.65	4.52
305	7.72	1.38	5.59
381	8.82	1.17	7.54
457	7.72	1.38	5.59

Core 11

76	2.41	1.03	2.34
152	4.20	1.38	3.04
229	5.72	1.38	4.14
305	6.07	0.97	6.26
381	6.69	1.52	4.40
457	5.79	1.45	3.99

Simpson, 1975

Core 18

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	4.41	1.38	3.20
152	6.07	1.38	4.40
229	5.79	1.38	4.20
305	7.72	1.24	6.23
381	8.17	1.38	5.92
457	8.69	1.79	4.85

Core 19

76	1.52	0.69	2.02
152	5.29	1.17	4.52
229	5.79	1.65	3.51
305	7.45	1.93	3.86
381	5.79	1.52	3.81

Core 20

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	3.03	1.24	2.44
152	6.89	1.52	4.53
229	6.62	1.38	4.80
305	9.10	1.65	5.52
381	10.89	1.79	6.08
457	8.00	1.65	4.85

Core 22

76	2.48	0.69	3.59
152	6.48	1.24	5.23
229	9.38	1.38	6.80
305	10.48	1.65	6.35
381	10.75	1.65	6.52
457	9.10		

Simpson, 1975

Core 23

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.34	0.69	3.39
152	5.24	1.10	4.76
229	6.34	1.38	4.59
305	8.82	1.38	6.39
381	8.82	1.38	6.39
457	13.10	1.79	7.32

Core 24

76	3.72	0.97	3.84
152	8.55	1.65	5.18
229	8.27	1.52	5.44
305	8.62	1.65	5.22
381	5.79	1.38	4.20

Core 25

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	6.89	0.97	7.10
152	7.17	1.10	6.52
229	6.34	1.38	4.59
305	9.30	1.65	5.64
381	10.20	1.65	6.18
457	7.72	1.65	4.68

Core 26

76	3.03	0.76	3.99
152	6.89	1.24	5.56
229	6.07	0.97	6.26
305	8.82	1.79	4.93
381	11.58	1.65	7.02
457	8.55	1.79	4.78

Simpson, 1975

Core 27

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.76	0.83	3.33
152	6.34	1.10	5.76
229	6.34	1.10	5.76
305	8.82	1.38	6.39
381	11.58	1.65	7.02
457	6.83	1.65	4.14

Core 28

76	3.31	0.62	5.34
152	5.79	0.97	5.97
229	5.52	0.97	5.69
305	6.89	1.10	6.26
381	8.41	1.10	7.65
457	7.51	1.24	6.06

Core 29

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	4.83	1.65	2.93
152	6.89	1.79	3.85
229	6.34	1.52	4.17
305	8.69	1.79	4.85
381	9.24	1.79	5.16
457	7.72	1.79	4.31

Core 30

76	6.34	1.65	3.84
152	6.07	2.21	2.75
229	9.38	2.07	4.53
305	13.51	2.48	5.45
381	9.24	2.07	4.46

Simpson, 1975

Core 31

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	3.03	0.97	3.12
152	6.07	1.79	3.39
229	7.72	1.79	4.31
305	9.65	1.65	5.85
381	8.96	1.93	4.64
457	6.20	1.65	3.76

Core 32

76	4.96	1.93	2.57
152	6.07	1.65	3.68
229	6.34	1.52	4.17
305	9.24	1.65	5.60
381	10.89	1.93	5.64
457	10.07	1.93	5.22

Core 33

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	12.96	2.90	4.47
152	22.20	3.58	6.20
229	20.54	3.31	6.21

Core 34

76	2.90	1.10	2.64
152	8.00	1.08	7.41
229	7.45	1.65	4.52
305	7.31	1.52	4.81
381	10.75	1.79	6.01
457	11.17	2.07	5.40

Simpson, 1975

Core 12

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	14.06	3.03	4.64
152	21.79	3.86	5.65
229	25.65	4.14	6.20
305	22.34	3.31	6.75

Core 13

76	18.75	3.03	6.19
152	26.20	4.41	5.94
229	26.20	3.86	6.79

Core 14

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.07	0.97	2.13
152	5.79	1.17	4.95
229	6.55	1.59	4.12
305	6.62	1.24	5.34
381	6.20	1.38	4.49
457	4.96	1.65	3.01

Core 15

76	9.65	2.48	3.89
152	10.07	1.93	5.22
229	9.03	1.65	5.47
305	9.36	1.65	5.67
381	7.72	1.38	5.59

Simpson, 1975

Core 35

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.48	0.83	2.99
152	4.27	1.24	3.44
229	5.52	1.38	4.00
305	2.48	1.65	1.50
381	8.96	1.65	5.43
457	12.41	2.21	5.62

Core 36

76	3.03	0.83	3.65
152	8.27	1.52	5.44
229	7.86	1.65	4.76
305	9.65	1.93	5.00
381	10.62	2.07	5.13

Core 37

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.34	0.83	2.82
152	5.52	1.38	4.00
229	7.45	1.38	5.40
305	10.48	1.93	5.43
381	10.75	1.52	7.07
457	8.82	1.79	4.93

Core 38

76	7.03	1.93	3.64
152	6.62	1.65	4.01
229	8.41	1.65	5.10
305	12.55	2.21	5.68
381	7.72	1.52	5.08

Simpson, 1975

Core 40

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensi-tivity
76	3.03	1.24	2.44
152	6.62	1.52	4.36
229	6.62	1.65	4.01
305	7.72	1.65	4.68
381	7.72	1.52	5.08

Core 41

76	3.31	1.38	2.40
152	7.17	1.65	4.35
229	7.86	1.79	4.39
305	7.72	1.65	4.68
381	7.72	1.65	4.68
457	6.34	1.65	3.84

Core 42

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensi-tivity
76	2.76	1.10	2.51
152	7.17	1.65	4.35
229	8.13	1.93	4.21
305	6.48	1.38	4.70
381	7.72	1.65	4.68
457	7.58	1.38	5.49

Core 43

76	1.70	0.83	2.05
152	4.83	1.38	3.50
229	5.24	1.10	4.76
305	6.89	1.24	5.56
381	8.46	1.10	7.69
457	7.72	1.52	5.08

Simpson, 1975

Core 44

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.21	0.69	3.20
152	4.41	0.97	4.55
229	5.38	1.10	4.89
305	8.00	1.10	7.27
381	9.24	1.38	6.70
457	8.89	1.45	6.13

Core 45

76	2.34	0.69	3.39
152	6.20	1.10	5.64
229	7.72	1.52	5.08
305	7.58	1.38	5.49
381	8.81	1.65	5.34

Core 46

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.07	0.69	3.00
152	5.38	1.24	4.34
229	6.89	1.38	4.99
305	6.34	0.97	6.54
381	10.89	1.38	7.89
457	8.00	1.24	6.45

Core 47

76	5.52	0.97	5.69
152	7.31	1.10	6.65
229	7.31	1.24	5.90
305	8.55	1.24	6.90
381	10.07	1.38	7.30
457	8.89	1.65	5.39

Simpson, 1975

Core 48

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	3.86	0.55	7.02
152	8.27	1.17	7.07
229	10.07	1.72	5.85
305	9.44	1.79	5.27
381	8.96	1.93	4.64

Core 51

76	6.27	0.97	6.46
152	7.86	1.38	5.70
229	7.51	1.10	6.83
305	6.96	0.97	7.18
381	7.45	1.17	6.37
457	8.27	1.38	5.99

Core 52

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	3.38	0.48	7.04
152	7.03	0.83	8.47
229	6.34	0.90	7.04
305	6.27	0.83	7.55
381	7.17	1.03	6.96
457	6.76	1.10	6.15

Core 53

76	3.52	0.69	5.10
152	13.37	2.90	4.61
229	17.58	3.52	4.99
305	15.51	3.52	4.41

Simpson, 1975

Core 54

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	4.83	0.76	6.36
152	5.52	0.97	5.69
229	9.44	1.10	8.58
305	10.62	1.24	8.56
381	9.31	0.97	9.60

Core 55

76	5.86	0.90	6.51
152	7.58	1.03	7.36
229	7.72	0.97	7.96
305	10.13	1.65	6.14
381	9.03	1.45	6.23

Core 56

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	3.17	0.55	5.76
152	6.07	0.97	6.26
305	6.76	0.90	7.51
381	7.51	1.17	6.42

Core 57

76	5.03	0.76	6.62
152	6.20	0.90	6.89
229	6.55	0.83	7.89
305	8.69	1.17	7.43
381	9.72	1.86	5.23
457	7.51	1.72	4.37

Simpson, 1975

Core 59

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity
76	2.48	.41	6.05
152	6.62	1.17	5.66
229	7.51	1.10	6.83
305	6.41	0.97	6.61
381	7.31	1.52	4.81

Core 60

76	4.14	0.55	7.53
152	6.69	1.66	4.03
229	6.20	1.03	6.02
305	5.65	0.69	8.19
381	5.65	0.62	9.11

Core

Depth, mm	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity

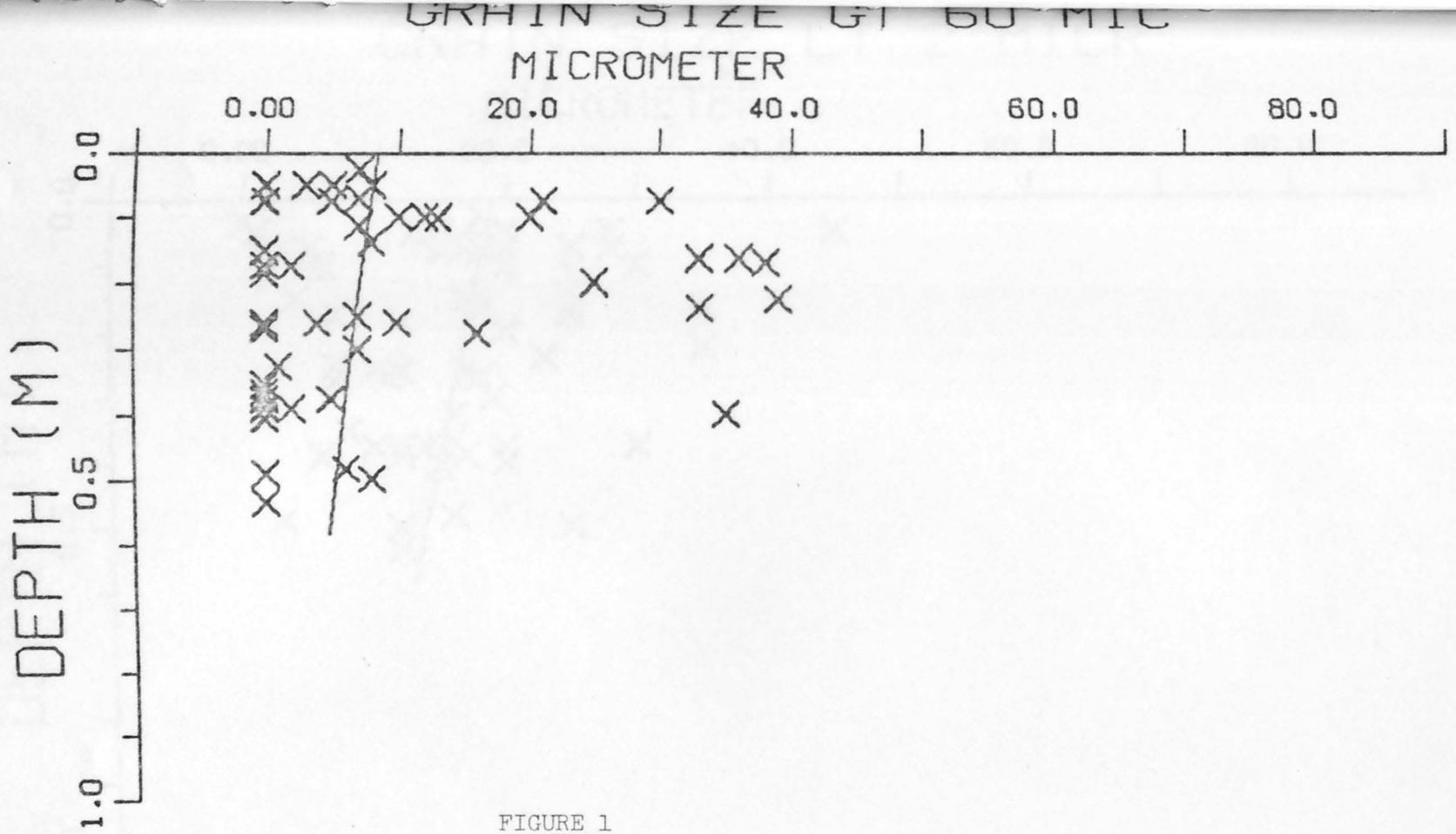


FIGURE 1

SITES A,B,C

EST VALUE = 8.370 + -6.228 X DEPTH (M)
STD ERROR OF EST = 11.043
CORR COEF = -.083

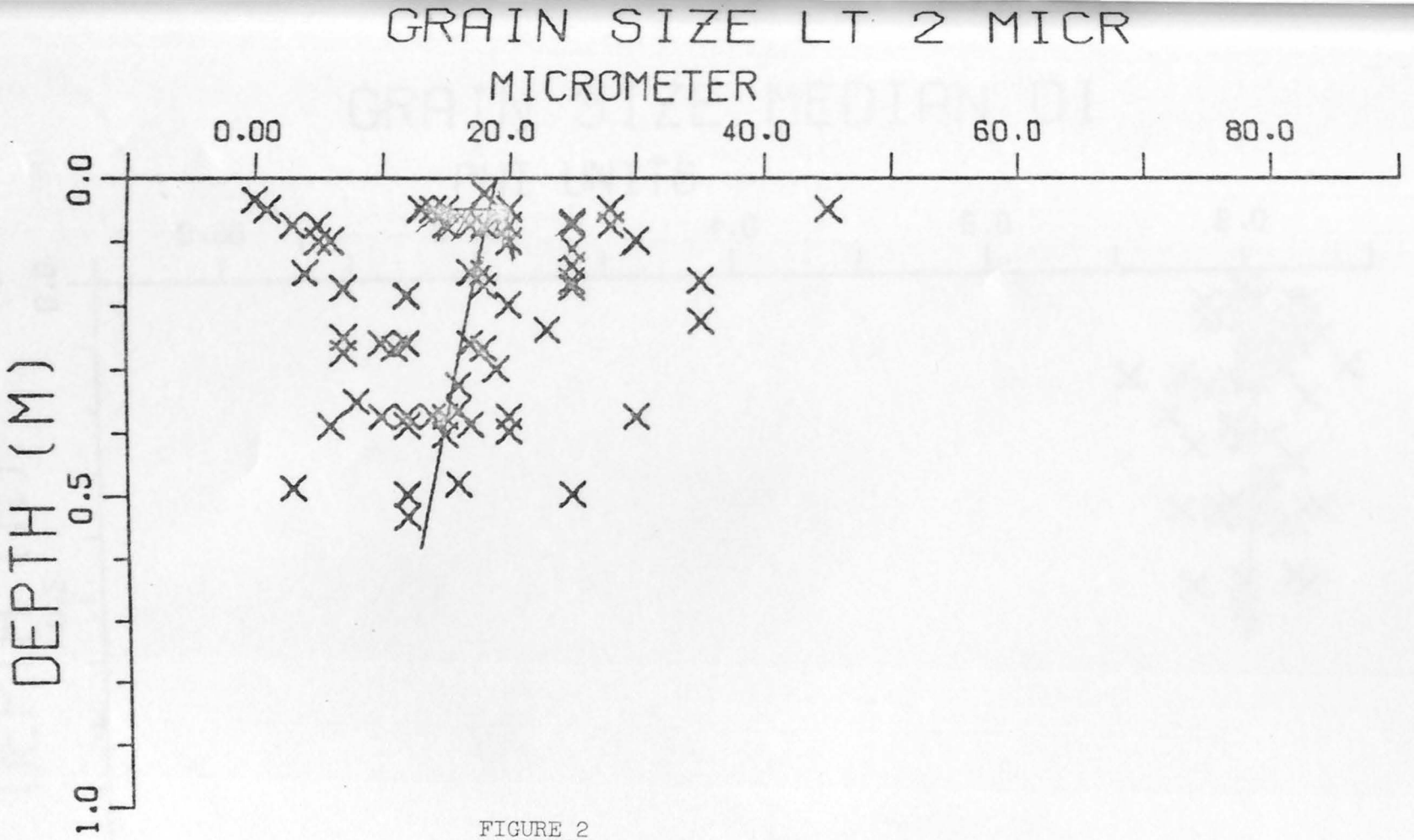


FIGURE 2

SITES A,B,C

EST VALUE = 18.922 + -10.243 X DEPTH (M)
STD ERROR OF EST = 8.514
CORR COEF = -.175

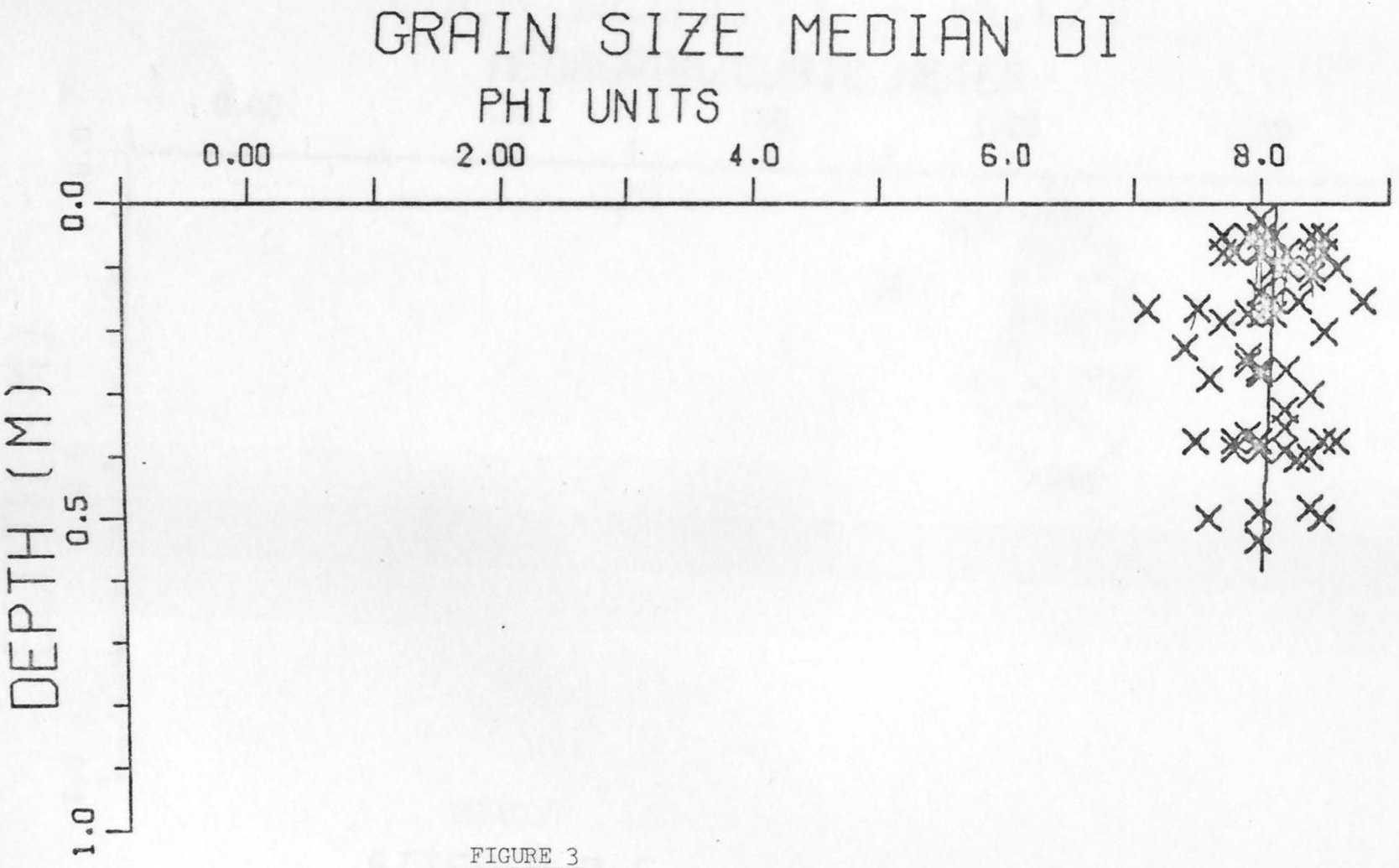


FIGURE 3

SITES A,B,C

EST VALUE = 8.119 + -.159 X DEPTH (M)
STD ERROR OF EST = .319
CORR COEF = -.073

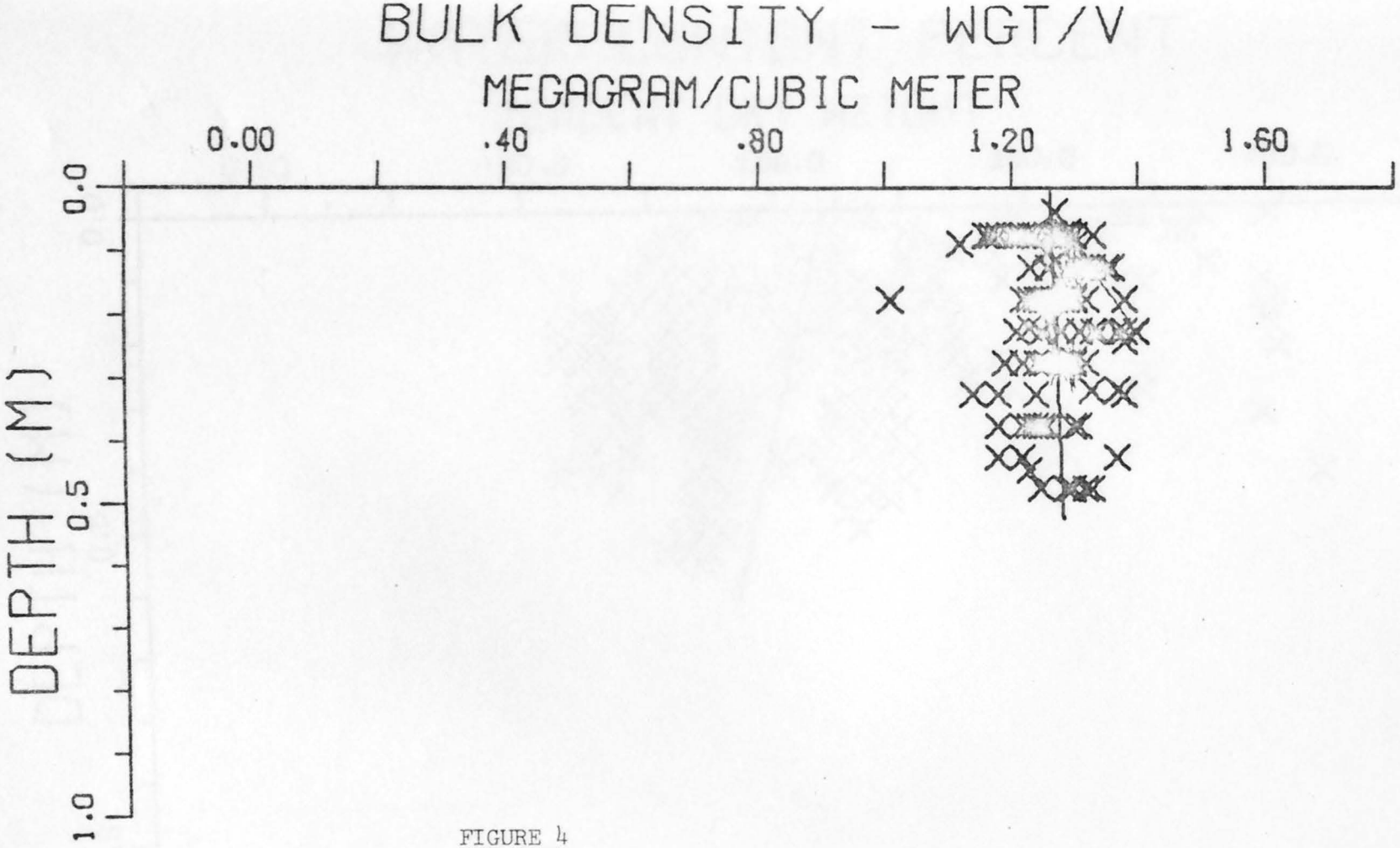


FIGURE 4

SITES A.B.C

EST VALUE = 1.263 + .044 X DEPTH (M)
STD ERROR OF EST = .061
CORR COEF = .089

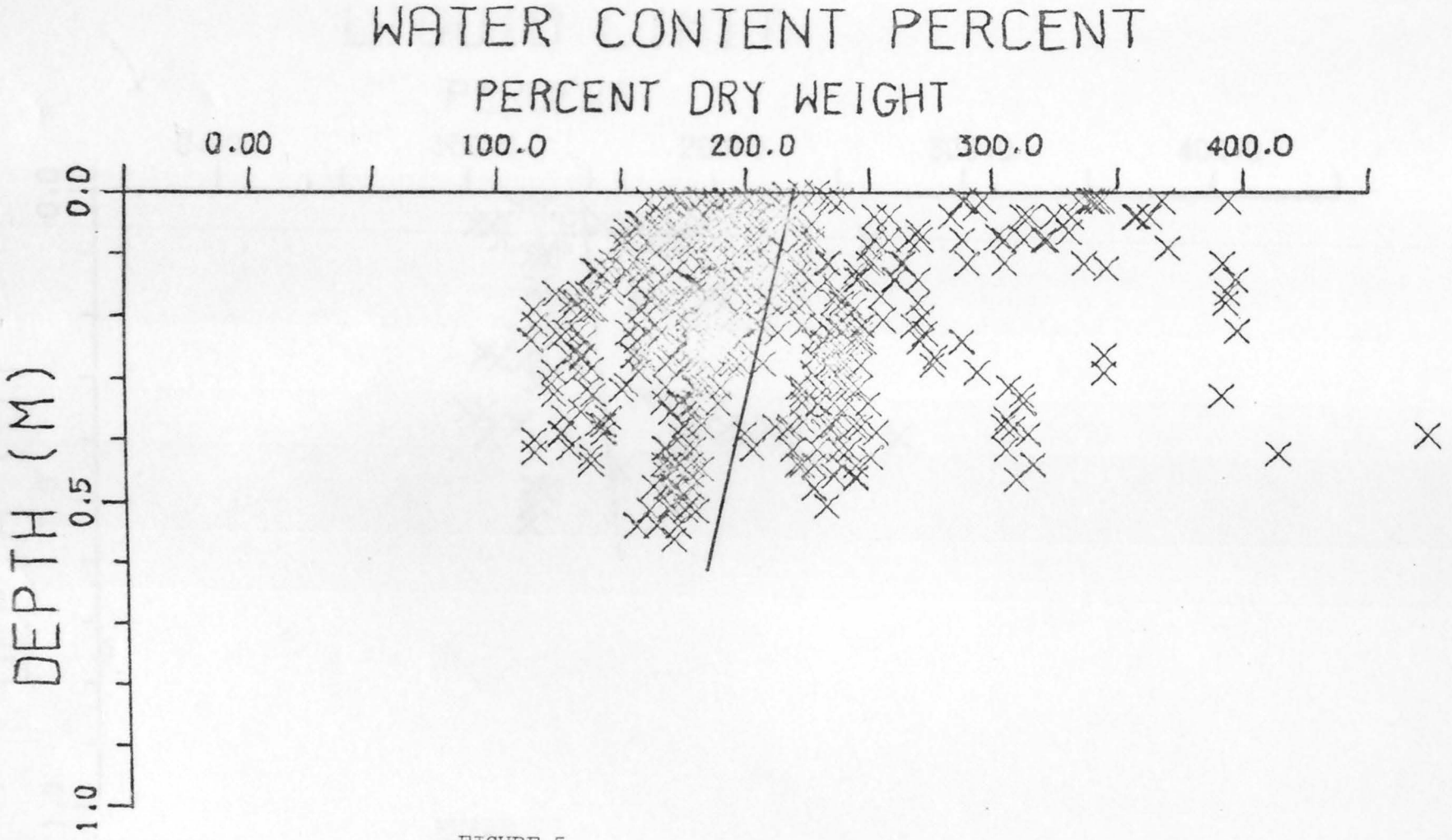


FIGURE 5

SITES A,B,C

EST VALUE = 219.249 + -57.682 X DEPTH (M)

STD ERROR OF EST = 56.694

CORR COEF = -.139

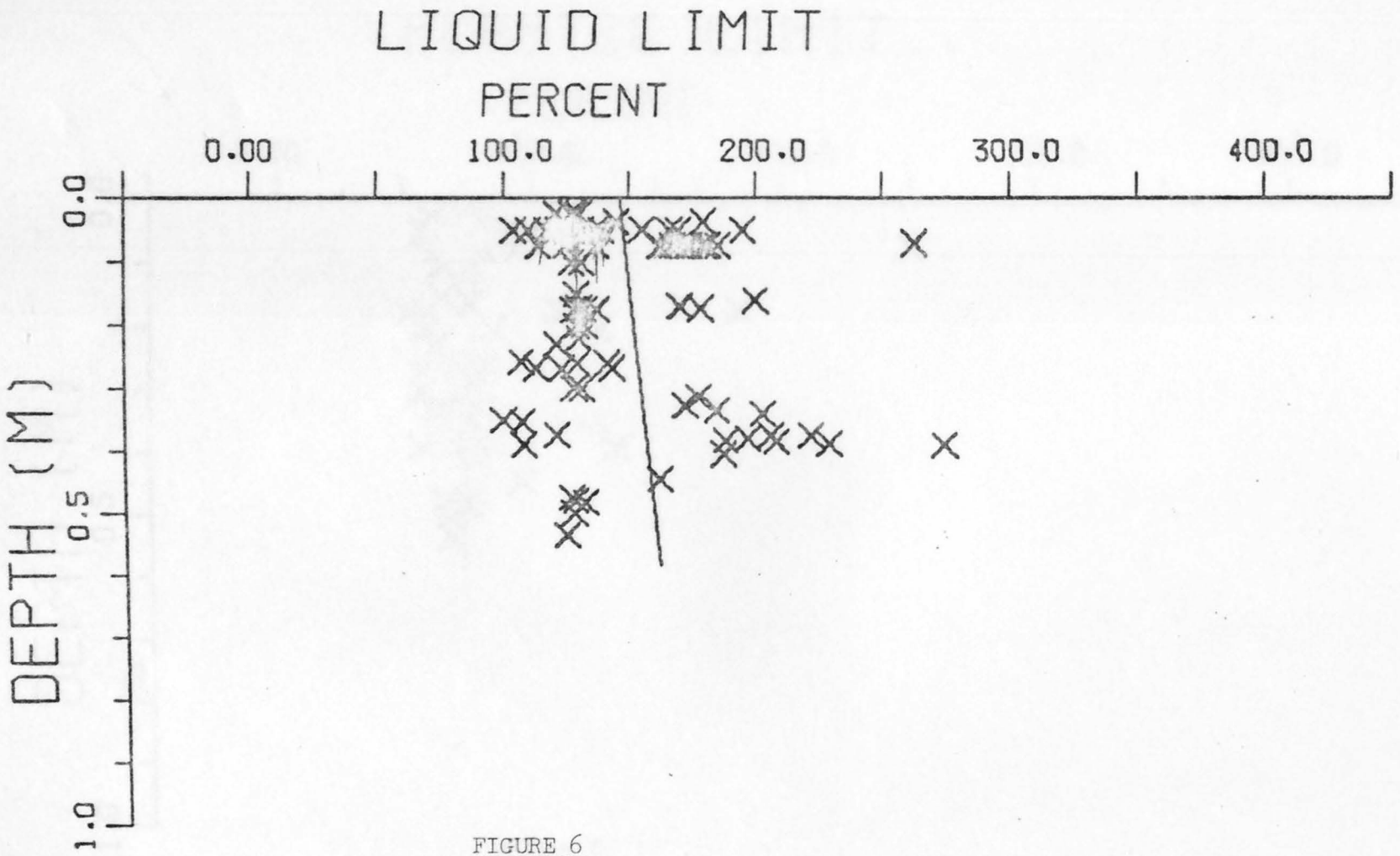


FIGURE 6

SITES A,B,C

EST VALUE = 146.334 + 27.059 X DEPTH (M)
STD ERROR OF EST = 36.348
CORR COEF = .112

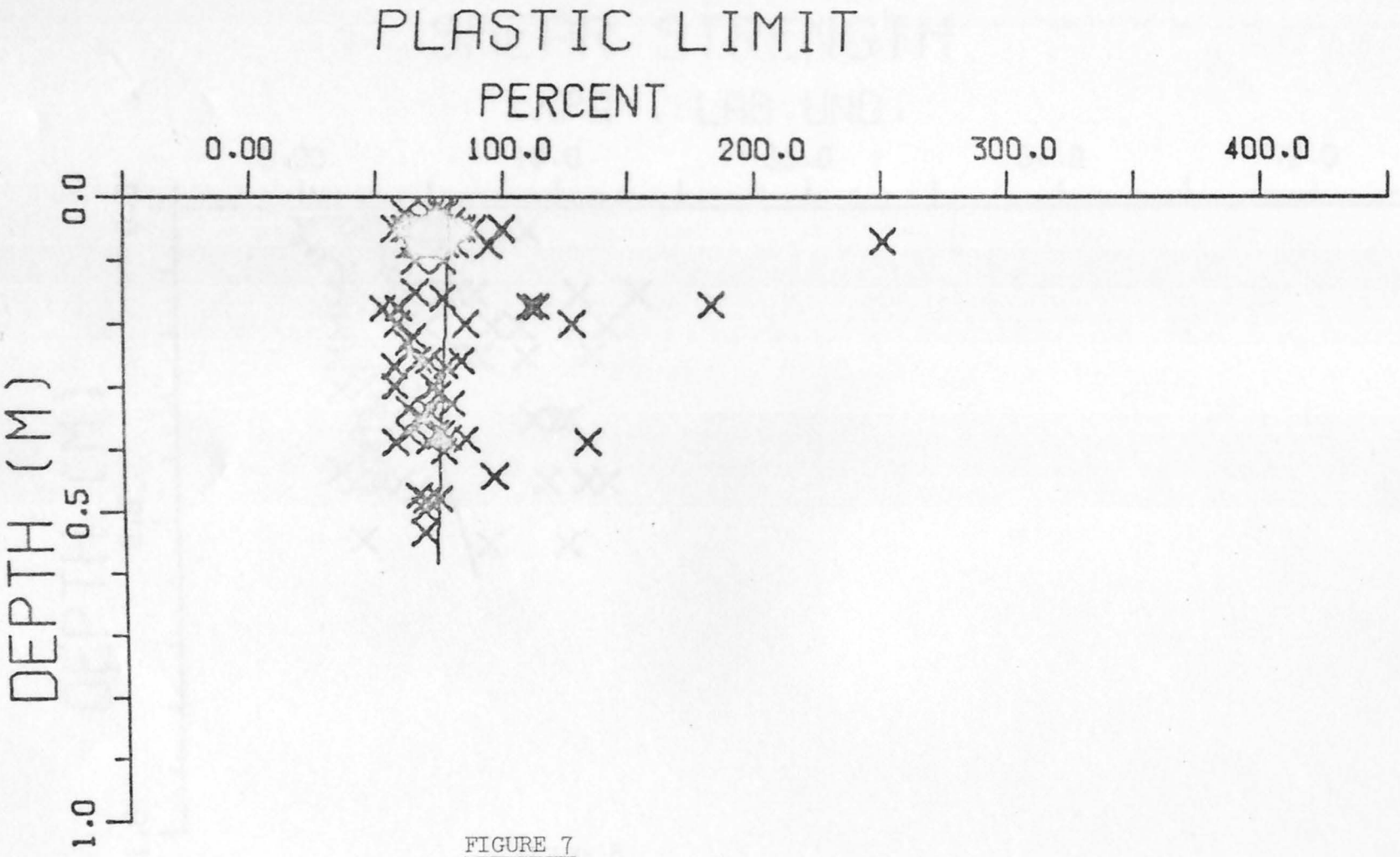


FIGURE 7

SITES A,B,C,

EST VALUE = 79.935 + -10.857 X DEPTH (M)
STD ERROR OF EST = 27.502
CORR COEF = -.059

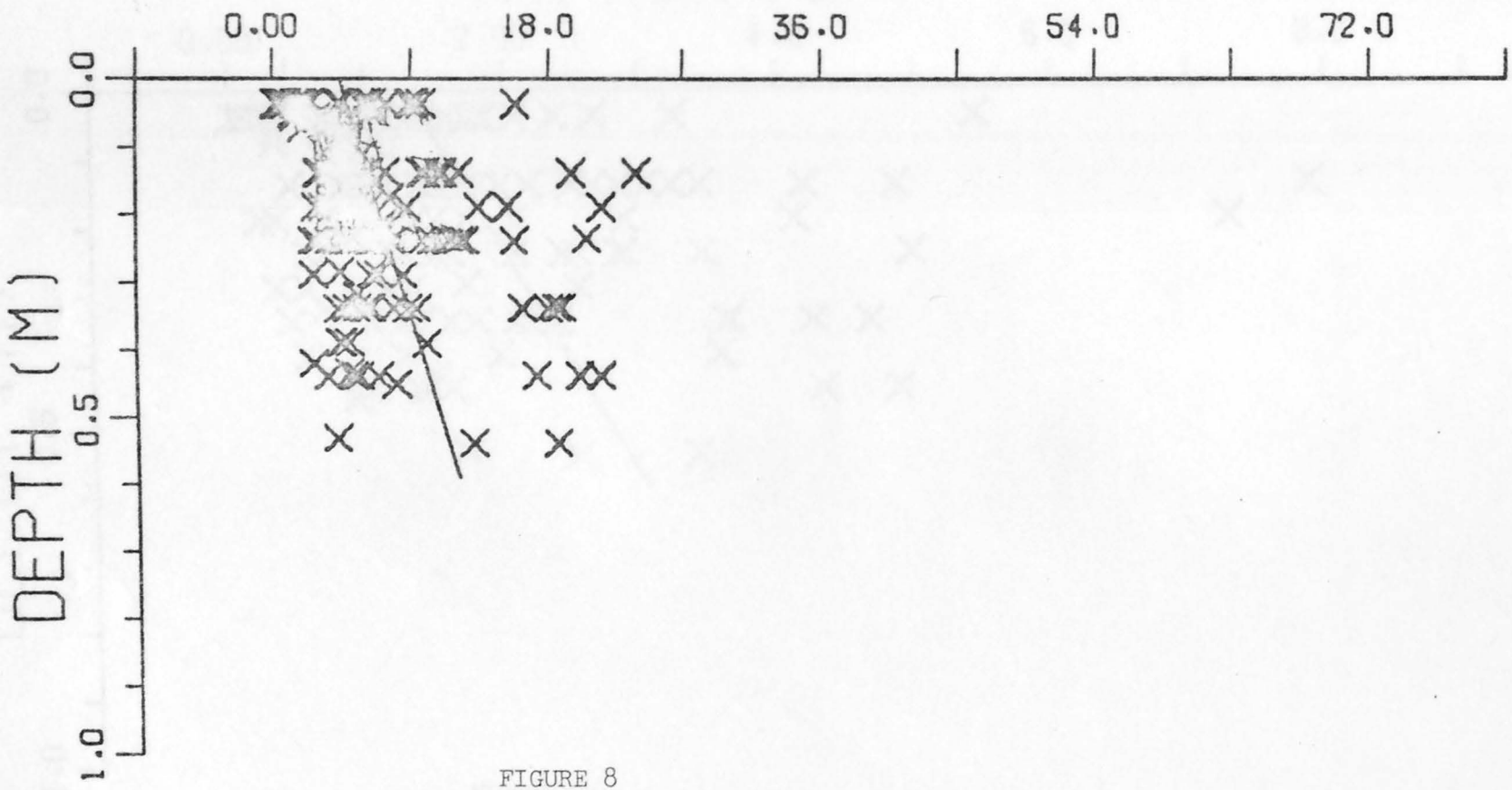


FIGURE 8

SITES A,B,C

EST VALUE = 4.432 + 13.215 X DEPTH (M)
STD ERROR OF EST = 4.840
CORR COEF = .346

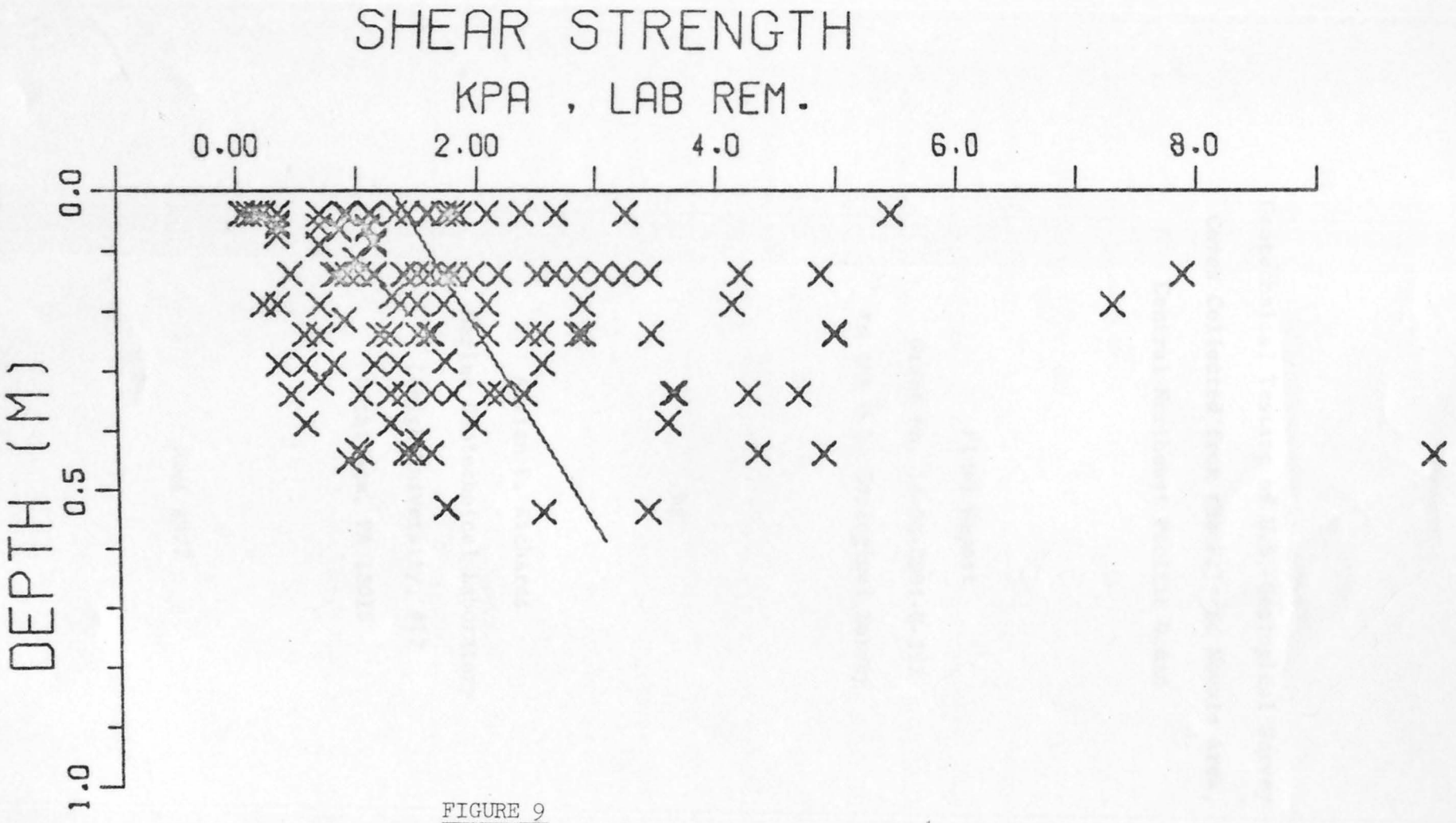


FIGURE 9

SITES A,B,C

EST VALUE = 1.313 + 3.010 X DEPTH (M)
STD ERROR OF EST = 1.554
CORR COEF = .253

CHAPTER 2

Geotechnical Testing of U.S. Geological Survey Cores Collected from the Pelagic Nodule Area, Central Northeast Pacific Ocean

Final Report

Grant No. 14-08-0001-G-257

to the U.S. Geological Survey

by

Adrian F. Richards

Marine Geotechnical Laboratory

Lehigh University, #17

Bethlehem, PA 18015

June 1977

ABSTRACT

Twenty seven cores subsampled from box cores collected on Deep Ocean Mining Environmental Study (DOMES) cruises 1 and 2 to Sites A, B, and C were geotechnically analyzed at the Marine Geotechnical Laboratory, Lehigh University.

Results are reported in three formats: a tabular listing of measured and computed geotechnical data, plus pore-water salinity, for each core; a computer-plotter generated graph of geotechnical and geochemical properties of each core plotted against depth below the top of the core; and as individual geotechnical property data, grouped by DOMES site, plotted against depth. In the latter presentation, linear least-squares regression lines or predictor equations were machine generated and both plotted on the graphs and arranged in a table in which related statistical data are also presented. Predictor equations having the highest correlation coefficients were the water content, clay-size fraction, and mean grain diameter in Area A; sand-size fraction, mean grain diameter, water content, and liquid limit in Area B; and undisturbed and remolded shear strength in Area C.

A list of publications resulting from this grant is given in an appendix.

INTRODUCTION

The purpose of this report is to present marine geotechnical data and a limited synthesis of the results of a U.S. Geological Survey-sponsored Marine Geotechnical Laboratory (MGL) program testing cores collected on Deep Ocean Mining Environmental Study (DOMES) cruises 1 and 2. Twenty-seven cores were collected from locations listed in Table 1, and analyzed in the MGL between November 28, 1975, and January 28, 1976. Most of the DOMES Site C geotechnical data were previously published by Richards et al. (1976b).

Cores collected on DOMES cruise 1 were subsampled by pushing small-diameter cellulose acetate butyrate (CAB) tubes into sediment contained within a box core. These CAB-contained cores were reported to be of medium to low quality, because the box cores sampled were not considered of the highest quality (Erickson, 1975, personal communication). The box cores raised on DOMES cruise 2, which were also sampled using small-diameter CAB tubes, are believed to be of higher quality.

All cores were shipped by air freight to the MGL carefully packed to minimize shock and vibration. They were refrigerated during transit by ice. At the MGL they were stored horizontally under refrigeration (about 5° C) and high relative humidity until tested.

LABORATORY PROCEDURES

The cores, within their unopened liners, were x-rayed and nondestructively analyzed for bulk density, using a fine-focus industrial-type x-ray machine and the Lehigh nuclear transmission densitometer. Results of these investigations are not reported.

Geotechnical and geochemical tests were performed using the methods listed in Table 2, in which ASTM refers to the American Society for Testing and Materials (1975). Neither triaxial nor consolidation tests were performed on the cores for two reasons: It was considered preferable to have the maximum number of other tests spaced at 50 to 100 mm intervals and the small diameter (as well as some of the DOMES cores being disturbed) was less suitable for these kinds of tests compared to other cores tested (Richards, 1977). Some data were calculated; formulas are listed in Table 3.

After laboratory analysis, the data were tabulated and entered on punched cards in the standardized format of the MGL marine geotechnical data bank. One method of output was to generate a CalComp plot of each measured and computed parameter against depth in the core. The basic computer-plotter program was described by Mann and Semple (1970); subsequently, the program was modified and adapted to the Lehigh University CDC 6400 computer. Symbols used in the individual core plots are listed in Table 4.

A second method of output was to plot individual geotechnical

properties obtained from all cores grouped together against depth. Data from sites A, B, and C were grouped separately. In each CalComp plot, a linear least-squares regression line, or predictor equation, was computer-fitted to the plotted values.

RESULTS

Graphs of geotechnical properties plotted against depth for each core are grouped according to the DOMES site: A (Figs. 1-2), B (Figs. 3-4), and C (Figs. 5-8).

The predictor equations and related statistical data also are grouped according to the DOMES site: A (Table 5 and Figs. 9-17), B (Table 6 and Figs. 18-26), and C (Table 7 and Figs. 27-35). Site C tabular and graphical presentations also include Deepsea Ventures data (this report) from cores raised from the company's mine site, which approximately corresponds to Site C.

Tabular data for each DOMES core is presented in Appendix 1 for Site A, Appendix 2 for Site B, and Appendix 3 for Site C. Data in Appendix 3 supercedes data reported by Richards et al. (1976b).

A list of publications resulting from this grant is given in Appendix 4.

DISCUSSION

All of the specific gravity values reported in Appendices 1-3 are believed to be too low because of a test error.

Unfortunately, a faulty aspirator was not discovered until after the test program had been completed. As a result, water used in the specific gravity test was not adequately deaired. It is probable that the average specific gravity of Site C samples is about 2.70. The specific gravity of Site A and B samples may be different?

Bulk density values are given in the CalComp plots (Figs. 1-8) in units of kg/m^3. Dividing these values by 1000 yields the appropriate SI unit of Mg/m^3, which is dimensionally identical to g/cm^3.

Water content values for many core samples plot substantially above the 180 percent by dry weight upper limit of the water content in the CalComp graphs of core properties plotted against depth. Water content values can be read off scale, however, by extending the water content scale; for example, "0" shear strength also is 220 percent dry weight water content. Other properties plotting off scale can be read in a similar manner.

The predictor equations presented in Tables 5-7 update similar equations contained in a preliminary report (Richards and Parks, 1977).

It is of interest to compare relatively high correlation coefficients for predictor equations of data from the three sites. At Site A (Table 5) the measured water content, clay-size fraction, and the calculated median grain size predictor equations have the

highest correlation coefficients. At Site B, the highest correlation coefficients are for predictor equations of the sand-size fraction, mean grain size, water content, and liquid limit. At Site C, "undisturbed" and remolded shear strength predictor equations have the highest correlation coefficients.

At Site C, a few of the cores collected on Deepsea Ventures, Inc. (DVI), cruises (Richards, 1977) were desiccated when tested in the laboratory. It is believed that these few lower water content values probably should not affect significantly the results shown for the Site C water contents (Fig. 31). On the other hand, at least three groups of water contents versus depth data appear in Fig. 31. The lowest group may be related to a differing sediment type or possibly to desiccated samples. The highest group are believed to be related to the mineralization of sediment below about 200 mm in core DOMES 18B-37; high water contents are found above depths of 200 mm in DVI core 54P-8. It is interesting to note that both of these cores were raised from nearly identical longitudes, but differing latitudes, which suggests that the mineralized area in Site C extends north-south. Further, it is postulated that the mineralization occurs closer to the surface in the south (DVI core) than in the north (DOMES core). Both the DOMES and DVI cores also had high shear strengths, and the DVI core has a high calcium carbonate content; carbonate was not measured on DOMES cores at the MGL. The extrusion log for the

DVI core contains ample indicators of mineralization, which was first discovered in DOMES core 18B-37.

A wealth of information is contained in the predictor equations and their associated plots (Figs. 9-35), which will be synthesized in subsequent publications.

ACKNOWLEDGEMENTS

I am appreciative of the efforts of B. Erickson, NOAA, and F. Simpson, Lockheed Ocean Laboratory, for their assistance in subsampling box cores at sea, packing, and shipping. The cooperation of J. Bischoff, U.S. Geological Survey, in providing core information and in other matters was graciously given. I thank the many students who assisted in the laboratory analyses and data reduction at Lehigh; in particular, S. C. Helfrich and D. Volk who supervised the laboratory work, and G. Abdelnour who did most of the computer-plotter work.

This research was sponsored in major part by the U.S. Geological Survey, Department of Interior, under Grant No. 14-08-0001-G-257.

REFERENCES

American Society for Testing and Materials, 1975, 1975 annual book of ASTM standards, part 19, natural building stones; soil and rock; peats, mosses, and humus: Philadelphia, American Soc. Test. Mat., 476 p.

Mann, C. J., and Semple, R. M., 1970, Computer reduction and plotting of marine sediment data: Jour. Marine Tech. Soc., v. 4, p. 53-57.

Richards, A. F., 1977, Geotechnical testing of Deepsea Ventures box cores collected from pelagic nodule area, central northeast Pacific Ocean: unpub. Final Rept., U.S. Geol. Survey Grant No. 14-08-0001-G-256.

Richards, A. F., Hirst, T. J., and Parks, J. M., 1976a, Preliminary geotechnical properties northeast central Pacific nodule mining area: Oceans '76, Second Ann. Combined Conf., Marine Tech. Soc. and Inst. Electrical and Electronics Eng., p. 2B-1 to 2B-3.

Richards, A. F., Hirst, T. J., and Parks, J. M., 1976b, Preliminary geotechnical properties northeast central Pacific nodule mining area, in Bischoff, J. L., and others, 1976, Deep ocean mining environmental study, NE Pacific nodule province, site C, geology and geochemistry: U.S. Geol. Survey Open-file Rept. 76-548, p. 81-94.

Richards, A. F., and Parks, J. M., 1977, Geotechnical predictor equations for east central North Pacific nodule mining area sediments: Offshore Tech. Conf. Proc., v. 1, p. 377-386.

Core No.	N. Lat.	W. Long.	Water Depth, m	Date Collected	Date Analyzed
DOMES Cruise 2: Site A					
46-1	9° 20.7'	150° 50.7'	5160	October 24, 1975	January 16, 1976
46-5	9° 21.3'	150° 51.4'	5102	October 26, 1975	January 16, 1976
47-10	9° 00.3'	151° 10.9'	5108	October 28, 1975	January 16, 1976
47-14	9° 04.0'	151° 14.2'	5110	October 28, 1975	January 17, 1976
48-19	8° 16.5'	151° 07.3'	5043	October 30, 1975	January 18, 1976
49-25	8° 28.5'	150° 44.5'	5005	October 31, 1975	January 19, 1976
50-28	8° 41.7'	150° 18.7'	5009	November 1, 1975	January 21, 1976
DOMES Cruise 2: Site B					
51-33	11° 41.6'	139° 11.0'	4881	November 4, 1975	January 23, 1976
52-37	11° 13.7'	139° 09.9'	4872	November 5, 1975	January 24, 1976
52-39	11° 14.8'	130° 04.1'	4831	November 6, 1975	January 23, 1976
52-42	11° 15.5'	139° 03.3'	4871	November 6, 1975	January 24, 1976
53-45	11° 43.9'	138° 22.2'	4985	November 7, 1975	January 26, 1976
54-51	12° 08.9'	137° 44.6'	4934	November 9, 1975	January 28, 1976
55-53	11° 48.6'	137° 28.3'	4859	November 9, 1975	January 28, 1976

Core No.	N. Lat.	W. Long.	Water Depth, m	Date Collected	Date Analyzed
DOMES Cruise 1: Site C					
3-5	15° 15.9'	126° 38.4'	4675	April 26, 1975	January 7, 1976
5-10	15° 14.7'	126° 32.1'	4493	April 27, 1975	January 6, 1976
6-18	14° 15.0'	126° 11.5'	4430	April 29, 1975	January 5, 1976
9-21	15° 16.4'	126° 9.6'	4630	April 30, 1975	January 8, 1976
11-53a	16° 0.7'	126° 46.3'	4603	May 29, 1975	January 15, 1976
11-53b	16° 0.7'	126° 46.3'	4603	May 29, 1975	January 8, 1976
18A-36a	15° 15.7'	126° 0.0'	4339	May 21, 1975	January 14, 1976
18A-36b	15° 15.7'	126° 0.0'	4339	May 21, 1975	January 9, 1976
18B-37	15° 12.2'	125° 58.6'	4406	May 22, 1975	November 28, 1975
20-27a	15° 59.3'	126° 11.6'	4672	May 16, 1975	January 15, 1976
20-27b	15° 59.3'	126° 11.6'	4672	May 16, 1975	January 14, 1976
24B-29a	14° 15.4'	126° 1.4'	4468	May 19, 1975	January 15, 1976
24B-29b	14° 15.4'	126° 1.4'	4468	May 19, 1975	January 9, 1976

Table 2. Marine Geotechnical Laboratory Test Methods

Parameter	Method	Notes & Reference
Grain Size, Unit Weight, and Consistency		
Grain size	ASTM 422-63	ASTM D2217 preparation
Grain specific gravity	ASTM 854-28	
Bulk density (wet unit weight)	Weight/volume	Volume = 23 cm^3; no salt correction
Water content	ASTM 2216-71	No salt correction
Liquid limit	ASTM 423-66	Not sieved nor dried; no salt correction
Plastic limit	ASTM 424-59	Not sieved nor dried; no salt correction
Shear Strength		
Laboratory vane test	Motorized vane, 1.3 x 2.5 cm, rotated at 23 mrad/s	
Triaxial test	ASTM 2850-70	$\overline{\text{ICU}}$
Consolidation		
One-dimensional test	ASTM 2435-70	Back pressure applied to saturate sample
Chemical Properties		
Calcium carbonate	Gasometric	Müller & Gastner (1971)
Pore-water salinity	Index of refraction	A. O. refractometer

Table 3. Calculated Geotechnical Properties

Property	Symbol	Calculation	Notes
Void ratio	e	$e = \frac{Gw}{100}$	Assumed 100% saturation
Porosity	n	$n = \frac{e}{1+e}\ (100)$	
Liquidity index	I_L	$I_L = \frac{w - w_p}{I_p}$	
Plasticity index	I_p	$I_p = w_L - w_p$	

Table 4. List of Symbols Used on Marine Geotechnical Laboratory Calcomp Graphs

Name	Calcomp Symbol	Notes
Test interval	=	
Void ratio	+	
Porosity	+	
Grain size, % >62μm	z	
Grain size, % <2μm	■	
Median diameter, phi	△ or ➤	$\phi = -\log_2$ diam. in mm
Specific gravity	x	
Bulk density	◇ or ♥	$Mg/m^3 = \frac{\text{measurement}}{1000} = g/cm^3$
Water content (% dry weight)	○ or ●	symbol w
Liquid limit	y or ≺	
Plastic limit	⌑ or ⧗	
Shear strength (lab vane undisturbed)	⧈	symbol τ
Shear strength (lab vane remolded)	⊙	symbol τ
Sensitivity (undist./remolded)	⧖	
Effective overburden pressure		not plotted, see text
Shear strength/effect. overburden press.(c/p)		not plotted
Salinity (°/₀₀)	■	
Calcium carbonate	+	
Organic carbon		not measured
Sulfate		not measured

Table 5. Geotechnical Predictor Equations: DOMES Site A (7 Cores)

Parameter	Predictor Equation[1]	Standard Error of Estimate	Correlation Coefficient	Number of Data
Grain Size, % >62μm	1.235 - 0.687 x z	2.466	-.045	12
Grain Size, % <2μm	23.623 - 16.039 x z	5.348	-.435	12
Median Grain Size, ϕ	8.201 - 0.608 x z	0.278	-.333	12
Bulk Density, Mg/m^3	1.216 + 0.009 x z	0.027	.044	25
Water Content, % dry weight	297.463 - 135.584 x z	40.168	-.410	95
Liquid Limit, %	182.837 + 41.461 x z	28.670	.221	13
Plastic Limit, %	99.624 - 62.734 x z	50.886	-.189	13
Shear Strength, undist., kPa	5.081 + 4.699 x z	4.876	.121	26
Shear Strength, remold., kPa	1.242 + 1.108 x z	1.387	.100	26

[1] z = depth below seafloor in meters.

Table 6. Geotechnical Equations: DOMES Site B (6 Cores)

Parameter	Predictor Equation[1]	Standard Error of Estimate	Correlation Coefficient	Number of Data
Grain Size, % >62μm	15.222 + -35.567 x z	9.283	-.514	11
Grain Size, % <2μm	13.742 + 3.380 x z	7.243	.073	11
Median Grain Size, ϕ	7.898 + 0.657 x z	0.281	.344	11
Bulk Density, Mg/m^3	1.203 + 0.117 x z	0.054	.264	22
Water Content, % dry weight	288.367 - 163.313 x z	45.079	-.452	82
Liquid Limit, %	169.120 + 83.326 x z	12.653	.725	12
Plastic Limit, %	69.707 + 10.393 x z	5.348	.297	12
Shear Strength, undist., kPa	3.512 + 6.570 x z	2.934	.305	26
Shear Strength, remold., kPa	1.685 + 0.220 x z	1.638	.019	26

[1] z = depth below seafloor in meters.

Table 7. Geotechnical Predictor Equations: DOMES Site C, Including Deepsea Ventures Core Data (27 Cores)

Parameter	Predictor Equation[1]	Standard Error of Estimate	Correlation Coefficient	Number of Data
Grain Size, % >62μm	8.523 - .264 x z	12.264	-.003	45
Grain Size, % <2μm	18.994 - 12.227 x z	9.342	-.192	45
Median Grain Size, ϕ	8.149 - .223 x z	.340	-.097	45
Bulk Density, Mg/m^3	1.289 + .071 x z	.048	.179	73
Water Content, % dry weight	189.751 - 49.810 x z	39.279	-.173	343
Liquid Limit, %	133.459 + 3.312 x z	27.221	.019	53
Plastic Limit, %	77.737 - 4.123 x z	22.794	-.028	54
Shear Strength, undist., kPa	4.493 + 18.517 x z	4.948	.459	80
Shear Strength, remold., kPa	1.241 + 4.505 x z	1.539	.374	80

[1] z = depth below seafloor in meters.

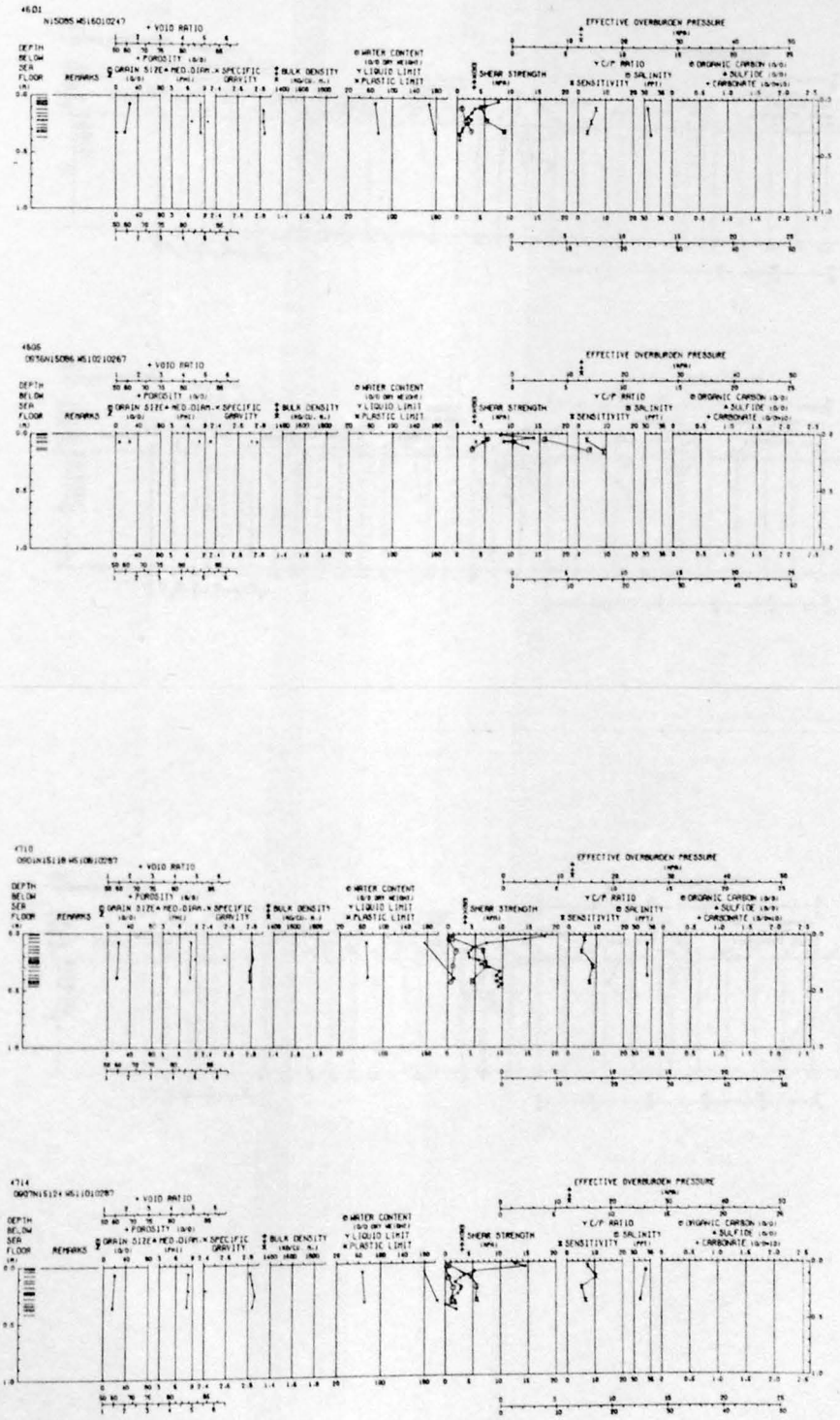


Figure 1. Geotechnical properties for DOMES Site A cores

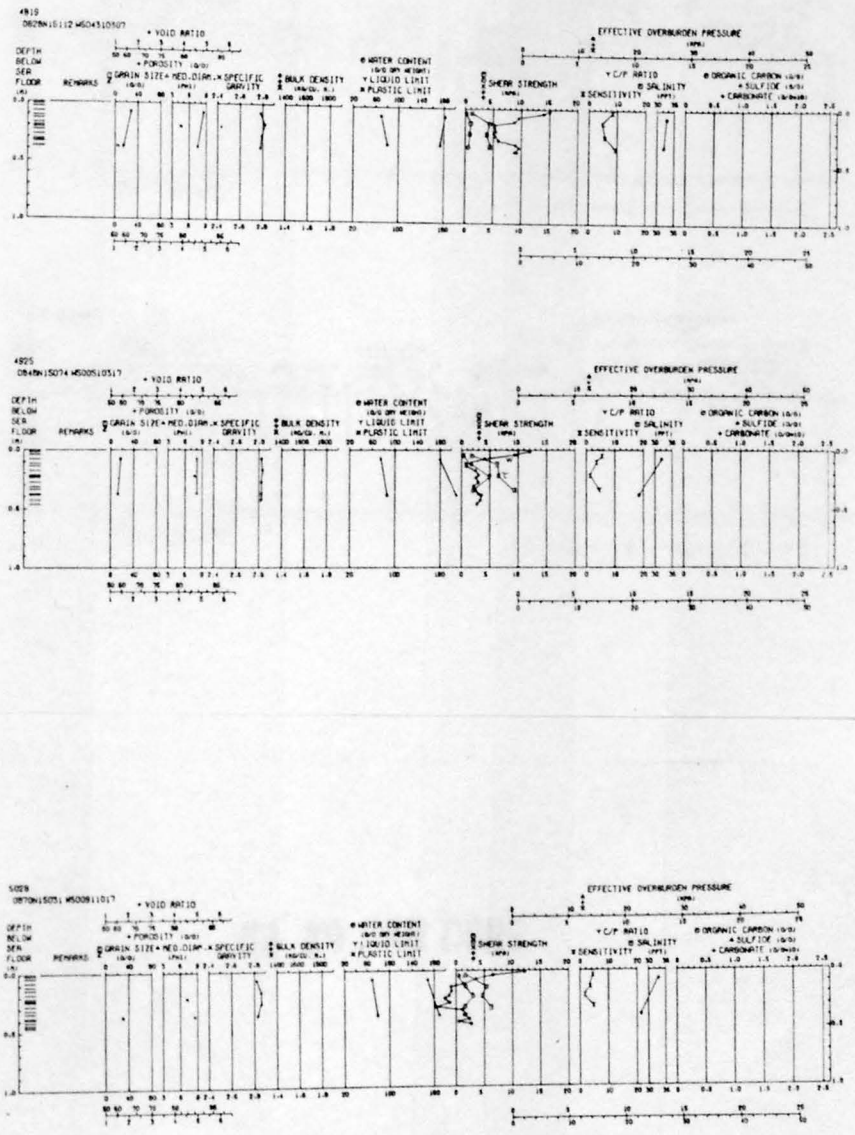
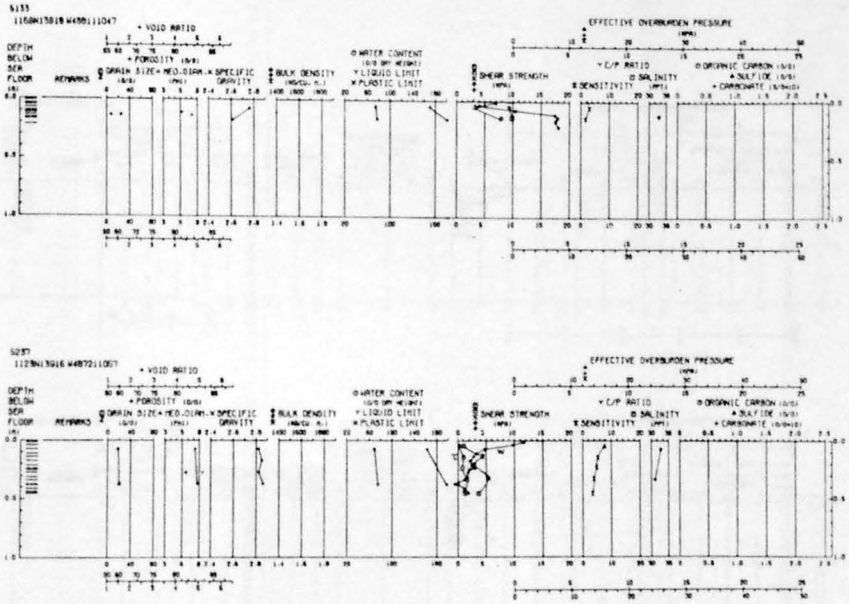


Figure 2. Geotechnical properties
for DOMES Site A cores



52 39 NO CORE

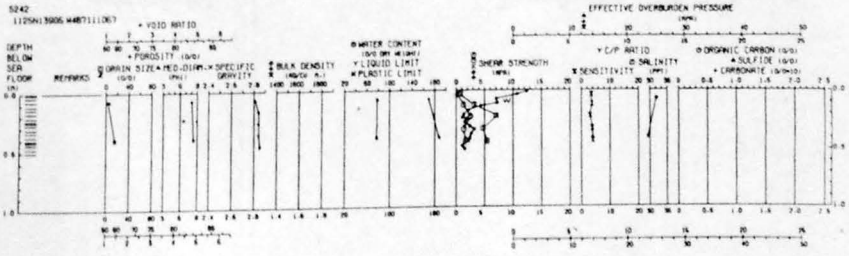


Figure 3. Geotechnical properties for DOMES Site B cores

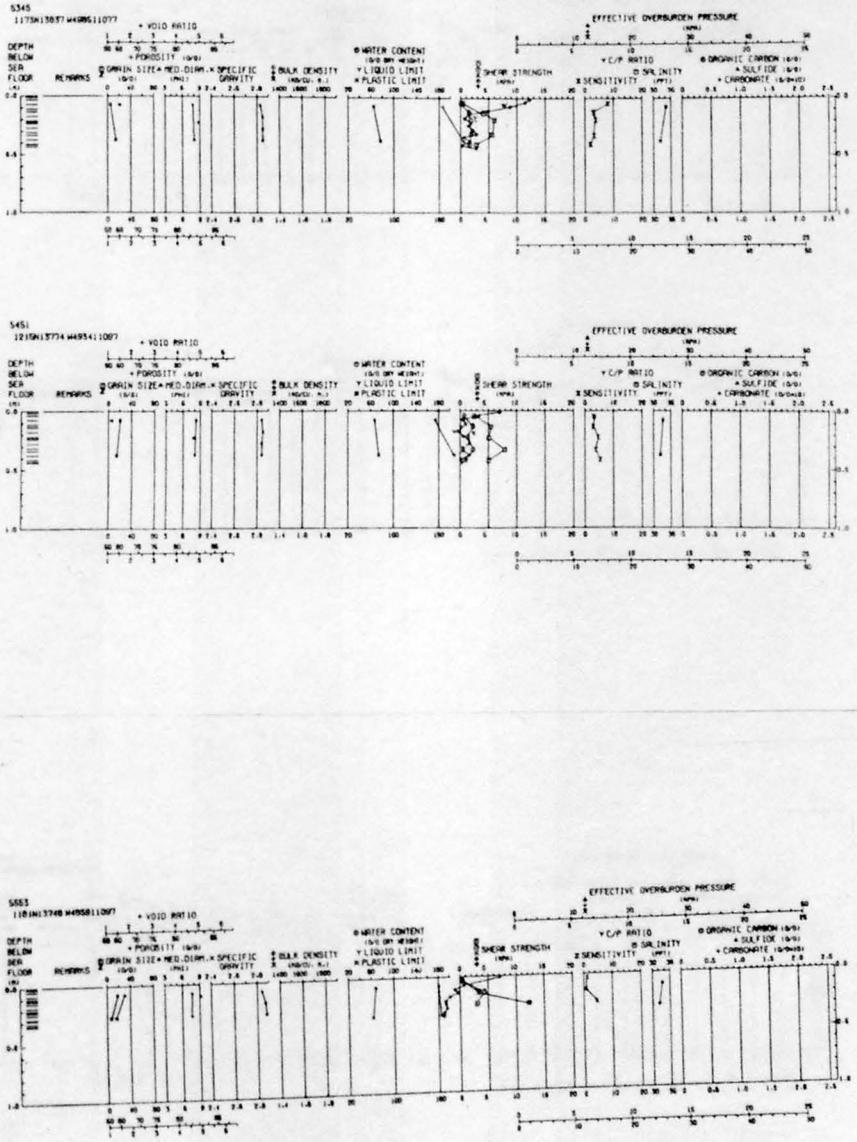


Figure 4. Geotechnical properties
for DOMES Site B cores

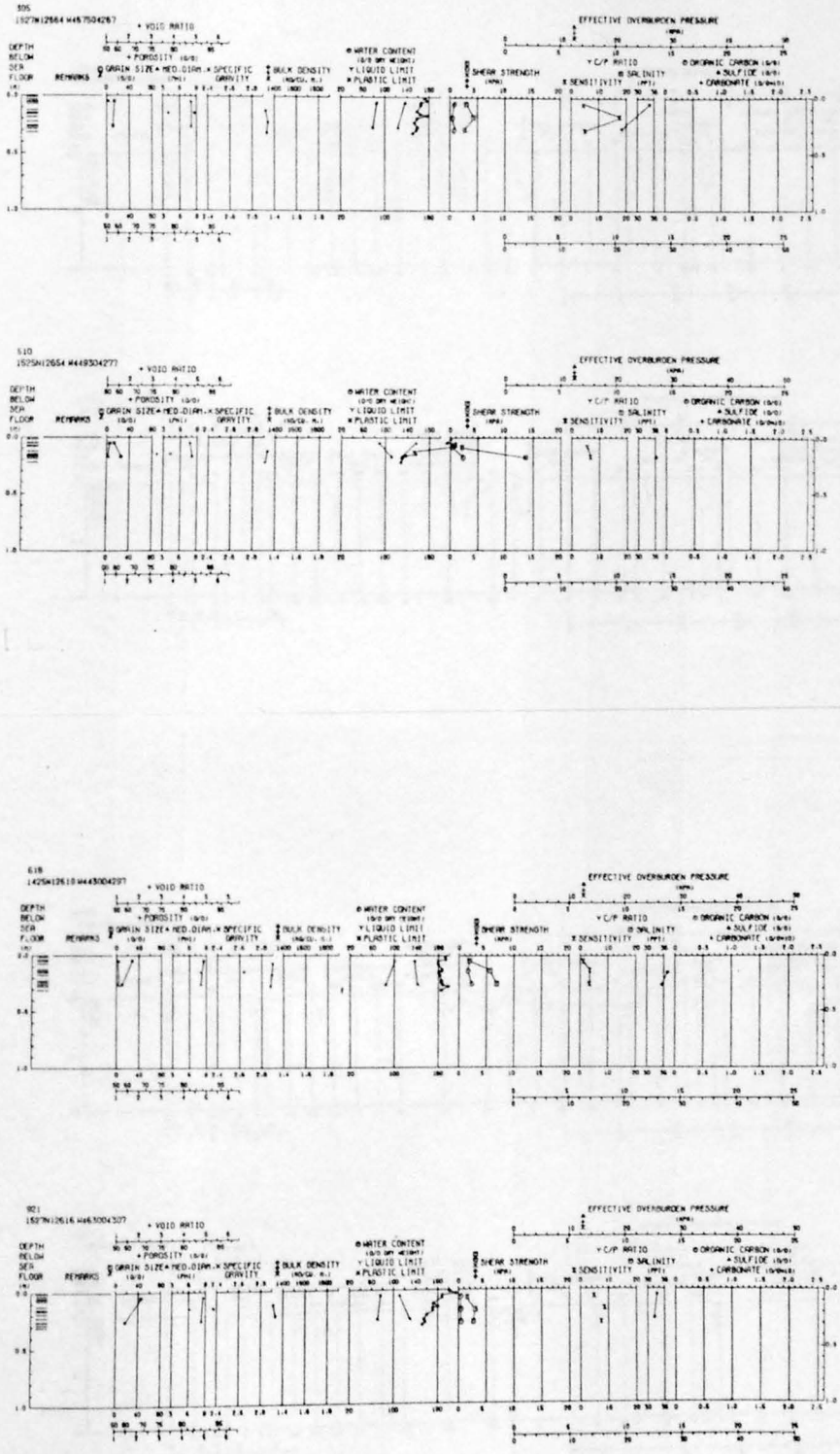


Figure 5. Geotechnical properties for DOMES Site C cores

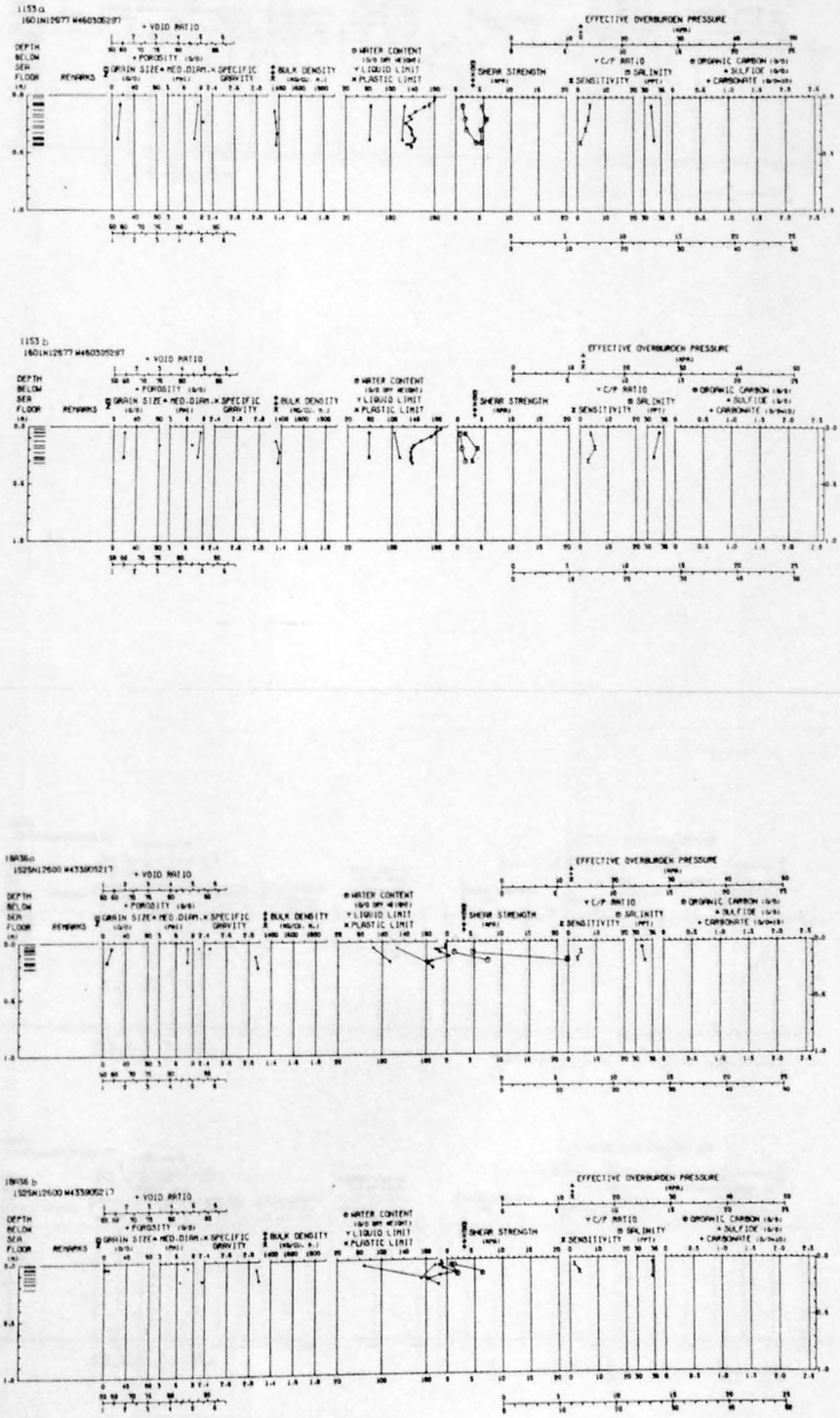


Figure 6. Geotechnical properties
for DOMES Site C cores

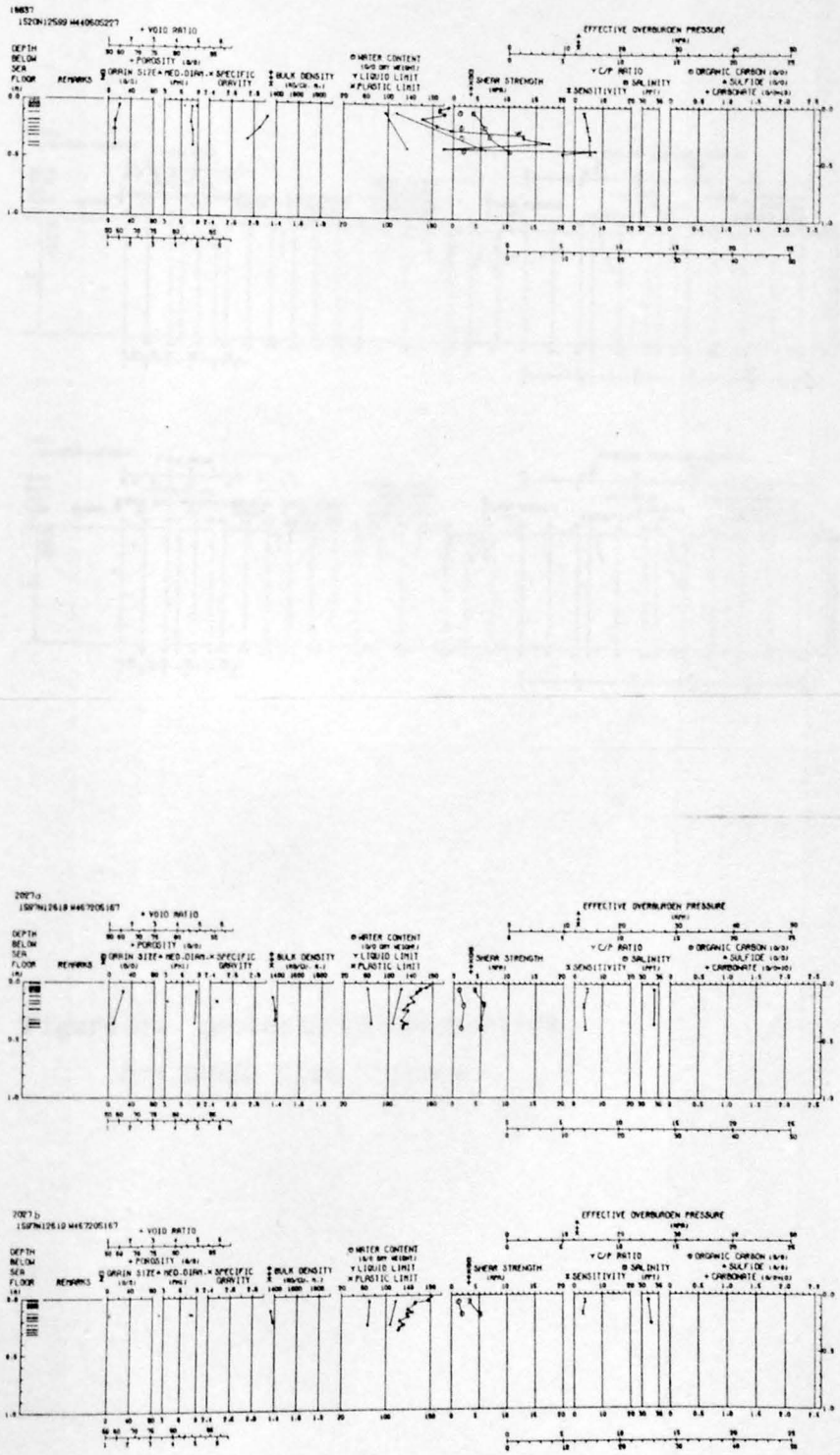


Figure 7. Geotechnical properties for DOMES Site C cores

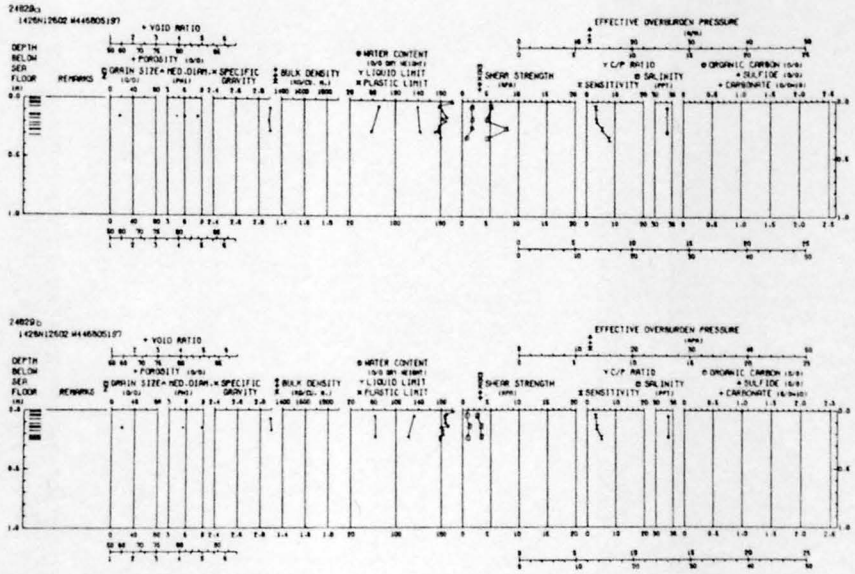


Figure 8. Geotechnical properties for DOMES Site C cores

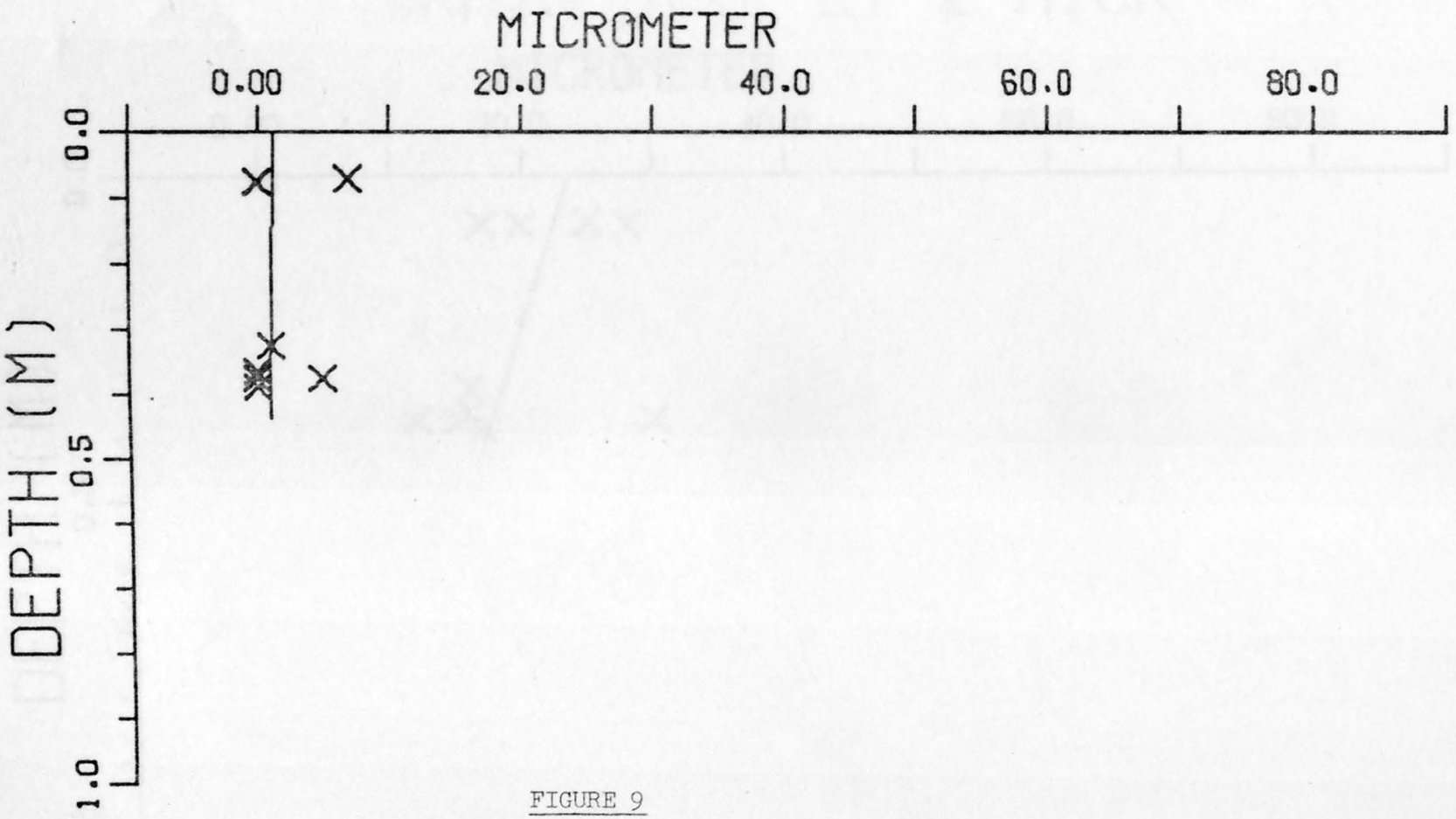


FIGURE 9

SITE A, DOMES 2

EST VALUE = 1.235 + -.687 X DEPTH (M)
STD ERROR OF EST = 2.466
CORR COEF = -.045

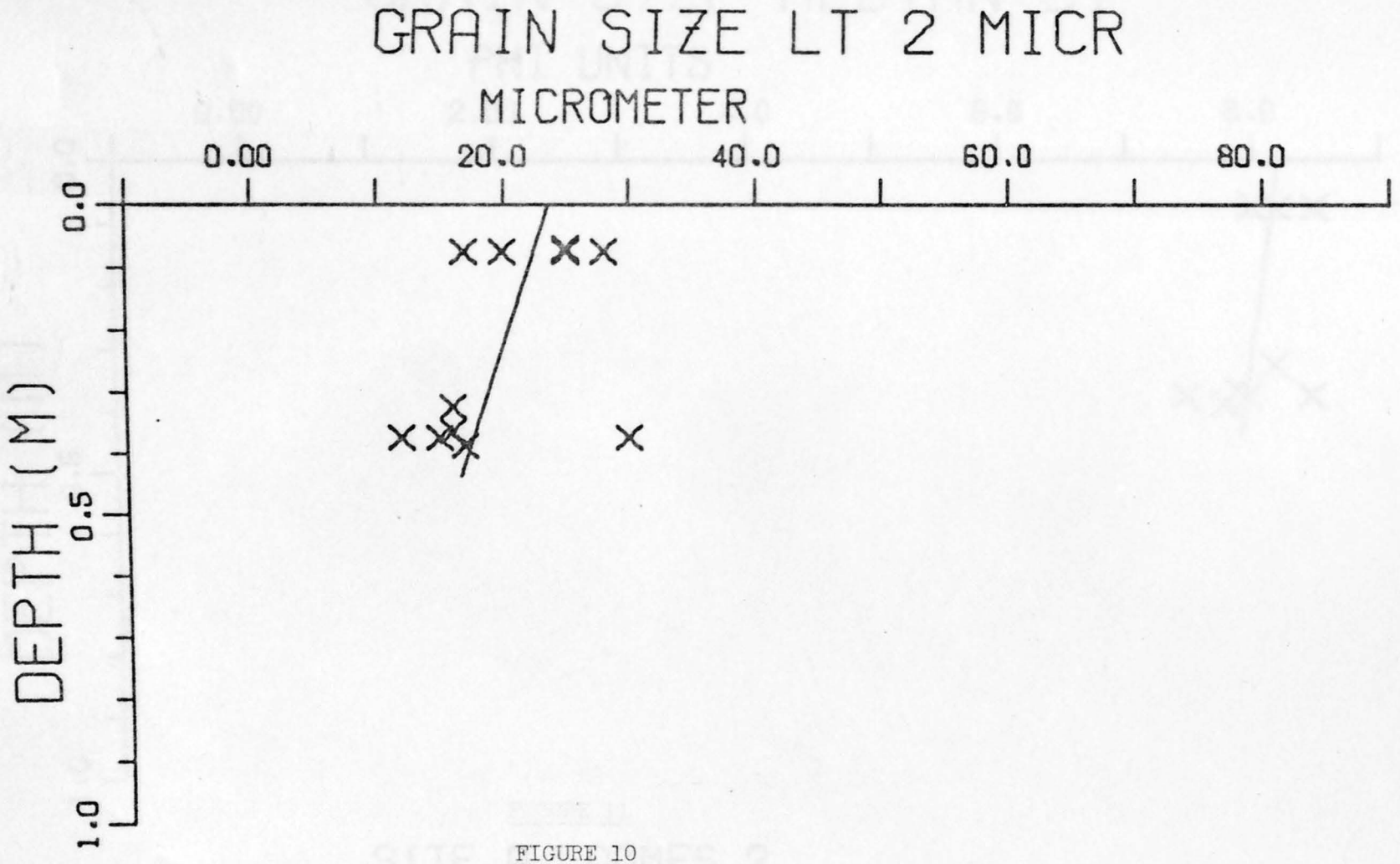


FIGURE 10

SITE A, DOMES 2

EST VALUE = 23.623 + -16.039 X DEPTH (M)

STD ERROR OF EST = 5.348

CORR COEF = -.435

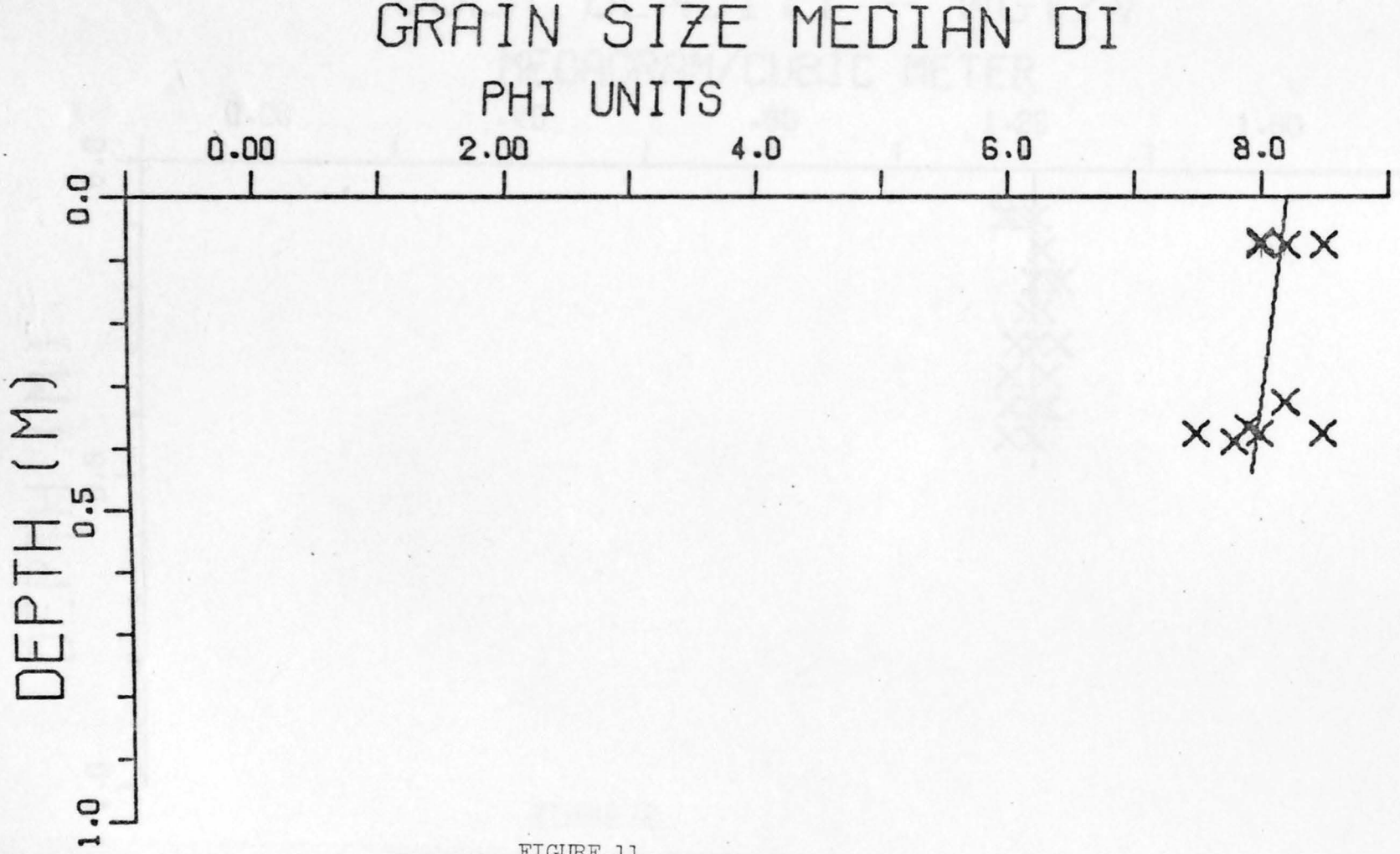


FIGURE 11

SITE A, DOMES 2

EST VALUE = 8.201 + -.608 X DEPTH (M)
STD ERROR OF EST = .278
CORR COEF = -.333

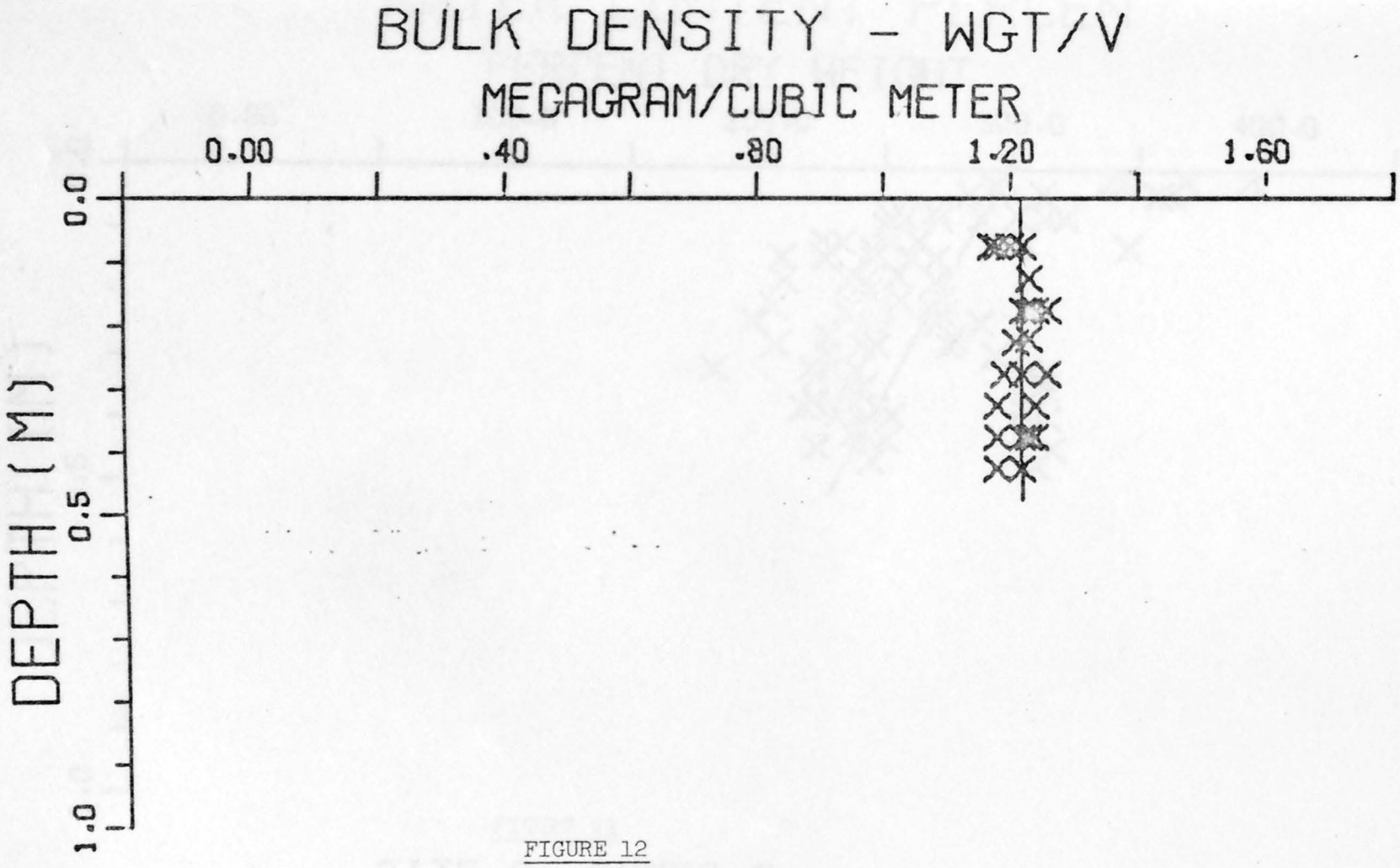


FIGURE 12

SITE A, DOMES 2

EST VALUE = 1.216 + .009 X DEPTH (M)
STD ERROR OF EST = .027
CORR COEF = .044

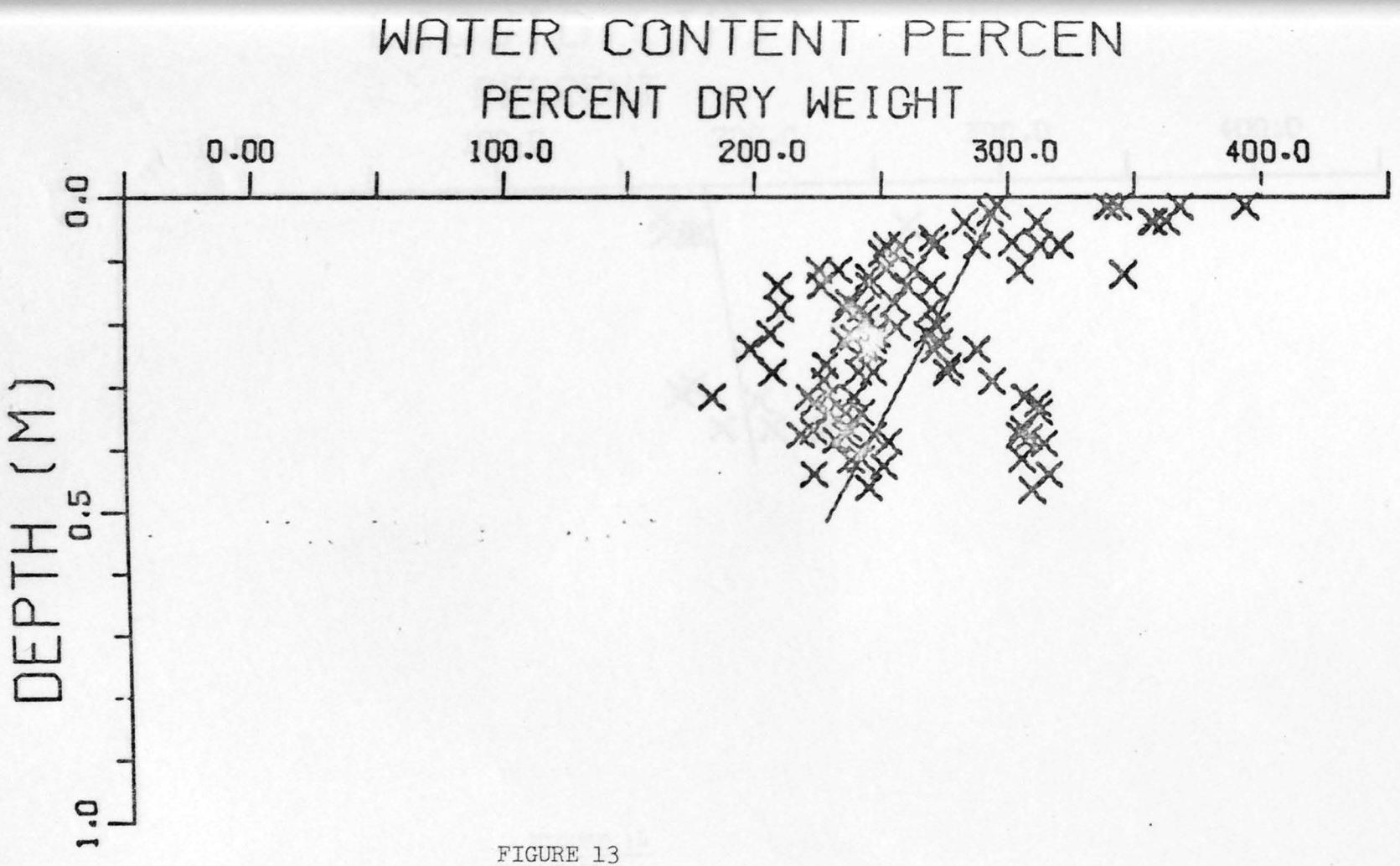


FIGURE 13

SITE A, DOMES 2

EST VALUE = 297.463 + -135.584 X DEPTH (M)
STD ERROR OF EST = 40.168
CORR COEF = -.410

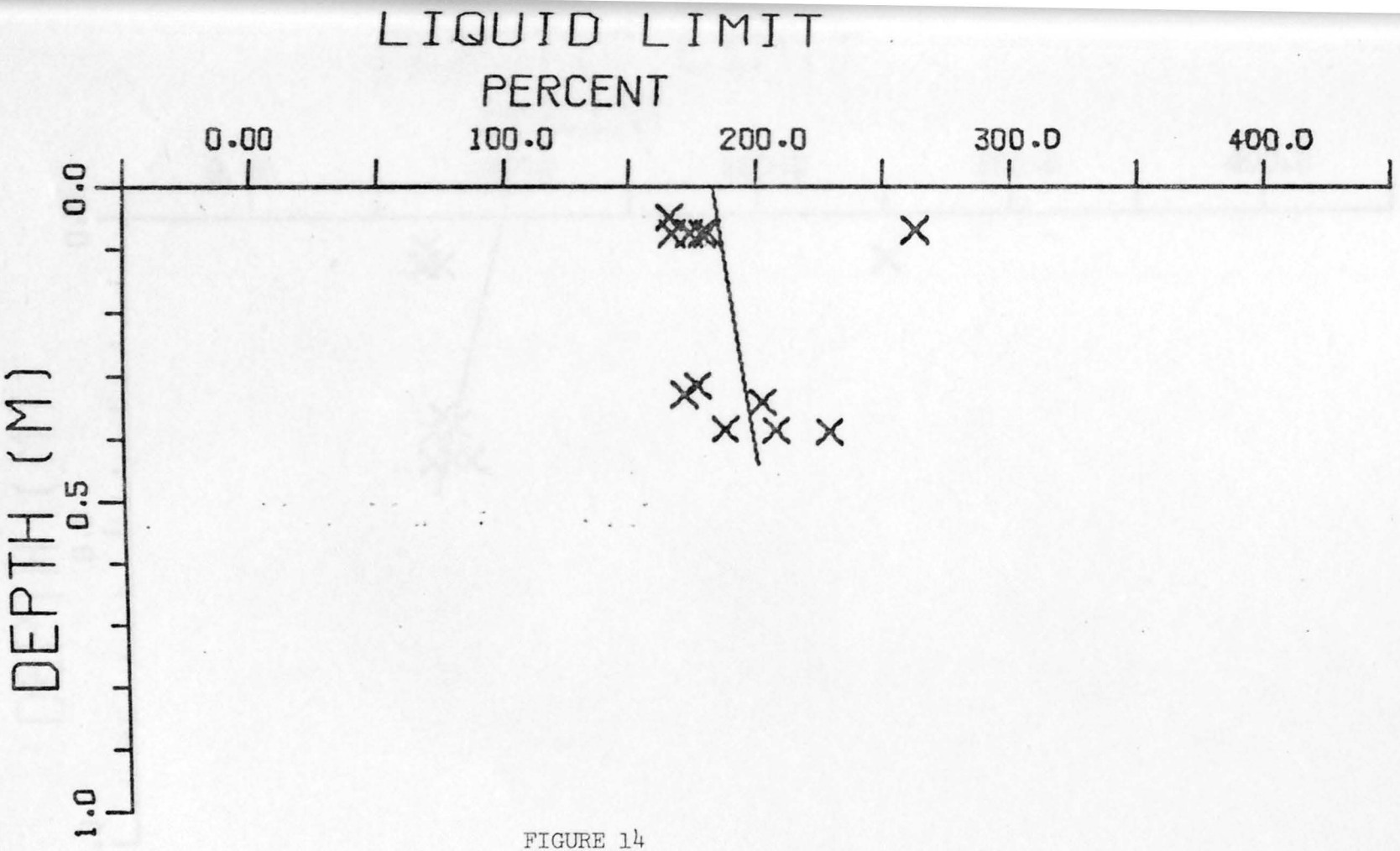


FIGURE 14

SITE A, DOMES 2

EST VALUE = 182.837 + 41.461 X DEPTH (M)
STD ERROR OF EST = 28.670
CORR COEF = .221

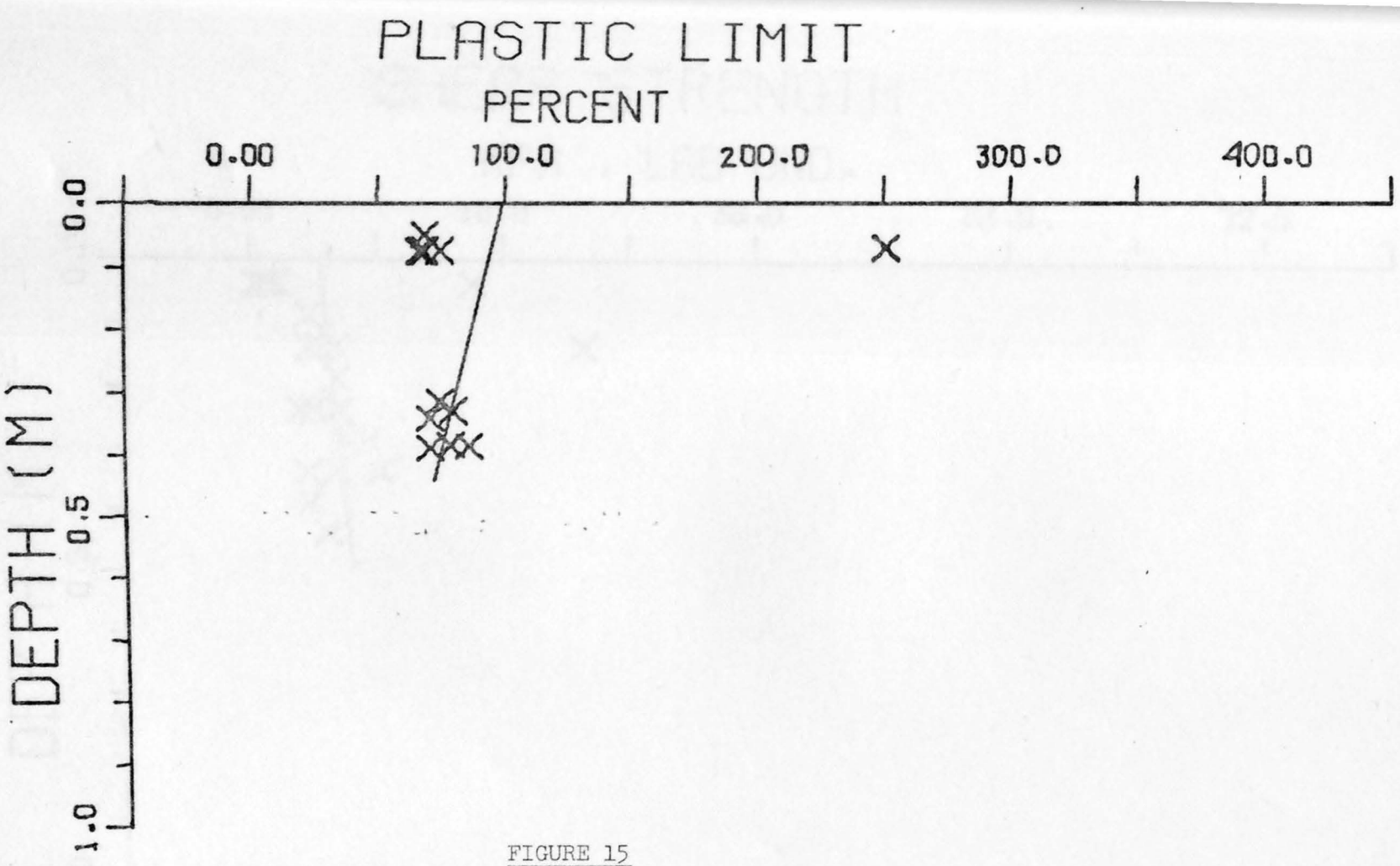


FIGURE 15

SITE A, DOMES 2

EST VALUE = 99.624 + -62.734 X DEPTH (M)
STD ERROR OF EST = 50.886
CORR COEF = -.189

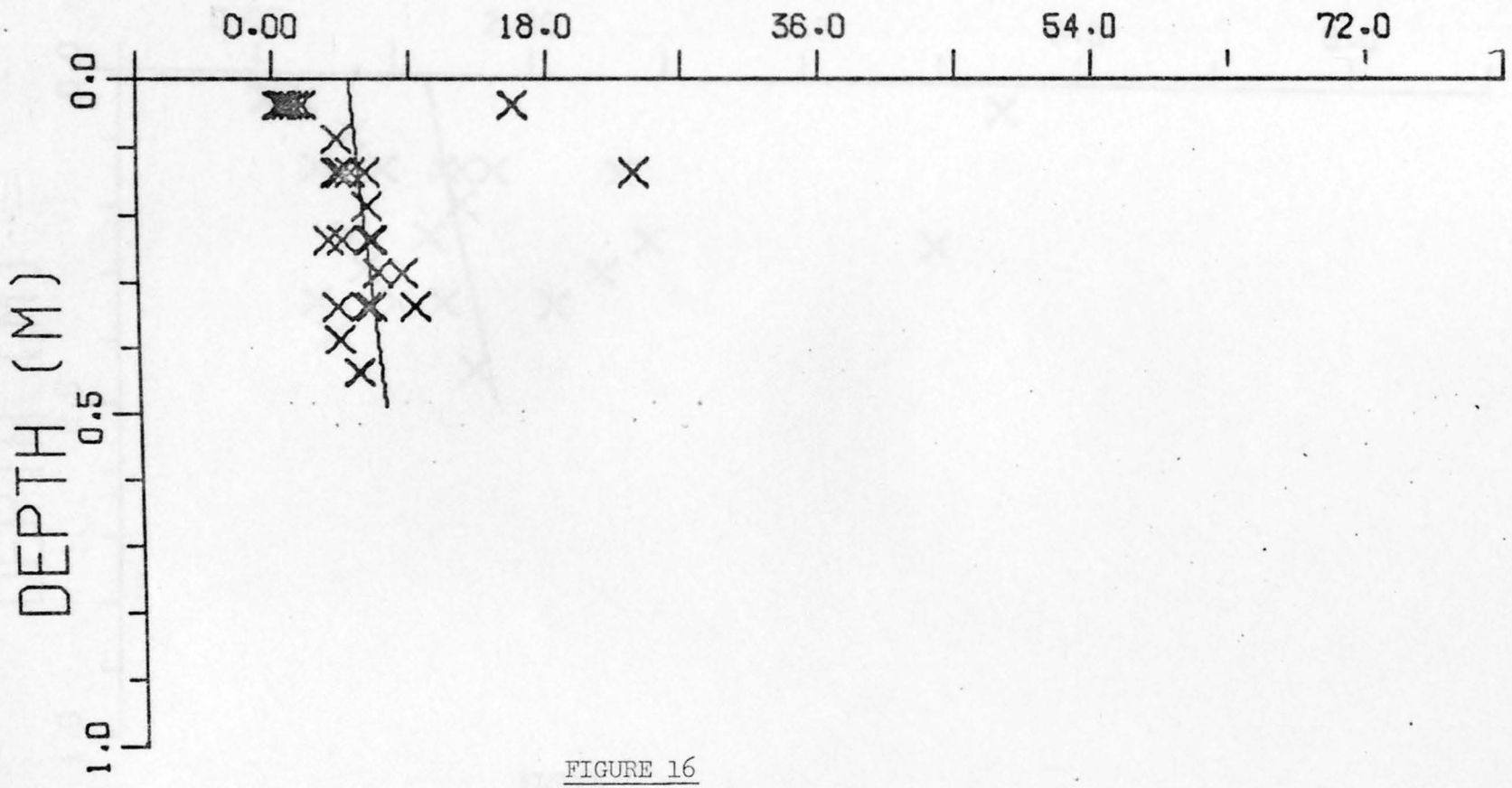


FIGURE 16

SITE A, DOMES 2

EST VALUE = 5.081 + 4.699 X DEPTH (M)
STD ERROR OF EST = 4.876
CORR COEF = .121

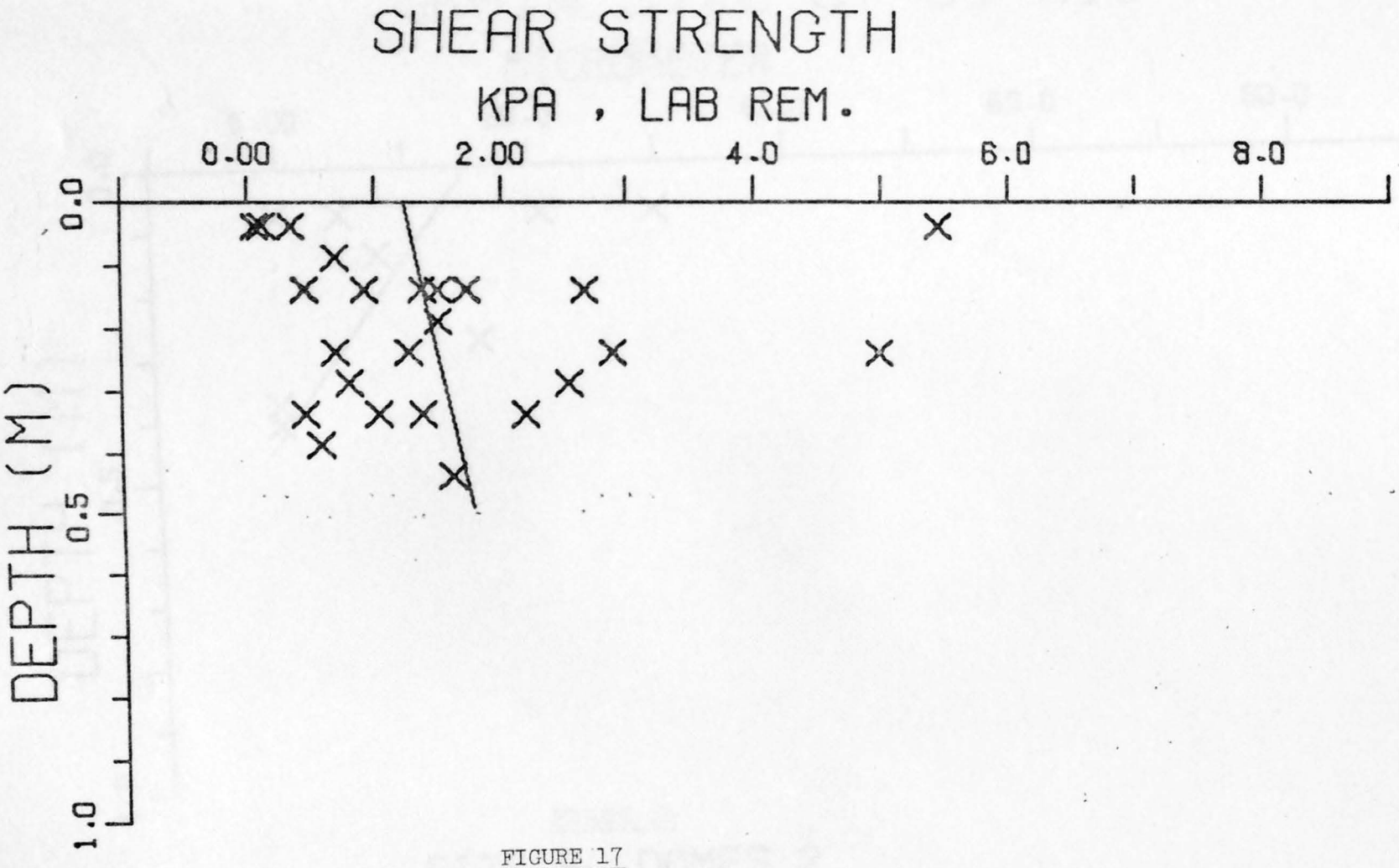


FIGURE 17

SITE A, DOMES 2

EST VALUE = 1.242 + 1.108 X DEPTH (M)

STD ERROR OF EST = 1.387

CORR COEF = .100

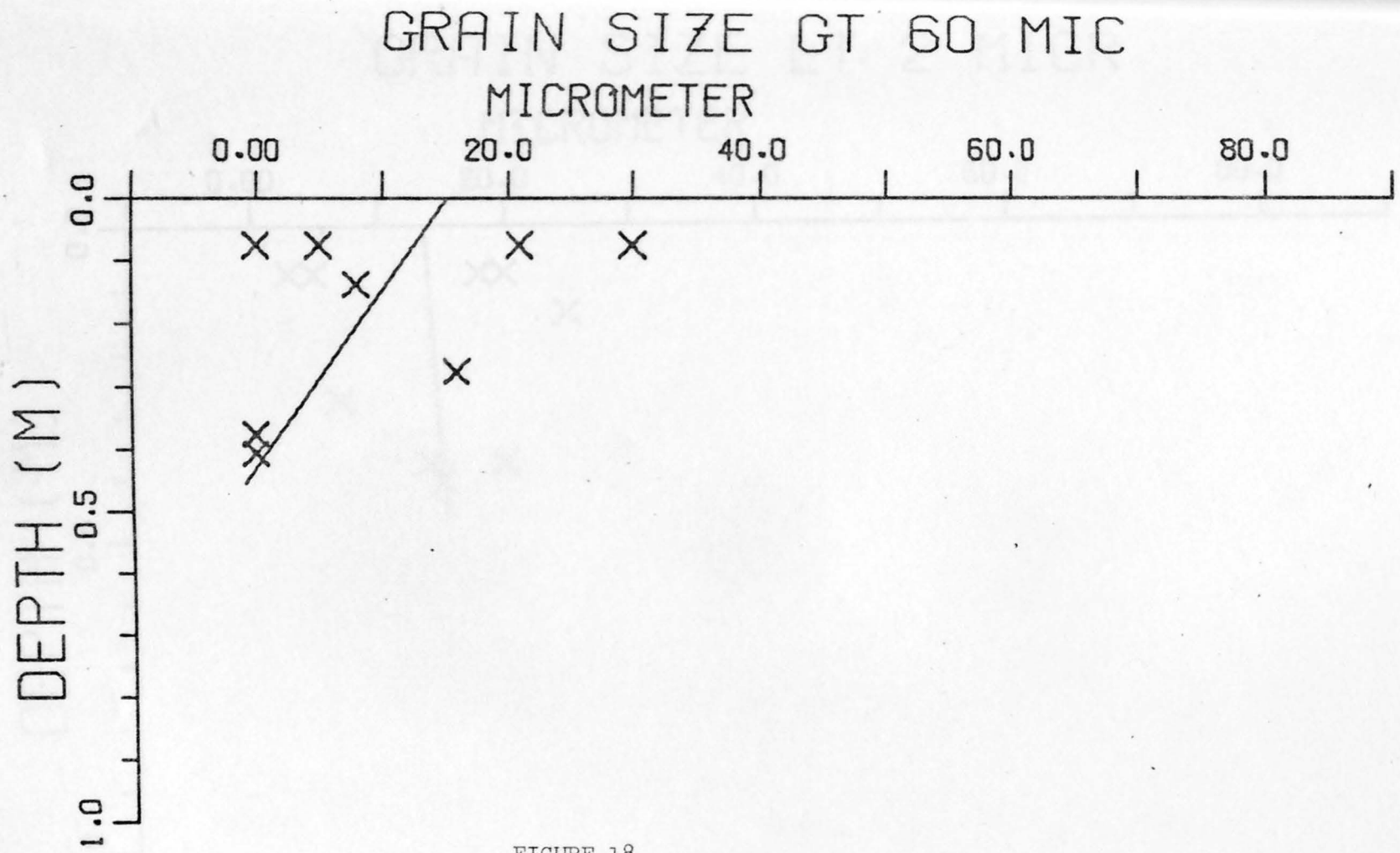


FIGURE 18

SITE B, DOMES 2

EST VALUE = 15.222 + -35.567 X DEPTH (M)
STD ERROR OF EST = 9.283
CORR COEF = -.514

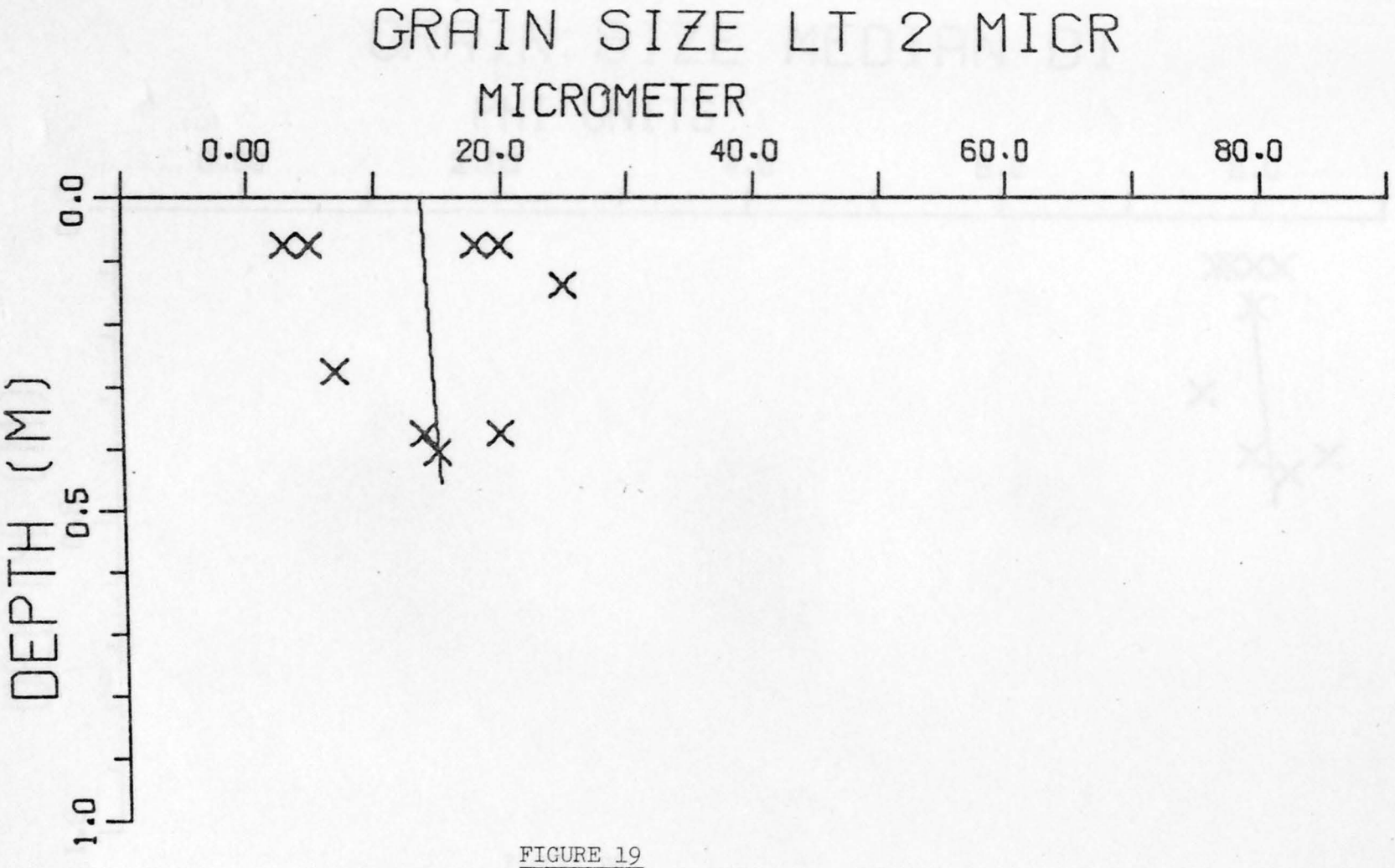


FIGURE 19

SITE B, DOMES 2

EST VALUE = 13.742 + 3.380 X DEPTH (M)
STD ERROR OF EST = 7.243
CORR COEF = .073

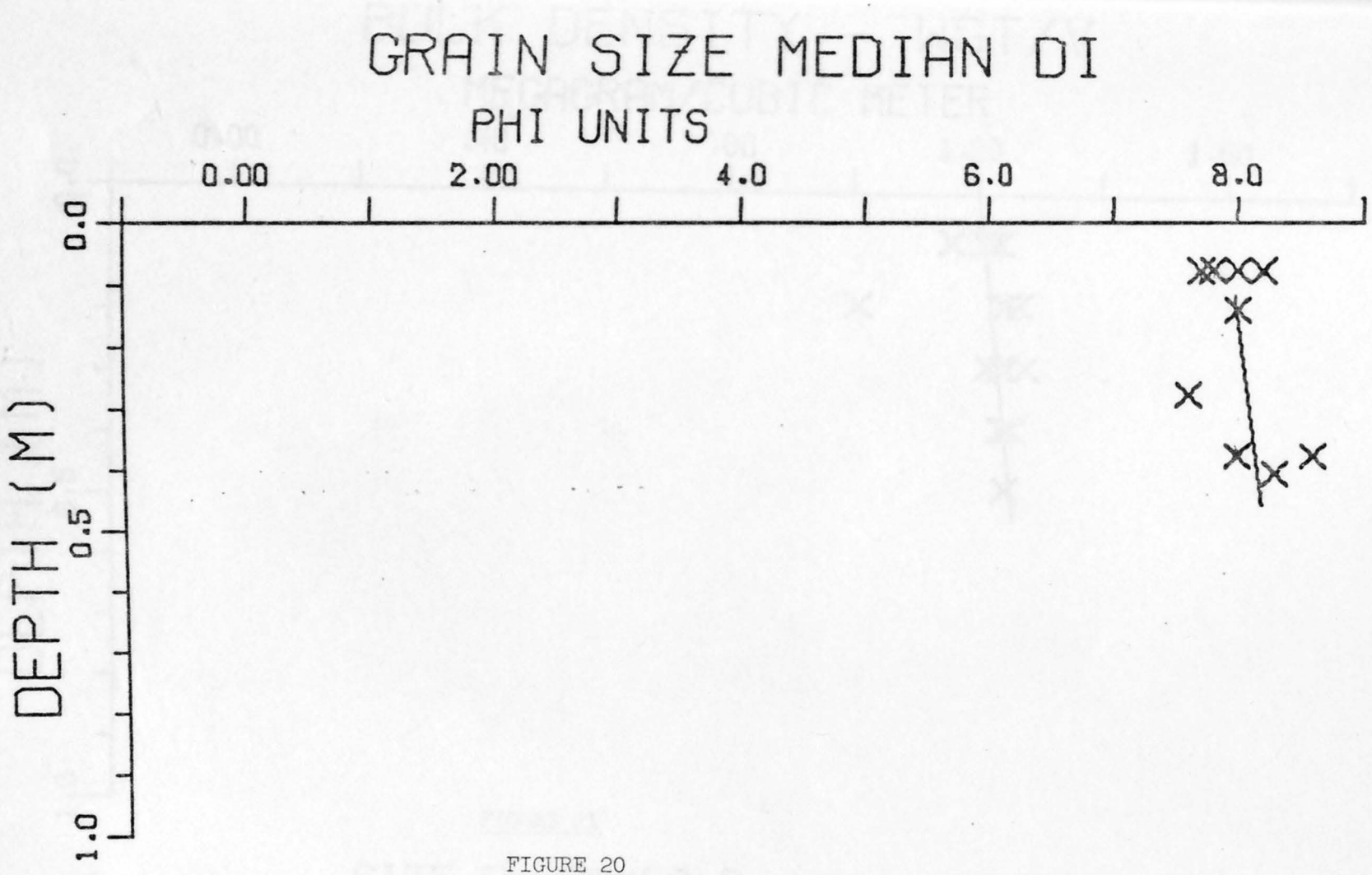


FIGURE 20

SITE B, DOMES 2

EST VALUE = 7.898 + .657 X DEPTH (M)
STD ERROR OF EST = .281
CORR COEF = .344

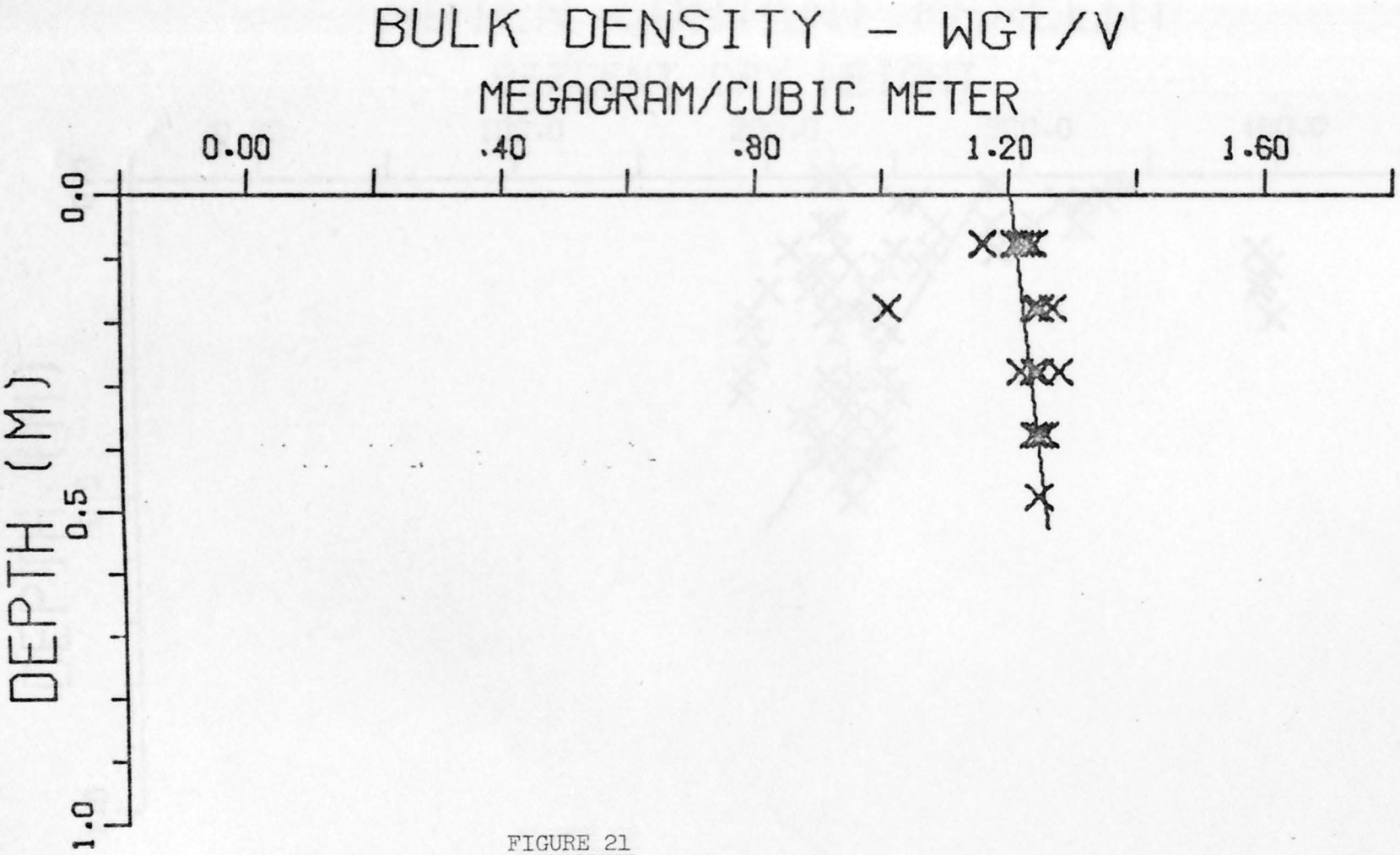


FIGURE 21

SITE B, DOMES 2

EST VALUE = 1.203 + .117 X DEPTH (M)
STD ERROR OF EST = .054
CORR COEF = .264

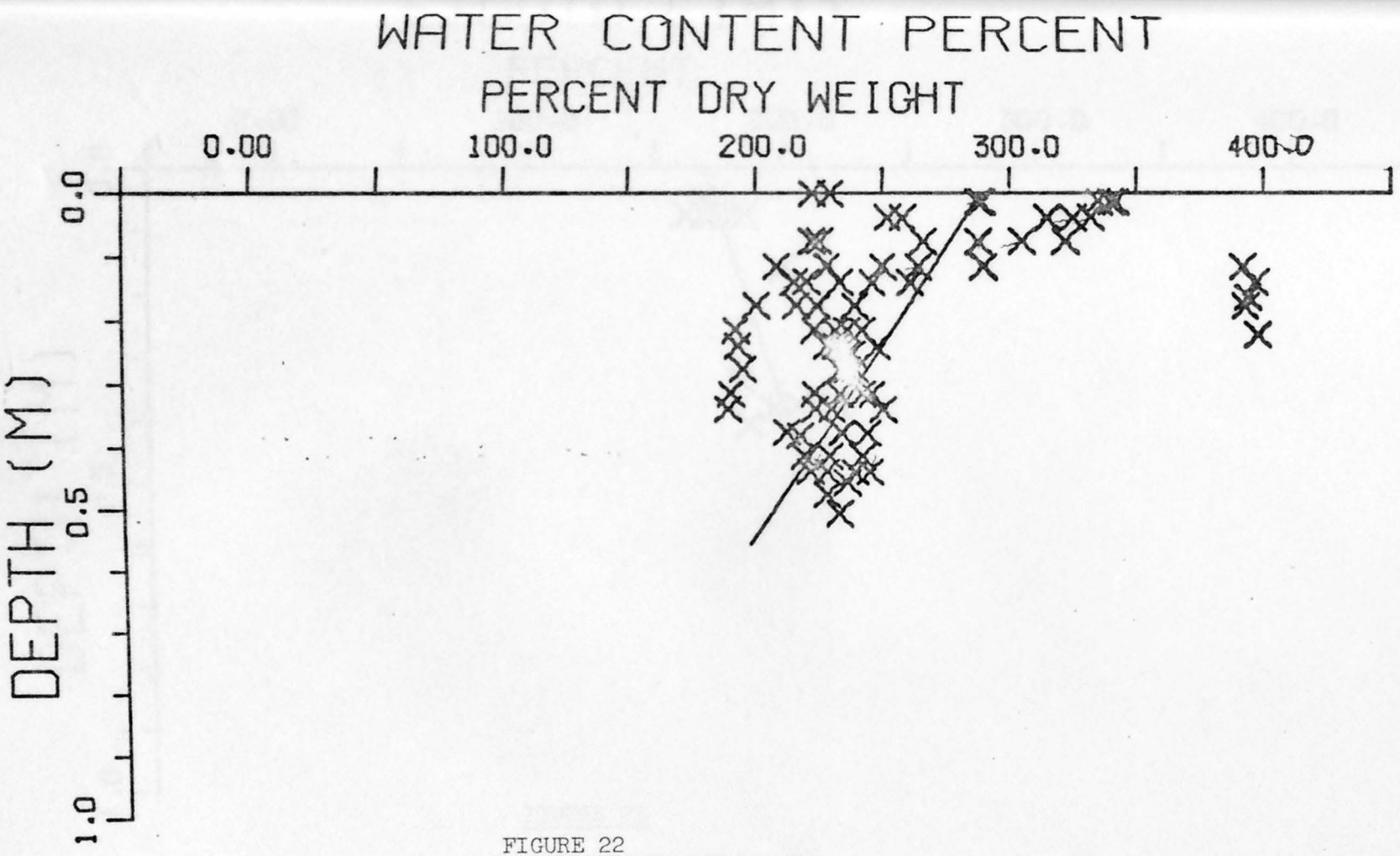


FIGURE 22

SITE B, DOMES 2

EST VALUE = 288.367 + -163.313 X DEPTH (M)
STD ERROR OF EST = 45.079
CORR COEF = -.452

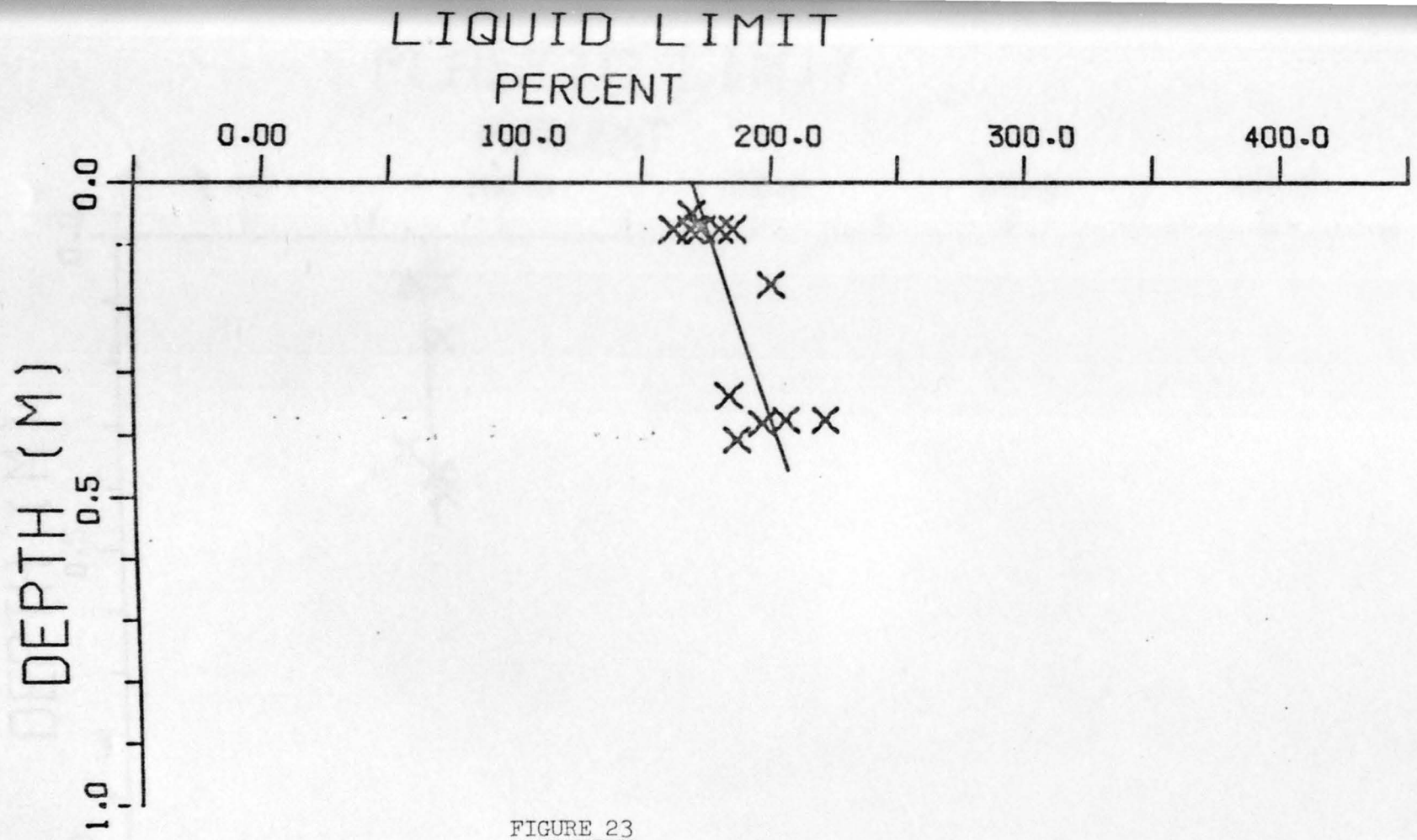


FIGURE 23

SITE B, DOMES 2

EST VALUE = 169.120 + 83.326 X DEPTH (M)
STD ERROR OF EST = 12.653
CORR COEF = .725

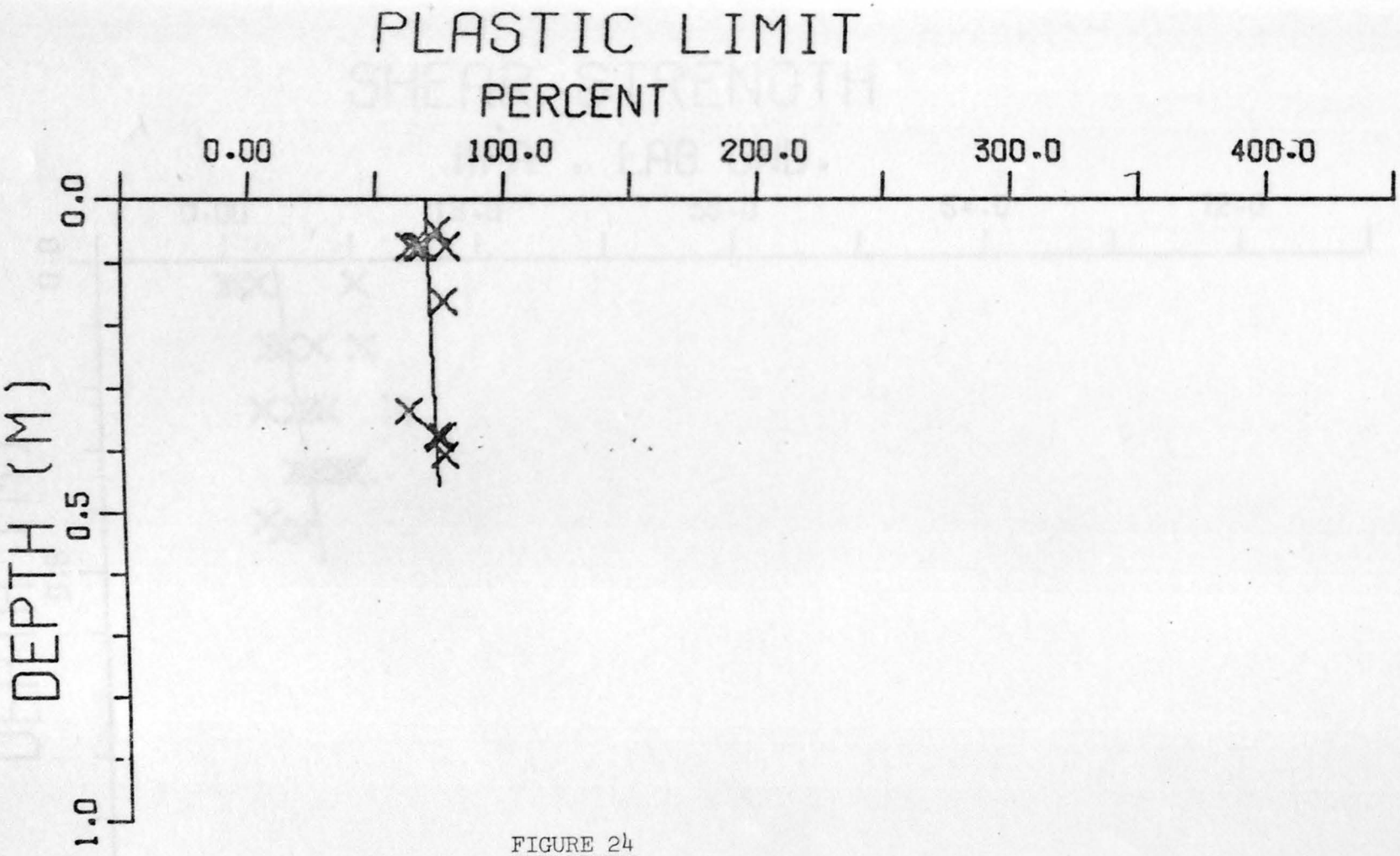


FIGURE 24

SITE B, DOMES 2

EST VALUE = 69.707 + 10.393 X DEPTH (M)
STD ERROR OF EST = 5.348
CORR COEF = .297

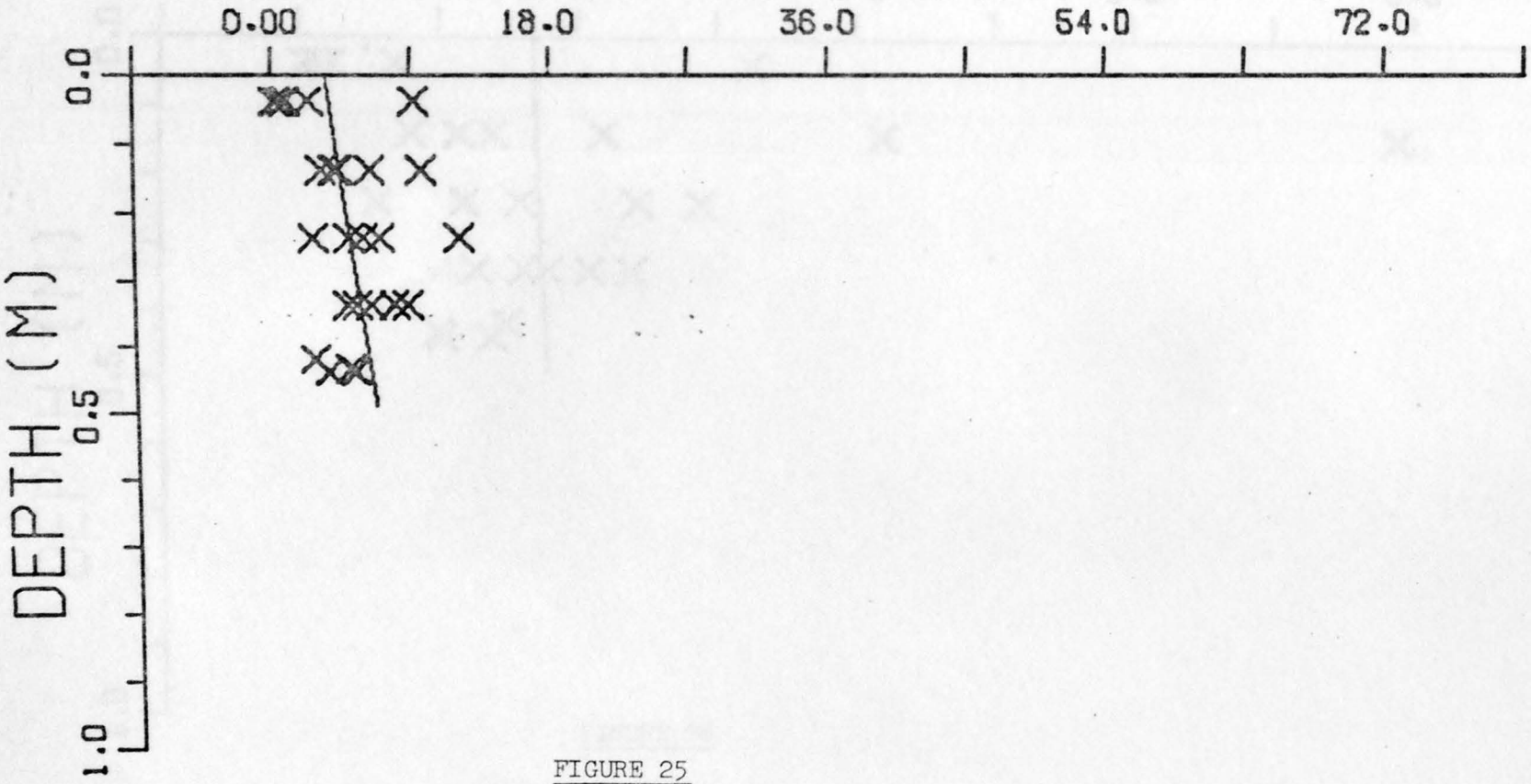


FIGURE 25

SITE B, DOMES 2

EST VALUE = 3.512 + 6.570 X DEPTH (M)
STD ERROR OF EST = 2.934
CORR COEF = .305

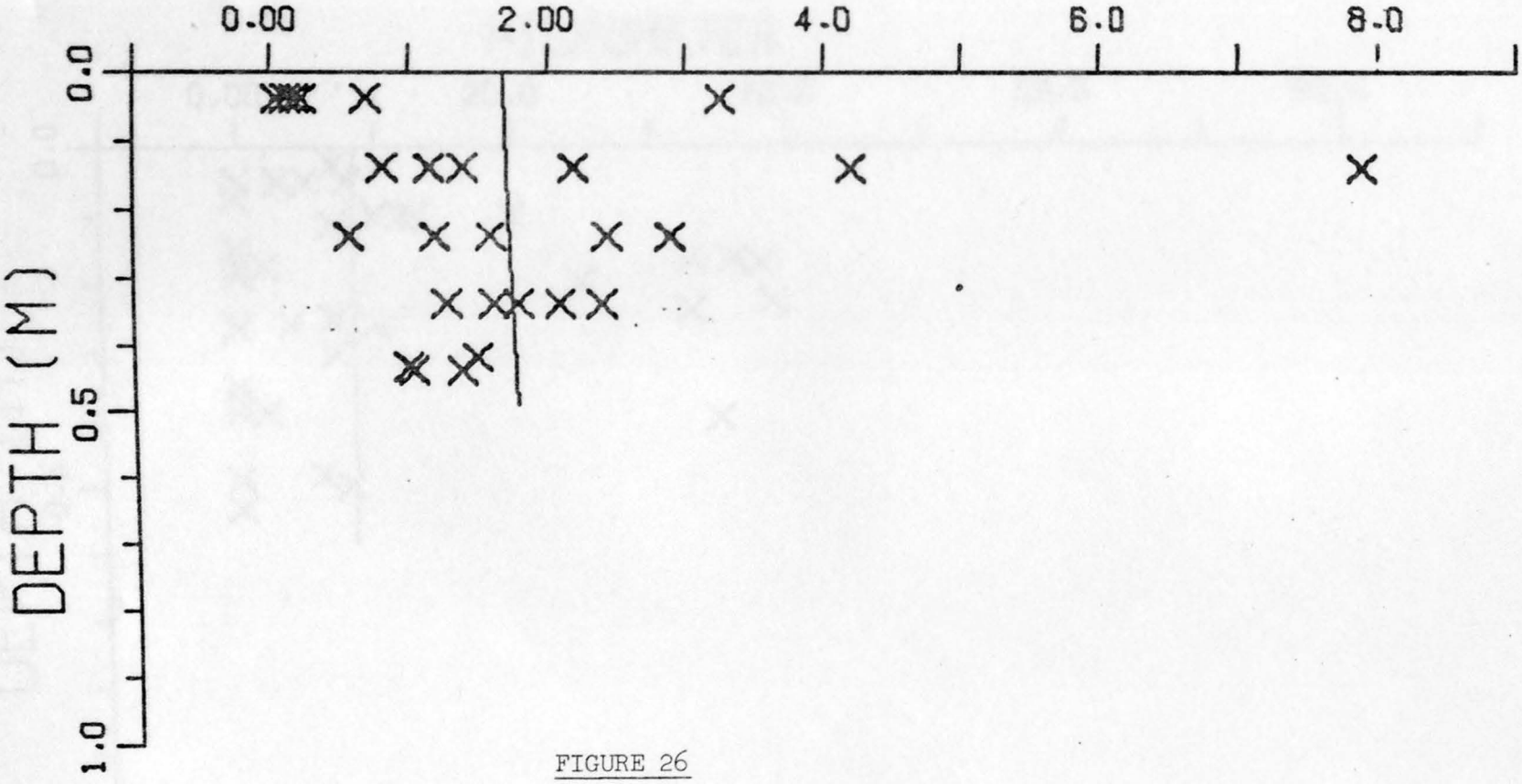


FIGURE 26

SITE B, DOMES 2

EST VALUE = 1.685 + .220 X DEPTH (M)
STD ERROR OF EST = 1.638
CORR COEF = .019

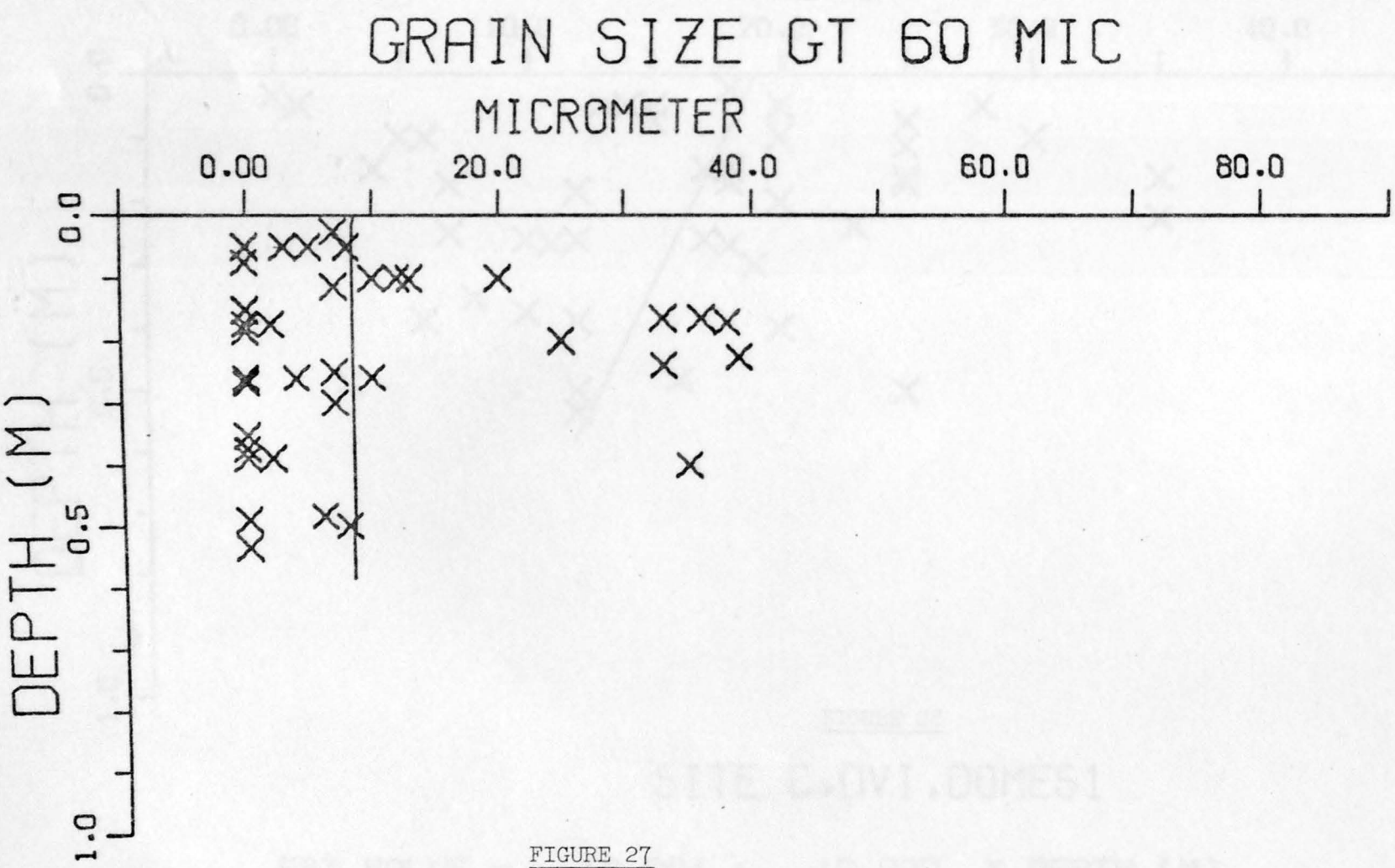


FIGURE 27

SITE C,DVI,DOMES1

EST VALUE = 8.523 + -.264 X DEPTH (M)
STD ERROR OF EST = 12.264
CORR COEF = -.003

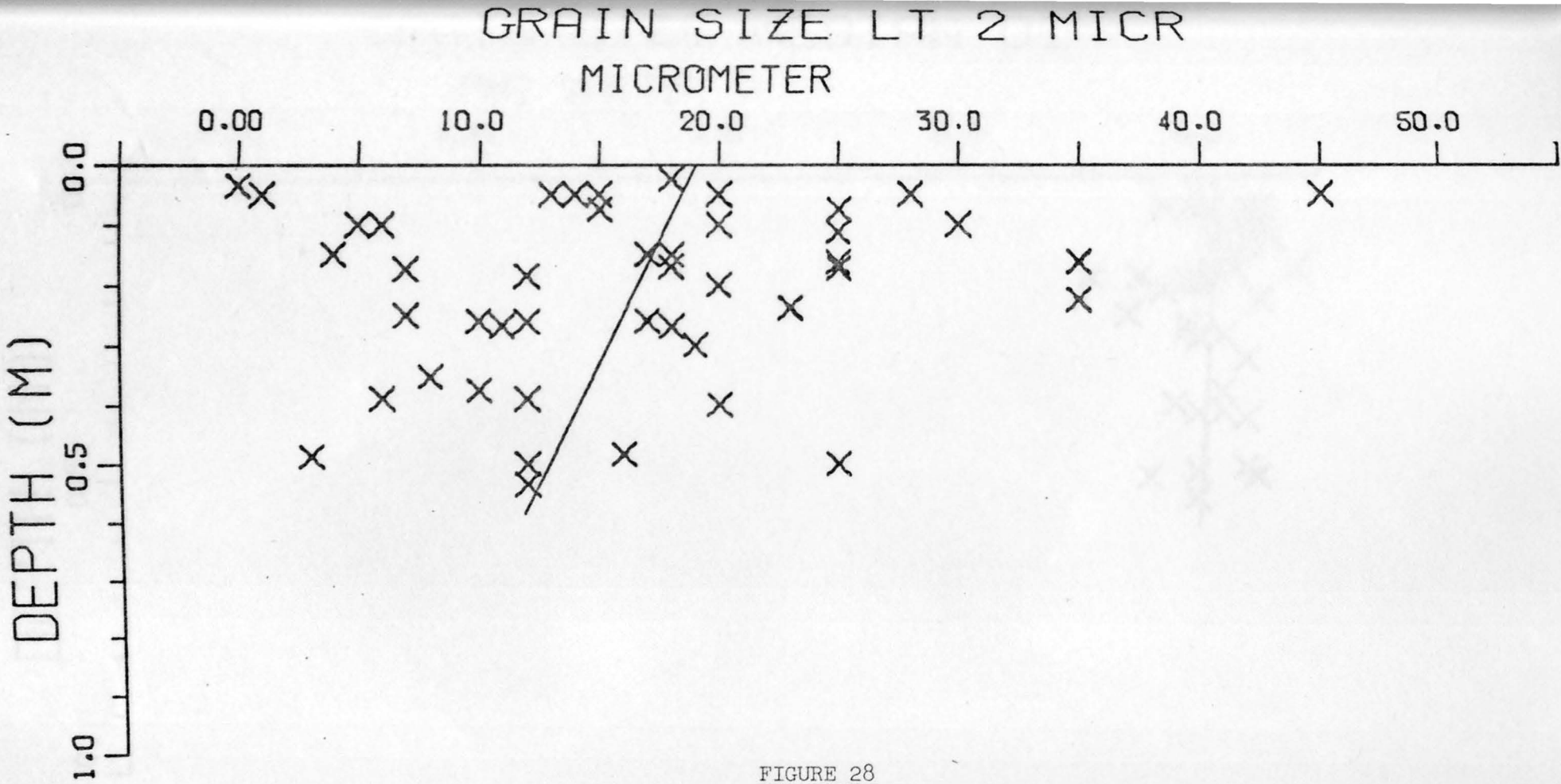


FIGURE 28

SITE C.DVI.DOMES1

EST VALUE = 18.994 + -12.227 X DEPTH (M)
STD ERROR OF EST = 9.342
CORR COEF = -.192

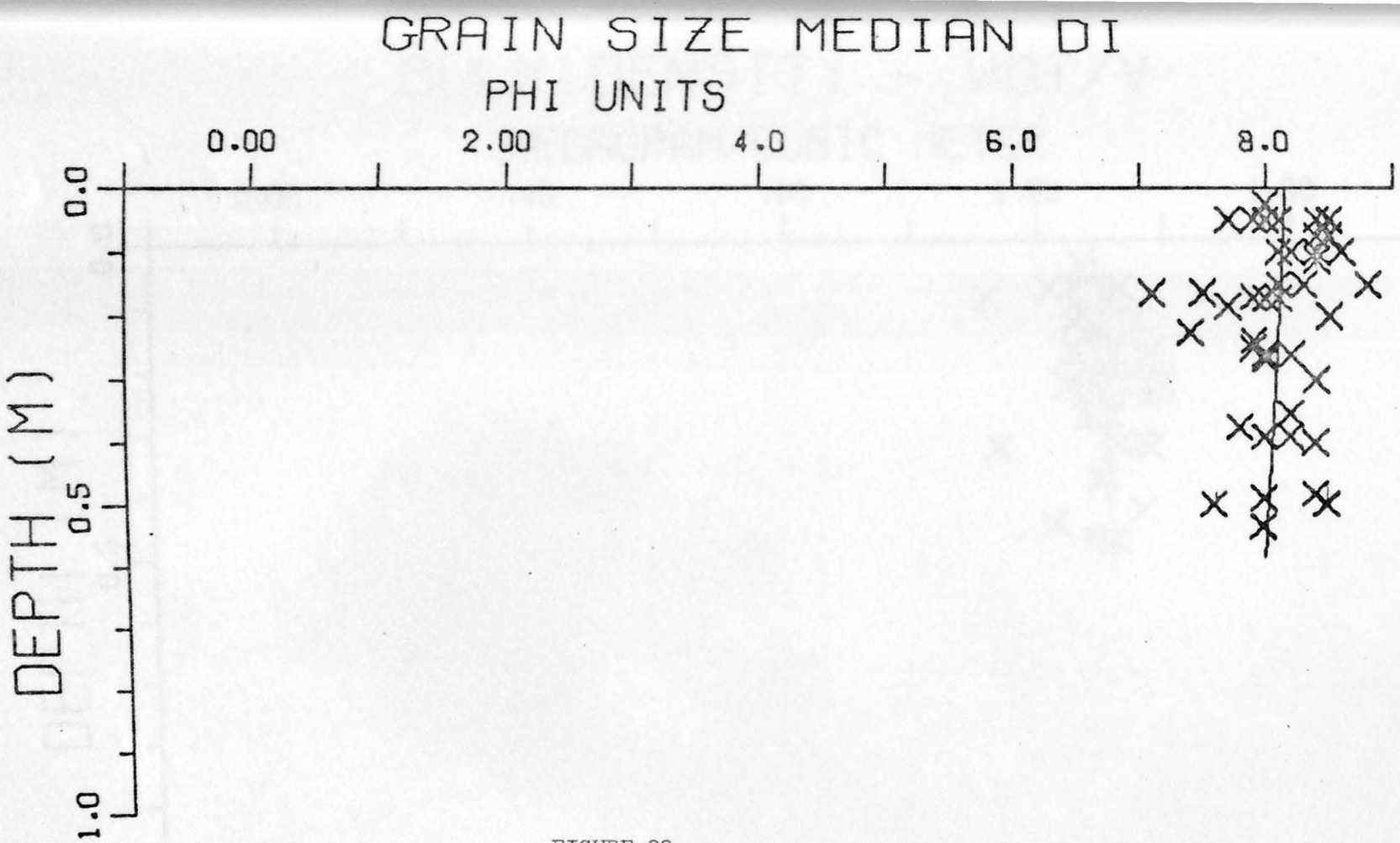


FIGURE 29

SITE C,DVI,DOMES1

EST VALUE = 8.149 + -.223 X DEPTH (M)
STD ERROR OF EST = .340
CORR COEF = -.097

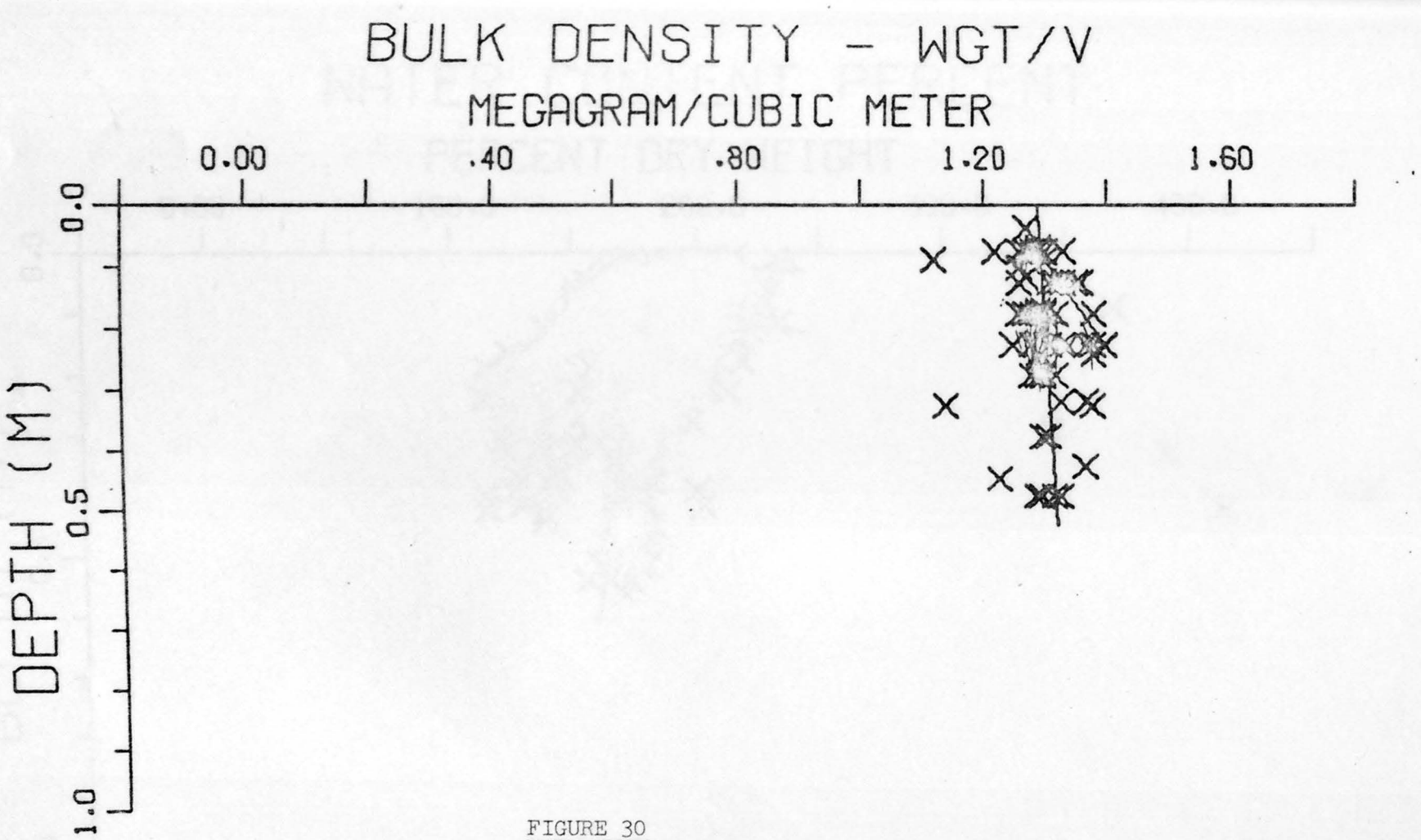


FIGURE 30

SITE C.DVI.DOMES1

EST VALUE = 1.289 + .071 X DEPTH (M)
STD ERROR OF EST = .048
CORR COEF = .179

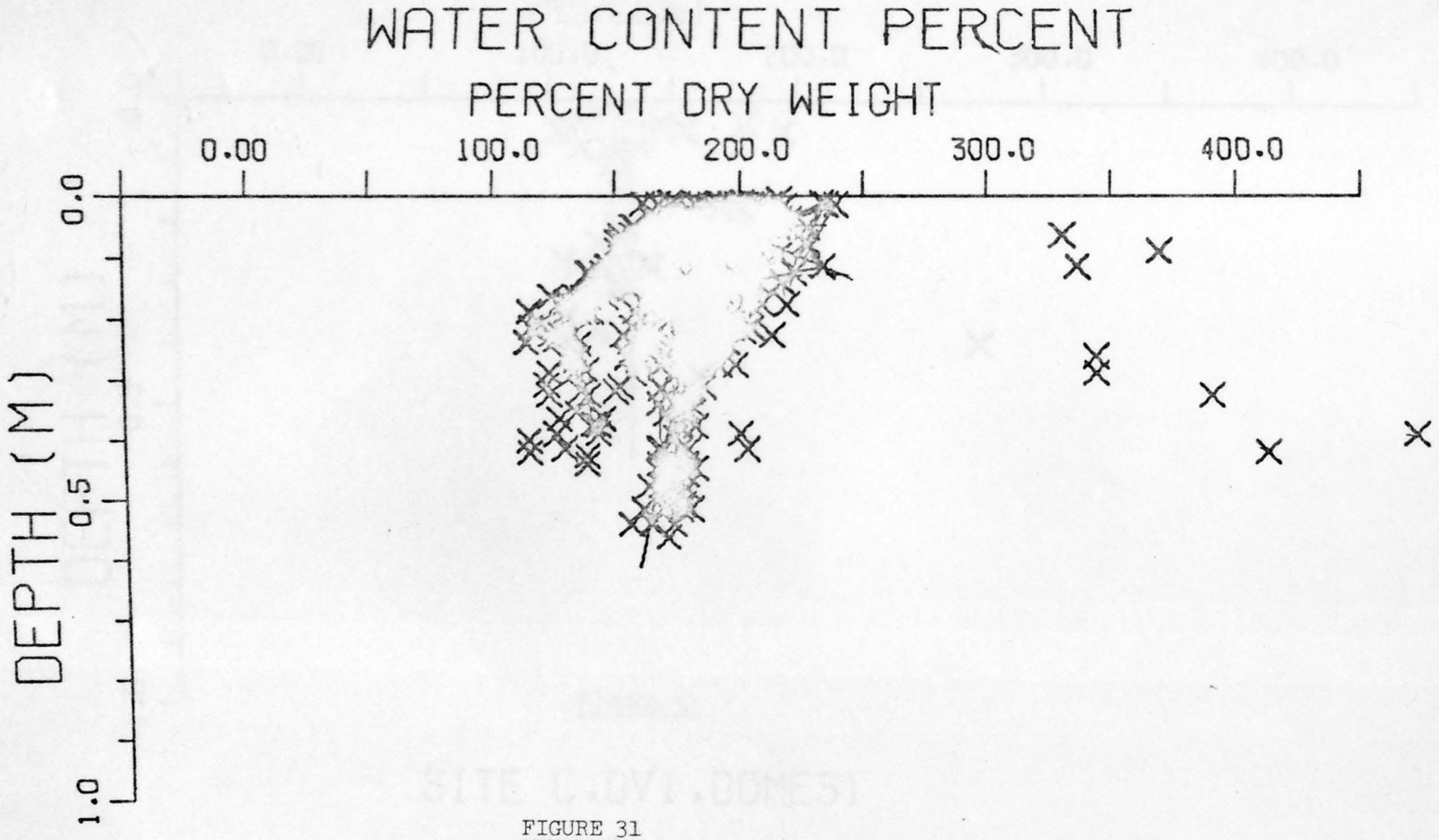


FIGURE 31

SITE C.DVI.DOMES1

EST VALUE = 189.751 + -49.810 X DEPTH (M)
STD ERROR OF EST = 39.279
CORR COEF = -.173

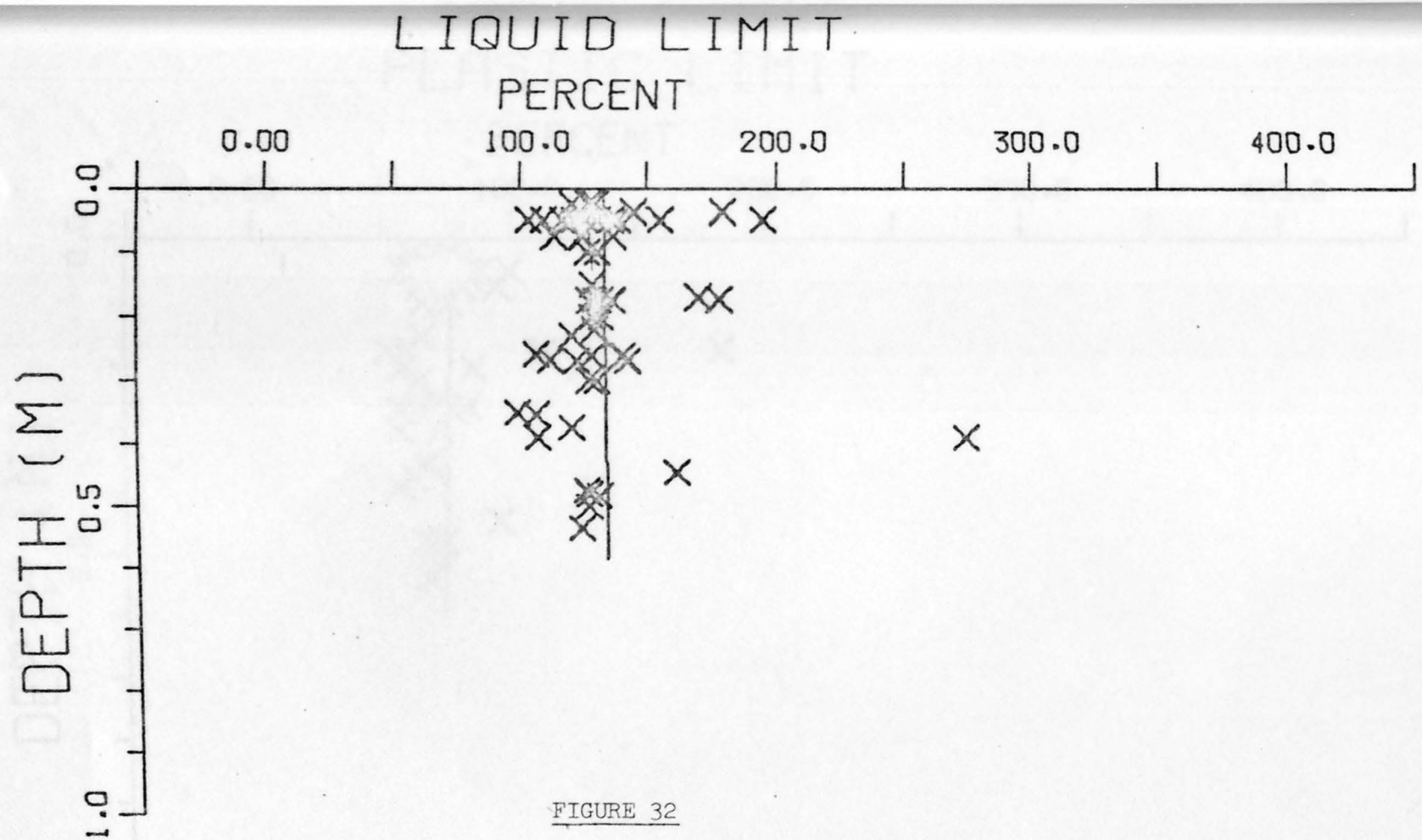


FIGURE 32

SITE C,DVI,DOMES1

EST VALUE = 133.459 + 3.312 X DEPTH (M)
STD ERROR OF EST = 27.221
CORR COEF = .019

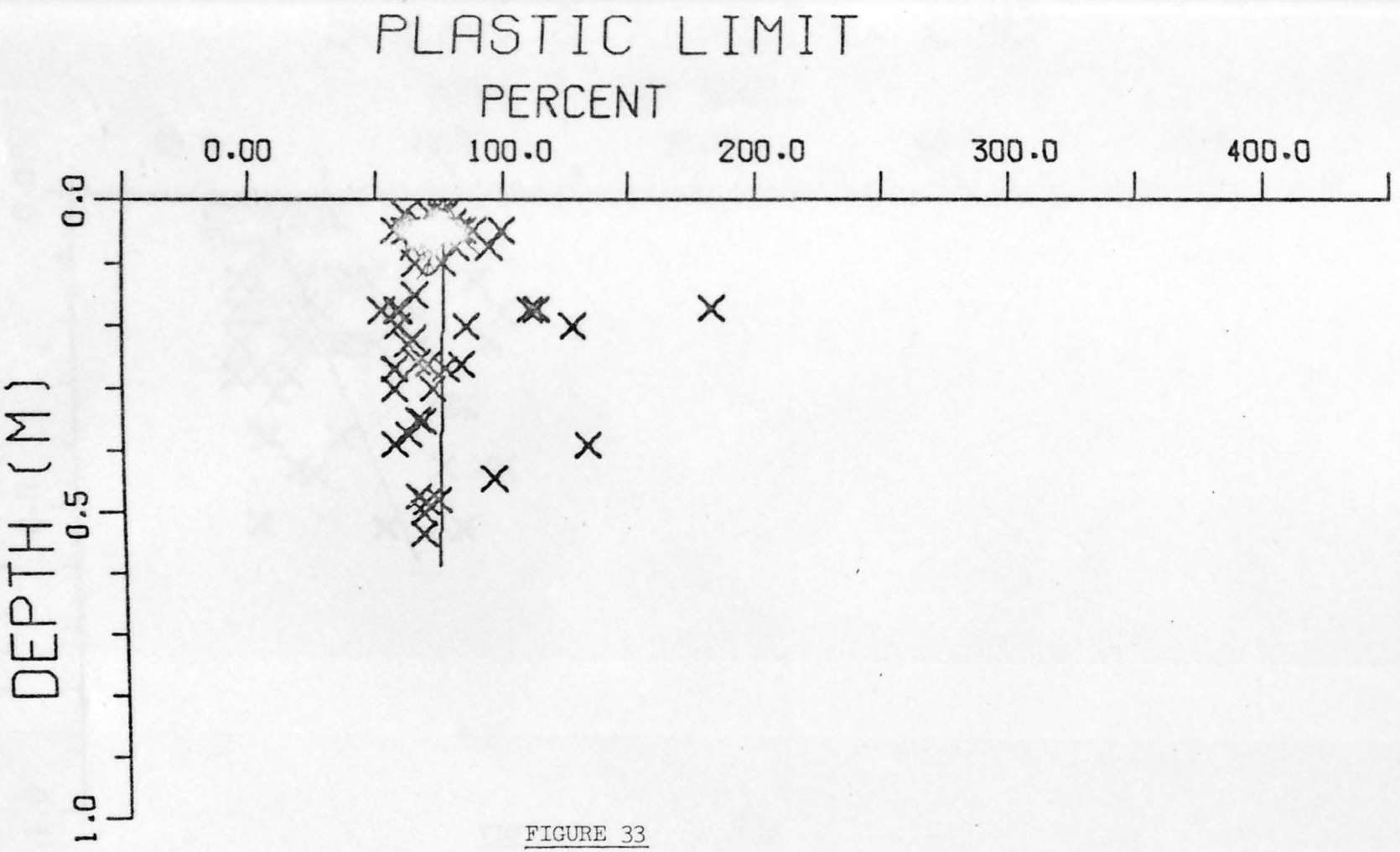


FIGURE 33

SITE C,OVI,DOMES1

EST VALUE = 77.737 + -4.123 X DEPTH (M)
STD ERROR OF EST = 22.794
CORR COEF = -.028

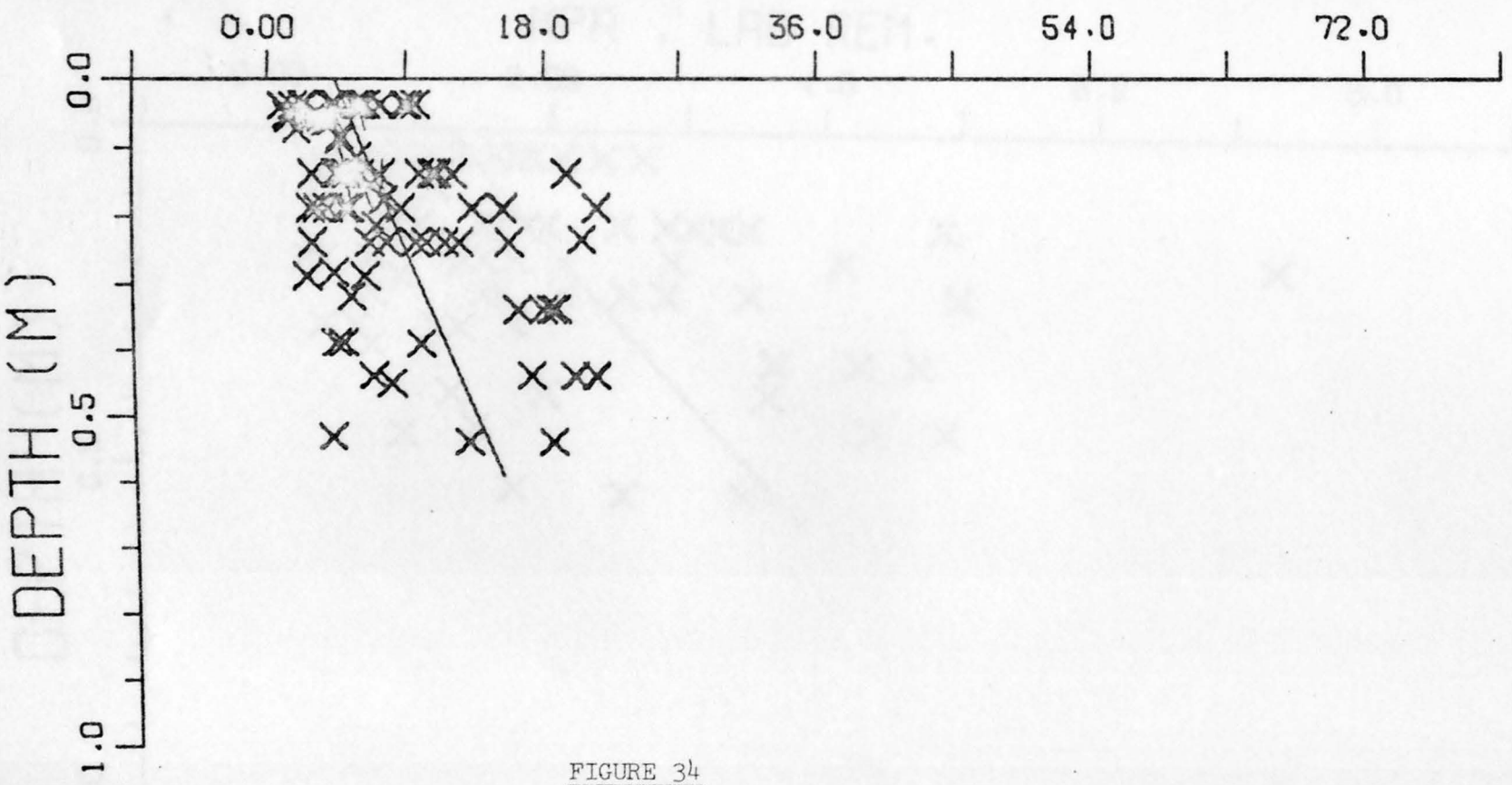


FIGURE 34

SITE C,DVI,DOMES1

EST VALUE = 4.493 + 18.517 X DEPTH (M)
STD ERROR OF EST = 4.948
CORR COEF = .459

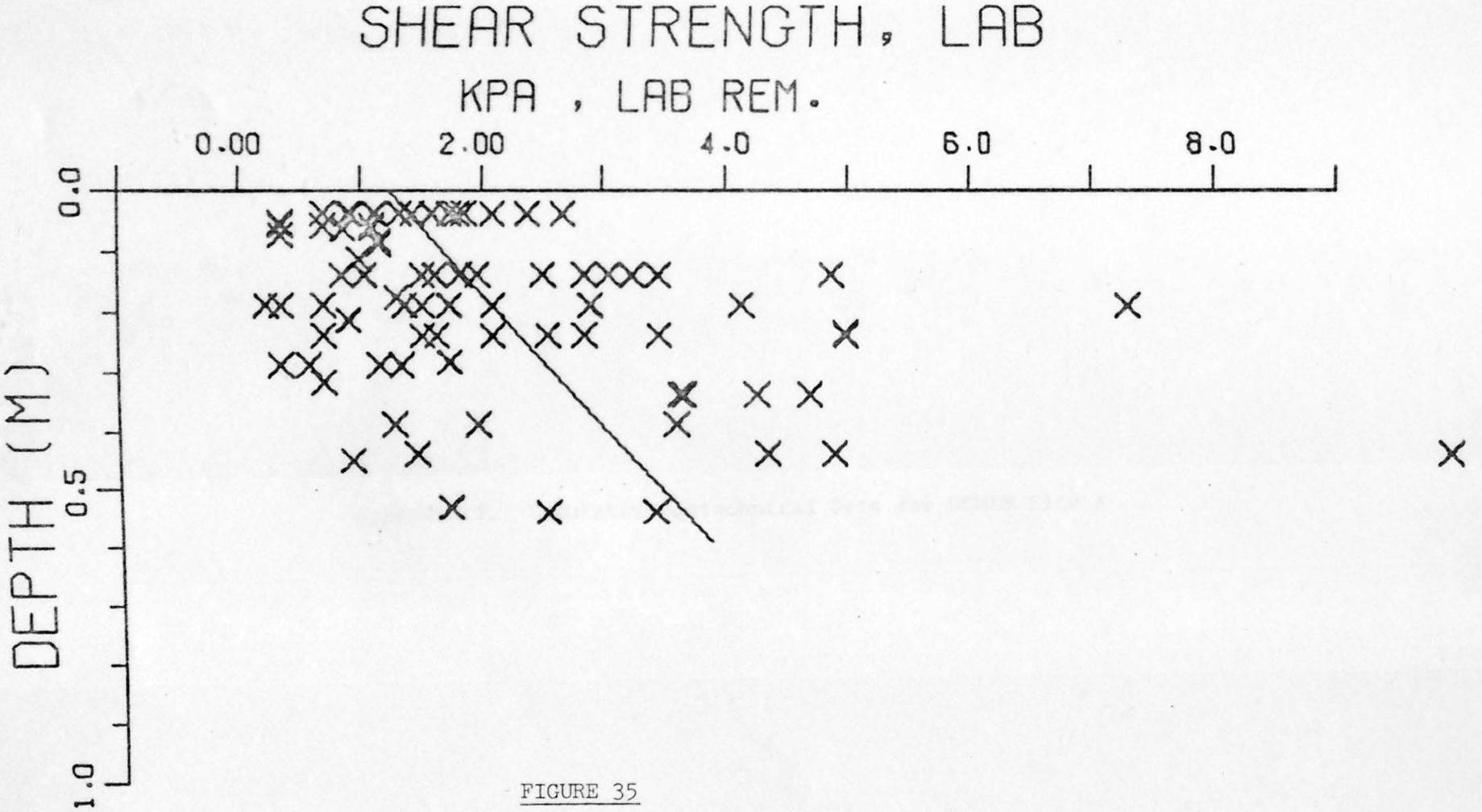


FIGURE 35

SITE C,DVI,DOMES1

EST VALUE = 1.241 + 4.505 X DEPTH (M)
STD ERROR OF EST = 1.539
CORR COEF = .374

Appendix 1. Tabulated Geotechnical Data for DOMES Site A

DOMES Site A

Core 46-1

Specific Gravity = 2.18 *

Depth, m	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m³	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
25					293	6.39	86									
50					282	6.15	86	166	69	97	2.2					
63					270	5.89	85									
75	25	0	8.2												31	
88					250	5.45	84					4.29	0.70	6.1		
125				1.23	245	5.34	84									
163					237	5.17	84									
188					244	5.32	84					6.26	1.51	4.1		
220				1.23	239	5.21	84									
225					235	5.12	84									
263					228	4.97	83									
288					277	6.04	86					8.58	2.55	3.4		
313					221	4.82	83	177	75	102	1.4				32	
325	16	1	8.2	1.24	223	4.86	83									
368					223	4.86	83									

* Values questionable, see text.

Core 46-5

Specific Gravity = 2.35 *

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					296	6.96	87									
38					357	8.39	89					15.89	5.45	2.9		
70	25	7	8.0		302	7.10	88	263	251	12	4.3				32	
75				1.17	321	7.54	88									
120					346	8.13	89								27	
138												23.90	2.67	9.0		

* Values questionable, see text.

Core 47-10

Specific Gravity = 2.29 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					394	9.02	90									
38					358	8.20	89					0.70	0.12	5.8		
75	20	0	8.0	1.20	288	6.60	87	174	68	106	2.1				34	
113					263	6.02	86									
138					260	5.95	86					6.15	1.39	4.4		
165					255	5.84	85									
203					256	5.86	85									
225				1.21	273	6.25	86									
238					288	6.60	87									
263					277	6.34	86									
288					294	5.82	85					6.94	0.81	8.6		
325					312	7.14	88									
363					306	7.01	88								34	
388	17	0	7.8		315	7.21	88	229	71	158	1.5	4.41	0.58	7.6		
413					306	7.01	88									
425				1.18												
438					317	7.26	88									
463					310	7.10	88									

* Values questionable, see text.

DOMES Site A

Core 47-14

Specific Gravity = 2.26 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					344	7.77	89									
38					363	8.20	89					0.46	0.06	7.7		
75	20	0	8.2	1.22	271	6.12	86	179	67	112	1.8				34	
113					252	5.70	85									
138					245	5.54	85					4.64	0.46	10.1		
175				1.24	236	5.33	84									
213					247	5.58	85									
225					247	5.58	85									
238					246	5.56	85					6.61	1.28	5.2		
275				1.26	241	5.45	84									
313					229	5.18	84									
338					236	5.33	84					6.50	1.04	6.3		
340					237	5.36	84	203	71	132	1.3				32	
365	16	0	7.9		237	5.36	84									
375				1.24	218	4.93	83									
415					238	5.38	84									

* Values questionable, see text.

DOMES Site A

Core 48-19

Specific Gravity = 2.08 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					368	7.65	88									
38					357	7.43	88					1,04	0.12	8.7		
75	28	0	8.5	1.18	313	6.51	87	181	69	112	2.2				33	
113					305	6.34	86									
138					270	5.62	85					4.29	0.93	4.6		
175				1.22	270	5.62	85									
200					272	5.66	85									
213					268	5.57	85									
238					271	5.64	85					3.71	0.70	5.3		
275				1.19	276	5.74	85									
313					307	6.39	86									
328					310	6.45	87	172	80	92	2.5				32	
338					313	6.51	87					4.29	0.46	9.3		
375	15	5	7.5	1.18	305	6.34	86									

* Values questionable, see text.

DOMES Site A

Core 49-25

Specific Gravity = 2.23*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					339	7.56	88									
38					312	6.96	87					1.97	0.35	5.6		
75	17	0	8.0	1.22	258	5.75	85	179	75	104	1.8				32	
113					225	5.02	83									
138					226	5.04	83									
175				1.23	242	5.40	84									
213					248	5.53	85									
238					238	5.31	84					6.38	4.99	1.3		
275				1.22	247	5.51	85									
313					239	5.33	84									
338					242	5.40	84					9.40	2.20	4.3		
375	12	0	8.0	1.22	247	5.51	85									
385					253	5.64	85	208	86	122	1.4				24	
425				1.22	251	5.60	85									
460					245	5.46	85									

* Values questionable, see text.

DOMES Site A

Core 50-28

Specific Gravity = 2.21 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					340	7.51	88									
38					283	6.25	86					1.51	0.35	4.3		
75				1.22	252	5.57	85	167	69	98	1.9				33	
113					233	5.15	84									
138					209	4.62	82					5.22	1.51	3.5		
175				1.26	210	4.64	82									
213					206	4.55	82									
238					198	4.38	81					4.64	2.90	1.6		
275				1.26	207	4.57	82									
313					183	4.04	80									
338					229	5.06	84					6.15	1.39	4.4		
375	30	0	8.5	1.23	236	5.22	84									
383					232	5.13	84	188	79	109	1.4				27	
413					242	5.35	84									
438					223	4.93	83					5.68	1.62	3.5		
458					245	5.41	84									

* Values questionable, see text.

Appendix 2. Tabulated Geotechnical Data for DOMES Site B

DOMES Site B

Core 51-33

Specific Gravity = 2.16 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					288	6.22	86									
38					258	5.57	85					9.28	3.25	2.9		
50					290	6.26	86	169	74	95	2.3					
75				1.16	322	6.96	87								33	
113					392	8.47	89									
138	25	8	8.0		397	8.58	90					9.74	7.89	1.2		
160					394	8.51	89	200	77	123	2.6					
175				1.01	393	8.49	89									
220					398	8.60	90									

* Values questionable, see text.

DOMES Site B

Core 52-37

Specific Gravity = 2.18*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13					355	7.74	89									
38					315	6.87	87					0.93	0.12	7.8		
75	18	0	8.2	1.22	266	5.80	85	162	69	93	2.1				33	
113					250	5.45	84									
138					246	5.36	84					4.29	0.82	5.2		
175				1.25	239	5.21	84									
213					242	5.28	84									
238					248	5.41	84					2.67	0.58	4.6		
250					238	5.19	84									
275				1.22	236	5.14	84									
313					233	5.08	84									
338					230	5.01	83					6.38	1.62	3.9	31	
375	20	0	8.6	1.26	212	4.62	82									
380					217	4.73	83	197	75	122	1.2					
413					229	4.99	83									
438					228	4.97	83					3.60	1.04	3.5		
455					236	5.14	84									

* Values questionable, see text.

DOMES Site B

Core 52-39 Bag Sample* (No Core)

Specific Gravity =

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
A					222			138	68	70	2.2				23	
B					229											

* The depth the sample was collected from the box core is not known. Two samples were selected from the material in the bag for testing.

DOMES Site B

Core 52-42

Specific Gravity = 2.18 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, * %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					342	7.46	88									
38					325	7.09	88					0.81	0.23	3.5		
75	3	5	8.0	1.21	288	6.28	86	169	78	91	2.3				32	
113					290	6.32	86									
138					261	5.69	85					4.06	1.16	3.5		
175				1.24	239	5.21	84									
213					231	5.04	83									
238					228	4.97	83					6.96	2.44	2.9		
250					236	5.14	84									
275				1.24	233	5.08	84									
313					242	5.28	84									
338					250	5.45	84					4.87	1.28	3.8		
375					244	5.32	84									
405	15	0	8.3		243	5.30	84	187	77	110	1.5				29	
413					242	5.28	84									
438					239	5.21	84					5.34	1.39	3.8		
475				1.25	228	4.97	83									
505					233	5.08	84									

* Values questionable, see text.

DOMES Site B

Core 53-45

Specific Gravity = 2.29*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13					340	7.79	89									
38					332	7.60	88					0.40	0.05	8.0		
75	5	21	7.8	1.23	305	6.98	87	185	64	121	2,0				34	
113					264	6.05	86									
138					233	5.34	84					4.00	1.40	2.9		
175				1.24	224	5.13	84									
213					236	5.40	84									
238					231	5.29	84					5.90	1.60	3.7		
275				1.25	239	5.47	85									
313					246	5.63	85									
338					223	5.11	84					5.50	1.80	3.1		
375	14	0	8.0	1.25	234	5.36	84	222	76	146	1,1				32	
413					219	5.02	83									
418												2.70	1.50	1.8		
438					245	5.61	85									

* Values questionable, see text.

DOMES Site B

Core 54-5I

Specific Gravity = 2.24 *

Depth, mm	% < 2μm	% > 60μm	Median grain diam., φ	Bulk density, Mg/m³	Water Content, % dry weight *	Void ratio *	Porosity, % *	Liquid Limit, %	Plastic Limit, %	Plasticity index, %	Liquid-ity index,	Shear strength, undist., KPa	Shear strength remolded, KPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13					288	6.45	87									
38					252	5.64	85					2.40	0.70	3.4		
75	20	5	8.2	1.24	222	4.97	83	173	67	106	1.5				33	
113					228	5.11	84									
138					220	4.93	83					6.40	2.20	2.9		
175				1.25	216	4.84	83									
213					223	5.00	83									
238					232	5.20	84					5.00	1.20	4.2		
275				1.24	234	5.24	84									
313					223	5.00	83									
338					223	5.00	83					7.90	2.10	3.8		
375	14	0	8.0	1.24	234	5.24	84	206	74	132	1.2				32	
413					219	4.91	83									
433												5.00	1.00	5.0		
438					221	4.95	83									

* Values questionable, see text.

* Values descriptors, see text.

+ Value surface

mm depth,	% < 2um	20um %	grain %	weight %	MN/m^2, Kjb	* Water retention, %			Primary porosity, %	Time, hr	Time, %	Secondary porosity, %	Total porosity, %	Pore size distribution, %	Pore size - micrometers	Surface area, m^2/g	Surface activity, kJ/mol	Cation exchange capacity, meq/100g
12				587	0.098	47												
28																		
42	18	30	1.7	554	2.17	44	180	68	112	1.4				0.50		8.80		
113				508	4.80	82												
128				512	4.67	82								3.18				
142			1.54	500	4.65	85												
158				503	4.44	85												
172				505	4.39	85												
228				508	4.35	85												
232				510	4.39	81	184	63	121	1.1				15.50				
243				510	4.39	81												
282																		
272	7	16	1.9	502	4.20	85												
238			1.58	503	4.42	85												
213				505	4.44	85												
172			1.54	500	4.65	85												
138				512	4.67	82												
113				508	4.80	82												
72	18	30	1.7	554	2.17	84	180	68	112	1.4				0.50		8.80		
38																		
12				589	0.098	87												

Core 22-22

Specific Gravity = 2.21*

DOMES Site B

14.

Appendix 3. Tabulated Geotechnical Data for DOMES Site C

Core 3-5

Specific Gravity = 2.28*

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio*	Porosity,* %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
10					172	3.92	80									
33					177	4.04	80									
50	14	3	8.0	1.32	171	3.90	80	136	85	51	1.7				34	
58												2.90	0.70	4.1		
73					165	3.76	79									
125					164	3.74	79									
163					176	4.01	80									
188					158	3.60	78					4.06	0.23	17.6		
225				1.34	153	3.49	78									
263					159	3.63	78								24	
268	11	0	8.0		158	3.60	78	123	78	45	1.8					
288					157	3.58	78					2.67	0.58	4.6		
318				1.33	150	3.42	77									

* Values questionable, see text.

Core 5-10

Specific Gravity = 2.06*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
17					218	4.49	82									
47					211	4.35	81									
50	13	5	7.7		219	4.51	82	155	89	66	2.0					
73												1.97	0.35	5.6		
80					227	4.68	82									
125				1.33	156	3.21	76									
163					137	2.82	74									
173	25	2	8.1		134	2.76	73	130	111	19	1.2				36	
188					130	2.68	73					13.46	2.09	6.4		

* Values questionable, see text.

Core 6-18

Specific Gravity = 2.64 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					192	5.07	84									
38					193	5.10	84					1.74	1.74	1.0		
50	28	0	8.5		186	4.91	83	136	100	36	2.4					
75				1.30	179	4.73	83									
125					186	4.91	83									
138												5.34	1.51	3.5		
150															37	
175				1.29	182	4.80	83									
225					185	4.88	83									
238												6.73	2.09	3.2		
260	10	4	8.0		192	5.07	84	141	84	57	1.9				35	
275				1.28	198	5.23	84									
310					185	4.88	83									

* Values questionable, see text.

OMES Site C

ore 9-21

pecific Gravity = 2.37 *

epth, m	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
10					201	4.76	83									
33					213	5.05	83									
50	45	0	8.5		201	4.76	85	110	76	34	3.7				33	
58												1.51	0.35	4.3		
73				1.31	188	4.46	82									
125					181	4.29	81									
163					171	4.05	80									
188					171	4.05	80					2.90	0.35	8.3		
225				1.33	160	3.79	79									
260	17	0	8.2		158	3.74	79	129	71	58	1.5				32	
263					155	3.67	79									
288					157	3.72	79					2.67	0.35	7.6		
310					152	3.60	78									

* Values questionable, see text.

Core 11-53a

Specific Gravity = 2.32*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
23					180	4.18	81									
58					170	3.94	80									
75	15	0	8.4		166	3.85	79	125	65	60	1.7				32	
83												4.81	1.16	4.1		
85					161	3.74	79									
125				1.36	145	3.36	77									
163					134	3.11	76									
188					138	3.20	76					5.34	1.51	3.5		
225				1.37	135	3.13	76									
263					137	3.18	76									
283					138	3.20	76									
325				1.38	139	3.22	76									
363					145	3.36	77									
375	10	0	7.8		144	3.34	77	121	63	58	1.4				33	
388					143	3.32	77					4.52	3.60	1.3		
413					129	2.99	75									
425				1.37												
438					138	3.20	76									

* Values questionable, see text.

Core 11-53b

Specific Gravity = 2.20 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate %
20					187	4.11	80									
50	20	0	8.4		183	4.03	80	104	58	46	2.7				34	
53					178	3.92	80					1.39	0.35	4.0		
83					170	3.74	79									
125				1.35	152	3.34	77									
163					139	3.06	75									
188					135	2.97	75					3.36	0.70	4.8		
225				1.38	133	2.93	75									
263					134	2.95	75	113	58	55	1.4				32	
268	18	0	8.0									2.67	1.16	2.3		
288					133	2.93	75									
318				1.37	136	2.99	75									

* Values questionable, see text.

DOMES Site C

Core 18A-36a

Specific Gravity = 2.45*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
25					215	5.27	84									
50	15	0	8.1		206	5.05	84	126	83	43	2.9				32	
63					197	4.83	83									
88					205	5.02	83					4.87	1.16	4.2		
125				1.26	222	5.44	84									
163					190	4.66	82									
173					187	4.58	82	178	114	64	1.1				33	
188	7	0	8.0		184	4.51	82					21.58	7.31	3.0		
223					192	4.70	82									
225				1.28												

* Values questionable, see text.

DOMES Site C

Core 18A-36b

Specific Gravity = 2.38 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13					207	4.93	83									
38	1	8	8.0		209	4.93	83					1.04	0.70	1.5	35	
50					210	5.00	88	195	68	127	1.1					
75				1.27	211	5.02	83									
113					234	5.57	85									
138					205	4.88	83					6.15	1.97	3.1		
170					194	4.62	82	170	139	31	1.8				35	
175					183	4.36	81									
220					202	4.81	83									

* Values questionable, see text.

Core 18B-37

Specific Gravity = 2.29*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, %*	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
20					209	4.79	83									
38					193	4.42	82									
50	20	0	7.9													
58					192	4.40	81					3.66	1.10	3.3		
75					197	4.51	82	114	95	19	5.4					
85	12	0	7.7		202	4.63	82									
125				1.32	161	3.69	79									
188												5.52	1.37	4.0		
190					188	4.31	81									
225				1.25	213	4.88	83									
288					345	7.90	89					6.44	1.34	4.8		
325				1.14	392	8.98	90									
390	12	0	8.0		476	10.90	92	275	134	141	2.4	10.04	1.97	5.1		
420					415	9.50	90									

* Values questionable, see text.

DOMES Site C

Core 20-27a

Specific Gravity = 2.46 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					175	4.31	81									
38					168	4.13	81									
50					163	4.01	80	122	62	60	1.7				34	
63					157	3.86	79					3.94	0.87	4.5		
75	25	0	8.5													
88					151	3.71	79									
125				1.36	135	3.32	77					5.45	1.74	3.1		
233					135	3.32	77									
240				1.38												
325				1.38	134	3.30	77									
353	8	0	8.2		131	3.22	77	107	69	38	1.6				34	
363					127	3.12	76					4.99	1.28	3.9		
390					126	3.10	76									

* Values questionable, see text.

Core 20-27b

Specific Gravity = 2.24*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					182	4.08	80									
38					176	3.94	80									
50					164	3.67	79	117	70	47	2.0				32	
63												4.18	1.10	3.8		
75					152	3.40	77									
125				1.36	147	3.29	77									
150	4	0	8.1													
163					137	3.07	75									
188					140	3.14	76									
225				1.38	132	2.96	75					5.10	1.74	2.9		
258					131	2.93	75	107	67	40	1.6				33	
263					129	2.89	74									
288					123	2.76	73									
308					122	2.73	73									

* Values questionable, see text.

DOMES Site C

Core 24B-29a

Specific Gravity = 2.15*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					201	4.32	81									
38					178	3.83	79					6.15	1.86	3.3		
50					180	3.87	80	139	71	68	1.6				34	
75				1.30	182	3.91	80									
138					191	4.11	80					5.22	1.62	3.2		
150	17	0	8.3													
175				1.29	189	4.06	80									
213					178	3.83	79									
238					177	3.81	79					7.89	1.51	5.2		
268					178	3.83	79	143	58	85	1.4				34	
270				1.30												
275					178	3.83	79									
318					180	3.87	79					5.57	0.70	8.0		

* Values questionable, see text.

Core 24B-29b

Specific Gravity = 2.29*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13					201	4.60	82									
38					189	4.33	81					2.55	0.93	2.7		
50					188	4.31	81	131	63	68	1.8				34	
75				1.29	187	4.28	81									
113					187	4.28	81									
138					192	4.40	81					3.02	1.04	2.9		
150	18	0	8.8													
175				1.30	183	4.19	81									
213					184	4.21	81									
230					181	4.14	81	121	63	58	2.0				34	
238					178	4.08	80					3.02	0.70	4.3		
255					178	4.08	80									

* Values questionable, see text.

CHAPTER 3

Geotechnical Testing of Deepsea Ventures Box Cores Collected from Pelagic Nodule Area, Central Northeast Pacific Ocean

Final Report

Grant No. 14-08-0001-G-256

to the U.S. Geological Survey

by

Adrian F. Richards

Marine Geotechnical Laboratory

Lehigh University, #17

Bethlehem, PA 18015

June 1977

ABSTRACT

Core subsamples from 12 box cores raised by Deepsea Ventures, Inc. (DVI), personnel on Deepsea cruises to their mine site (DOMES Site C) were geotechnically analyzed in the Marine Geotechnical Laboratory (MGL) of Lehigh University. In addition, the salinity of pore-water squeezed from the core samples and the calcium carbonate content was determined.

Results are reported in the MGL computer-plotter graphical format in which individual measured and calculated geotechnical and geochemical properties are plotted against depth below the top of the core. Tabular data are presented in an appendix. Samples from three cores were tested by isotropically-consolidated undrained ($\overline{ICU}$) triaxial tests, in which a stress-path analysis yielded an effective cohesion intercept of 5.1 kPa and an effective angle of internal friction of 21.3°. A one-dimensional consolidation test resulted in the following compressional characteristics of the sample: a compression index of 3.3, an overconsolidation ratio of 49, and a coefficient of consolidation ranging from about 50 to 175 nm^2/s. Predictor equations for key geotechnical properties were generated from combined DVI core and DOMES Site C core data.

Mineralization was discovered in core 54P-8, which was geotechnically characterized by high values of Atterberg limits, water content, and shear strength. It is postulated that the mineralized area is located near 125° 58' W. longitude, and extends at least from about 14° 58' to 15° 12' N. latitude; it occurs nearer the surface of the seafloor in the south.

INTRODUCTION

This report presents the results of geotechnical analyses made in the Marine Geotechnical Laboratory (MGL), Lehigh University, of cores collected by Deepsea Ventures, Inc., (DVI), personnel on Deepsea Ventures cruises to their mine site. This location includes the Deep Ocean Mining Environmental Study (DOMES) Site C.

Through an informal cooperative agreement between DVI and Lehigh personnel, box cores raised from the DVI R/V Prospector (Table 1) were subsampled by DVI personnel using polyvinyl chloride (PVC) core tubes and bronze o-ring core-tube sealers provided by the MGL. Each 107-mm-I.D. PVC tube was externally sharpened at one end and very lightly coated inside and out with silicone grease before it was carefully inserted into the sediment contained within a DVI box core. After the tube ends were sealed with the sealers, and the vessel had returned to port, the cores were wrapped and packed in cases to minimize shock and vibration together with enough ice to insure refrigeration for 24 hours while the cases were air freighted to Bethlehem, PA. At the MGL, the cores were stored in high relative humidity at a temperature of about 5° C until they were tested.

LABORATORY PROCEDURES

The cores, within the unopened liners, were first x-rayed and nondestructively analyzed for bulk density, using a fine-focus

industrial-type x-ray machine and the Lehigh nuclear transmission densitometer. Results of these investigations are not reported.

Geotechnical and geochemical tests were performed using the methods listed in Table 2, in which ASTM refers to the American Society for Testing and Materials (1975). Some data were calculated, these are listed in Table 3.

In Appendix 1, a number of low specific gravity values are questionable. A weak aspirator was not discovered until towards the end of the testing program, with the result that the water used in this test was not properly deaired. It is highly doubtful if any specific gravity values less than about 2.65 are valid. The specific gravity values known to be good were about 2.70.

Three triaxial tests were performed on 54-mm-diameter samples carefully trimmed from selected core sections. The isotropically-consolidated undrained ($\overline{ICU}$) with pore-pressure tests were performed under a backpressure of 690 kPa to saturate the samples and at a constant strain rate.

A one-dimensional consolidation test was made on one sample. This sample was back pressured and loads were applied every 24 h for five days. Difficulties in maintaining a constant backpressure was encountered, which resulted in inaccuracies of consolidation pressure about ±20% of measured values. Although the preconsolidation pressure, σ_p', calculated from the e log p curve may be

suspect, it is believed that the values of the coeficient of consolidation, C_c, and the compression indices, c_v, were relatively unaffected. The estimated effective overburden pressure, σ_{vo}, was calculated assuming a seawater density of 1.025 Mg/m^3.

After laboratory analysis, the data were tabulated and entered on punched cards in the standardized format of the geotechnical data bank. One method of output was to generate a CalComp plot of each measured and computed parameter against depth in the core. The basic computer-plotter program was described by Mann and Semple (1970); subsequently, the program was modified and adapted to the Lehigh University CDC 6400 computer. Symbols used in the individual plots are listed in Table 4.

A second method of output was to plot individual geotechnical properties obtained from all cores grouped together against depth. Data from the DOMES Site C cores (Richards, 1977) are grouped with the DVI cores. In each CalComp plot, a linear least-squares regression line, or predictor equation, was computer-fitted to the plotted values.

RESULTS

Graphs of geotechnical properties plotted against depth for each core are given in Figs. 1-4. Tabular data for the DVI cores are given in Appendix 1.

Table 5 lists predictor equations and related statistical

data for the DOMES Site C and DVI cores grouped together. Graphs showing the data and the regression line are presented elsewhere (Richards, 1977).

Effective stress paths resulting from the $\overline{ICU}$ triaxial tests are shown in Fig. 5, and relevant test data are summarized in Table 6.

The consolidation void ratio-log of effective overburden pressure (e log p) plot (Fig. 6) assumes that no excess pore pressure was present. The overconsolidation ratio, OCR, while unusually high is fairly typical for samples taken from just below the seafloor (Richards, 1976).

DISCUSSION

It is believed that the tops of a few cores were desiccated when they were tested at the MGL. Through the cooperation of Dr. Hagerty, box core 53P-5 was sampled at close depth intervals at sea for special water content tests to be performed as soon as possible after the ship had returned to port. These samples were sealed and analyzed at the MGL for water content immediately upon receipt. Comparison of these water content values with values obtained when the PVC core 53P-C-5 was analyzed in the laboratory shows that the later samples had lower water contents, particularly near the top of the core. It is noteworthy that core 53P-C-5 was analyzed in the laboratory almost one year after it was received.

A second core, 53P-9, also was specially analyzed for water content, but a regular core was not collected.

It was not possible to obtain three high-quality contiguous samples from one core for triaxial testing; consequently, one sample was taken from each of three cores as closely as possible to the same depth below the top of the core (Table 6). Core 50P-2 was collected at a considerable distance from the other two cores (Table 1). While core 50P-2 has a lower specific gravity and somewhat different index properties, it is believed that the data presented in Table 6 and Fig. 5 are reasonable. The desiccation previously reported for the top of core 50P-2 is believed not to extend significantly to the core depths sampled for the triaxial test.

A discussion of the predictor equations (Table 5) for DVI and DOMES Site C cores is given elsewhere (Richards, 1977).

Core 54P-8 was found to contain mineralized sediment, which previously had been discovered in DOMES Site C core 18B-37. The geotechnical indicators of mineralization are unusually high water contents, Atterberg limits, and shear strength (Figure 4 and Appendix 1). The sediment appears dry, despite the high water content, and has a mottled appearance. Just below the mineralized zone the unusually high, for this region of siliceous pelagic clay, calcium carbonate value of 66% was measured.

It is noteworthy that the mineralized DOMES and DVI cores

are located at the same longitude, but have different latitudes. Because the DVI core is located farther south than the DOMES core, and has mineralization closer to the surface of the seafloor, it is speculated that the area of mineralization in this region extends north-south and occurs closer to the surface in the south.

ACKNOWLEDGEMENTS

The high degree of unselfish cooperation shown by Mr. R. Kaufman, Dr. R. Hagerty, and other Deepsea Ventures, Inc., personnel made this investigation possible. Most of the cores were raised, subsampled, packed for shipment, and shipped at DVI expense by Dr. Hagerty or under his direction. I am particularly grateful for the use of some of the DVI shipboard data, locations of the cores, and permission to publish the results.

The many students who assisted in the laboratory analyses and data reduction at Lehigh are acknowledged with appreciation. S. C. Helfrich and D. Volk supervised the laboratory work and G. Abdelnour did most of the computer-plotter work. P. Lemmond made the consolidation test. The triaxial tests were made by Woodward-Clyde Consultants, Plymouth Meeting, PA, when our equipment could not be readied in time.

This research was sponsored in major part by the U.S. Geological Survey, Department of Interior, under Grant No. 14-08-0001-G-256.

REFERENCES

American Society for Testing and Materials, 1975, 1975 annual book of ASTM standards, part 19, natural building stones; soil and rock; peats, mosses, and humus: Philadelphia, American Soc. Test. Mat., 476 p.

Mann, C. J., and Semple, R. M., 1970, Computer reduction and plotting of marine sediment data: Jour. Marine Tech. Soc., v. 4, p. 53-57.

Richards, A. F., 1976, Marine geotechnics of the Oslofjorden region, in Janbu, N., Jørstad, F., and Kjaerasli, B., eds., Laurits Bjerrum memorial volume; contributions to soil mechanics: Oslo, Norwegian Geotechnical Inst., p. 41-64.

Richards, A. F., 1977, Geotechnical testing of U.S. Geological Survey cores collected from the pelagic nodule area, central northeast Pacific Ocean: unpub. Final Rept., U.S. Geol. Survey, Grant No. 14-08-0001-G-257.

Richards, A. F., Hirst, T. J., and Parks, J. M., 1976b, Preliminary geotechnical properties northeast central Pacific nodule mining area, in Bischoff, J. L., and others, 1976, Deep ocean mining environmental study, NE Pacific nodule province, site C, geology and geochemistry: U.S. Geol. Survey Open-file Rept. 76-548, p. 81-94.

Richards, A. F., and Parks, J. M., 1977, Geotechnical predictor equations for east central North Pacific nodule mining area sediments: Offshore Tech. Conf. Proc., v. 1, p. 377-386.

Table 1. Location of Geotechnical Property Cores: Deepsea Ventures, Inc.

Core No.	N. Lat.	W. Long.	Water Depth, m corrected	Date Collected	Date Analyzed
DVI Cruise 1: Site C					
50P-1	15° 38.5'	125° 47.0'	4469	August 29, 1975	March 5, 1976
50P-2	14° 58.6'	127° 43.8'	4668	August 30, 1975	February 9, 1977
50P-3	15° 00.5'	124° 28.0'	4405	August 30, 1975	March 24, 1976
50P-5	14° 52.1'	125° 26.9'	4396	September 12, 1975	February 23, 1976
50P-6	14° 52.2'	125° 27.7'	4373	September 13, 1975	February 20, 1976
50P-8	14° 45.8'	125° 27.3'	4370	September 14, 1975	March 10, 1976
50P-9	14° 45.6'	125° 31.6'	4479	September 14, 1975	March 10, 1976
50P-10	14° 17.8'	125° 47.5'	4369	September 15, 1975	February 19, 1977
50P-11	14° 49.3'	125° 34.3'	4369	September 15, 1975	February 12, 1977
50P-13	14° 51.4'	125° 33.2'	4407	September 15, 1975	March 3, 1976
53P-C-5	14° 40.6'	125° 29.2'	4440	January 28, 1976	February 19, 1977
53P-5 (mini-core)	14° 40.6'	125° 29.2'	4440	January 28, 1976	February 9, 1976
53P-9 (mini-core)	14° 44.8'	125° 35.9'	4442	January 29, 1976	February 9, 1976
54P-8	14° 58.5'	125° 58.0'	4363	February 27, 1976	February 21, 1977

Table 2. Marine Geotechnical Laboratory Test Methods

Parameter	Method	Notes & Reference
Grain Size, Unit Weight, and Consistency		
Grain size	ASTM 422-63	ASTM D2217 preparation
Grain specific gravity	ASTM 854-28	
Bulk density (wet unit weight)	Weight/volume	Volume = 23 cm^3; no salt correction
Water content	ASTM 2216-71	No salt correction
Liquid limit	ASTM 423-66	Not sieved nor dried; no salt correction
Plastic limit	ASTM 424-59	Not sieved nor dried; no salt correction
Shear Strength		
Laboratory vane test	Motorized vane, 1.3 x 2.5 cm, rotated at 23 mrad/s	
Triaxial test	ASTM 2850-70	$\overline{\text{ICU}}$
Consolidation		
One-dimensional test	ASTM 2435-70	Back pressure applied to saturate sample
Chemical Properties		
Calcium carbonate	Gasometric	Müller & Gastner (1971)
Pore-water salinity	Index of refraction	A. O. refractometer

Table 3. Calculated Geotechnical Properties

Property	Symbol	Calculation	Notes
Void ratio	e	$e = \frac{Gw}{100}$	Assumed 100% saturation
Porosity	n	$n = \frac{e}{1+e}\ (100)$	
Liquidity index	I_L	$I_L = \frac{w - w_p}{I_p}$	
Plasticity index	I_p	$I_p = w_L - w_p$	

Table 4. List of Symbols Used on Marine Geotechnical Laboratory Calcomp Graphs

Name	Calcomp Symbol	Notes
Test interval	=	
Void ratio	+	
Porosity	+	
Grain size, % >62μm	z	
Grain size, % <2μm	■	
Median diameter, phi	△ or ▶	$\phi = -\log_2$ diam. in mm
Specific gravity	x	
Bulk density	◇ or ♥	$Mg/m^3 = \frac{\text{measurement}}{1000} = g/cm^3$
Water content (% dry weight)	○ or ●	symbol w
Liquid limit	y or ≺	
Plastic limit	⌑ or ⧗	
Shear strength (lab vane undisturbed)	⊡	symbol τ
Shear strength (lab vane remolded)	⊙	symbol τ
Sensitivity (undist./remolded)	⧗	
Effective overburden pressure		not plotted, see text
Shear strength/effect. overburden press.(c/p)		not plotted
Salinity (°/₀₀)	■	
Calcium carbonate	+	
Organic carbon		not measured
Sulfate		not measured

Table 5. Geotechnical Predictor Equations: DOMES Site C, Including Deepsea Ventures Core Data (27 Cores)

Parameter	Predictor Equation[1]	Standard Error of Estimate	Correlation Coefficient	Number of Data
Grain Size, % >62μm	8.523 - .264 x z	12.264	-.003	45
Grain Size, % <2μm	18.994 - 12.227 x z	9.342	-.192	45
Median Grain Size, ϕ	8.149 - .223 x z	.340	-.097	45
Bulk Density, Mg/m^3	1.289 + .071 x z	.048	.179	73
Water Content, % dry weight	189.751 - 49.810 x z	39.279	-.173	343
Liquid Limit, %	133.459 + 3.312 x z	27.221	.019	53
Plastic Limit, %	77.737 - 4.123 x z	22.794	-.028	54
Shear Strength, undist., kPa	4.493 + 18.517 x z	4.948	.459	80
Shear Strength, remold., kPa	1.241 + 4.505 x z	1.539	.374	80

[1] z = depth below seafloor in meters.

Table 6. Results of $\overline{ICU}$ Triaxial Tests on Deepsea Ventures Cores

Core	Depth, m	w, % dry weight initial	w, % dry weight final	S_r, %	σ_c, kPa	$\frac{\sigma_1'-\sigma_3'}{2}$ max., kPa	c', kPa	ϕ', degrees
50P-2	0.2 -0.4	163	142	96	24	10.5	5.1	21.3
50P-11	0.25-0.43	157	116	95	48	16.1		
50P-10	0.2 -0.38	168	117	97	96	31.1		

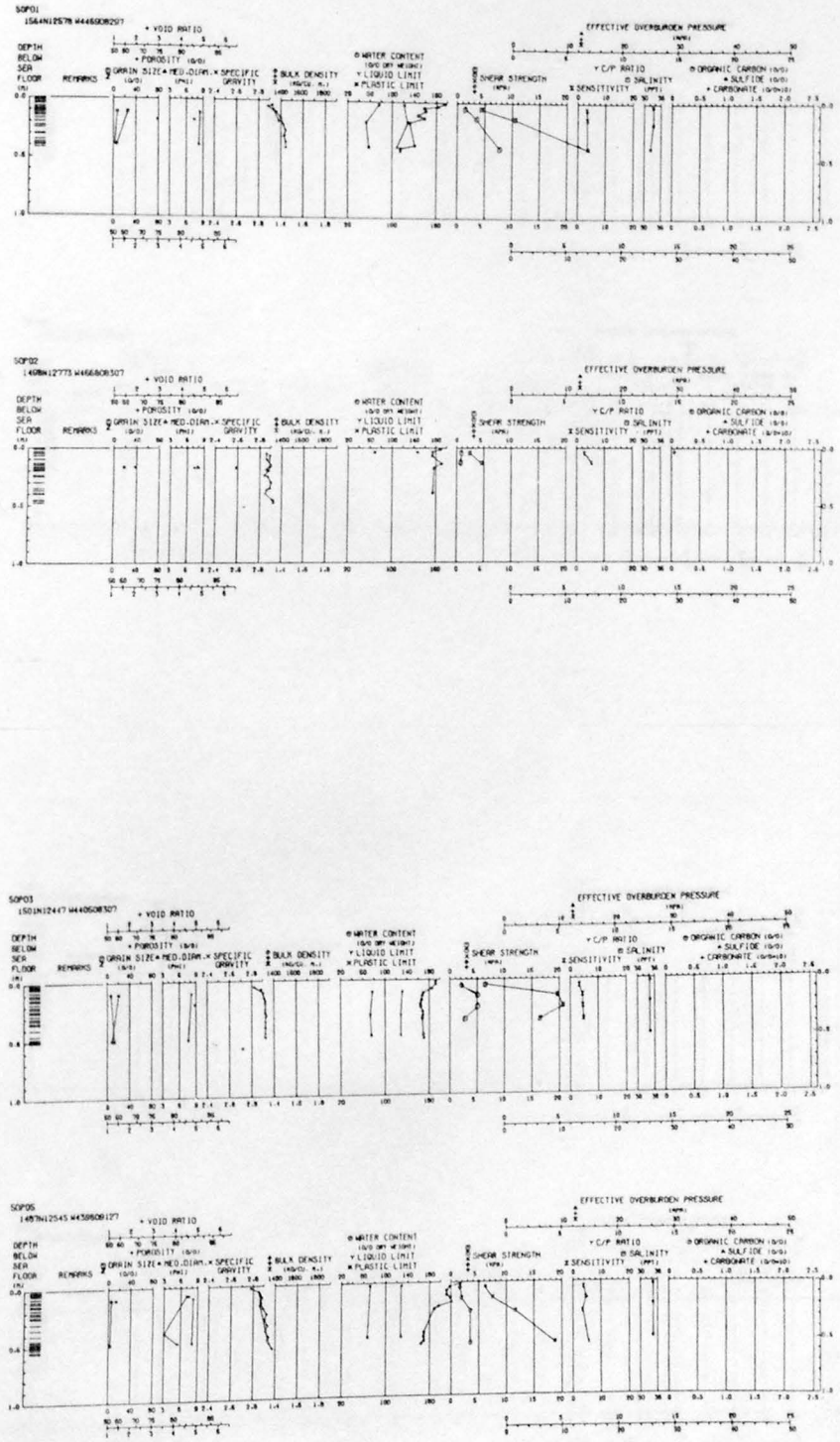


Figure 1. Geotechnical properties
of cores from Deepsea Ventures mining claim and Site C

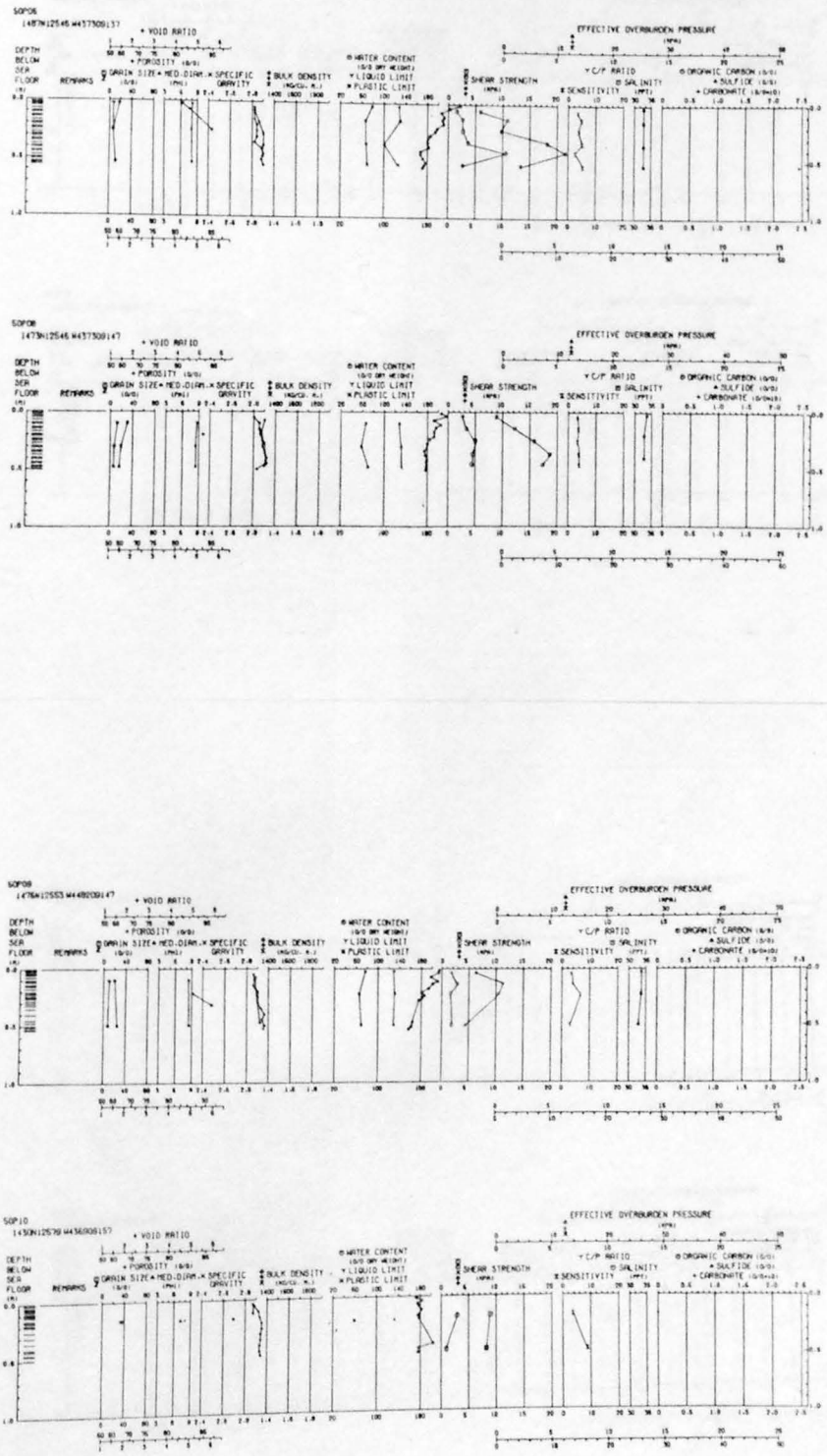


Figure 2. Geotechnical properties
of cores from Deepsea Ventures mining claim and Site C

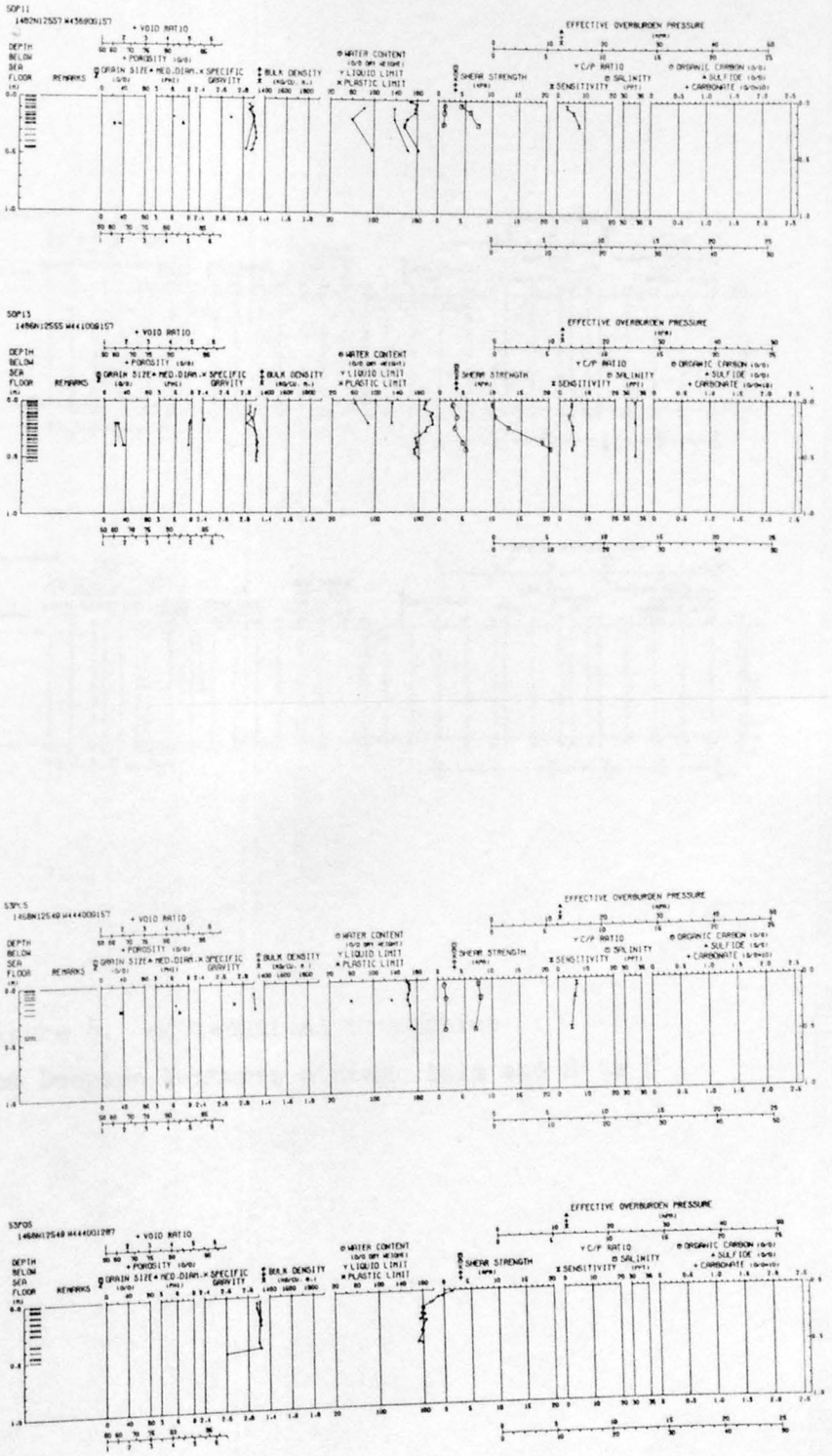


Figure 3. Geotechnical properties of cores from Deepsea Ventures mining claim and Site C

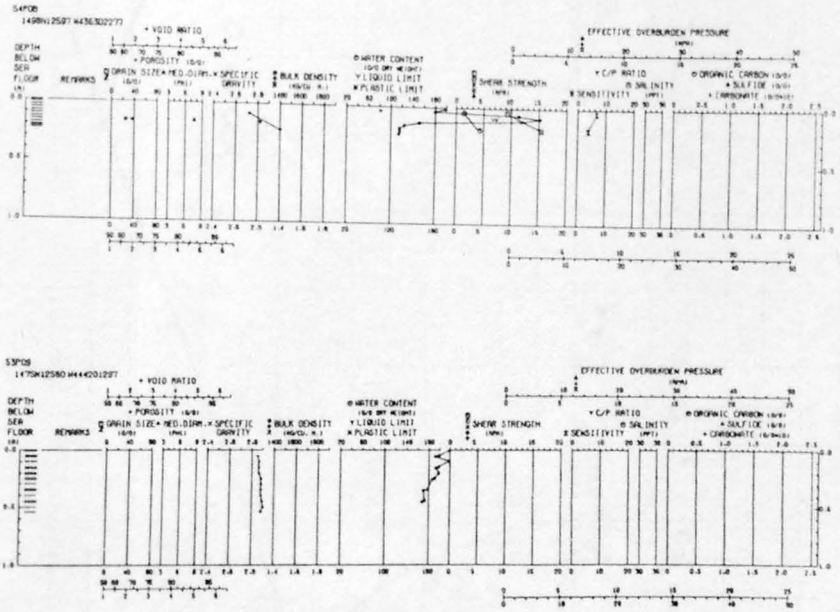


Figure 4. Geotechnical properties
of cores from Deepsea Ventures mining claim and Site C

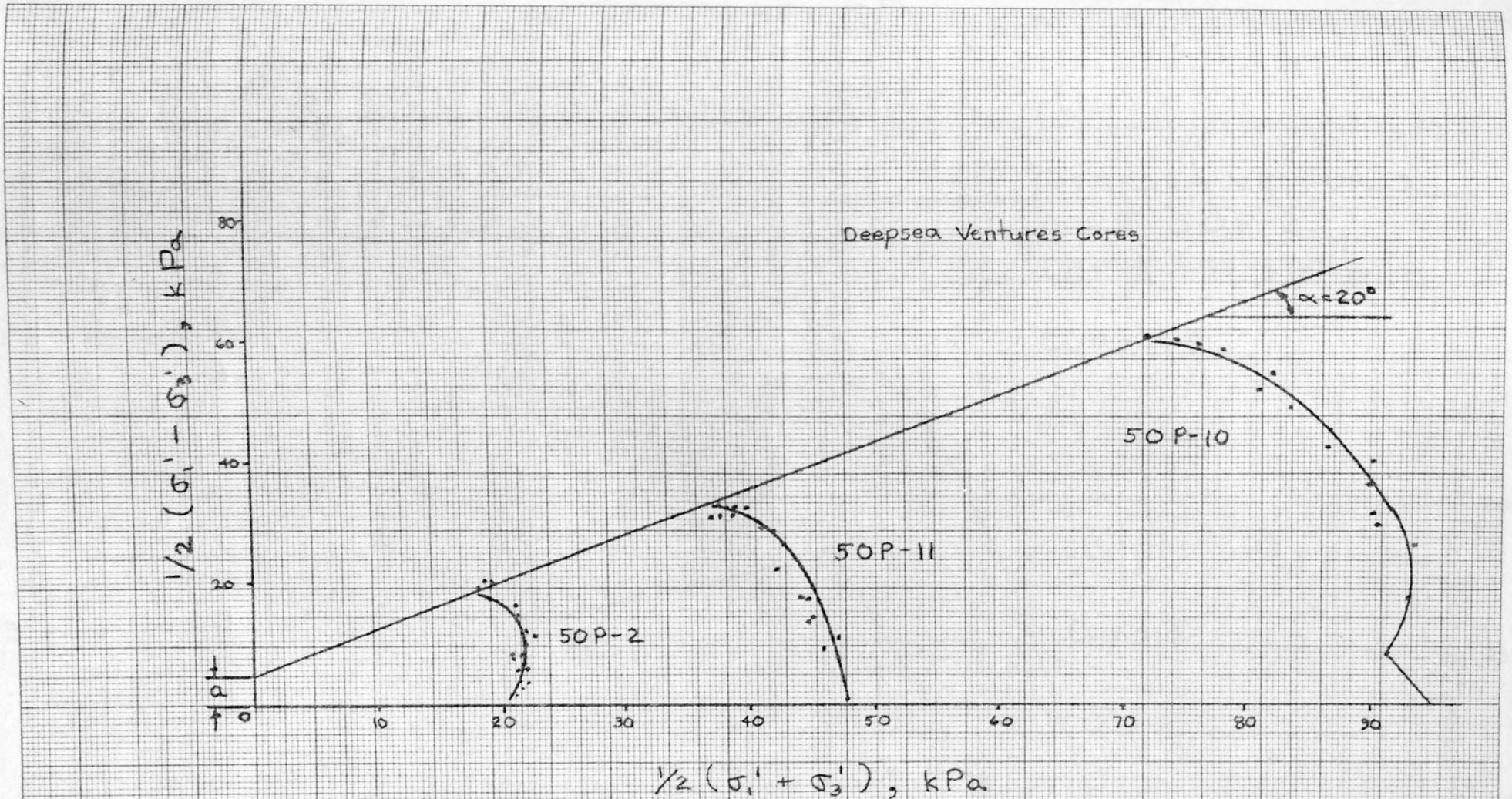


FIGURE 5. Effective stress paths for Deepsea Ventures cores 50P-2, 50P-11, and 50P-10. Note: $\sin \phi' = \tan \alpha'$ and $c' = a'/\cos \phi'$

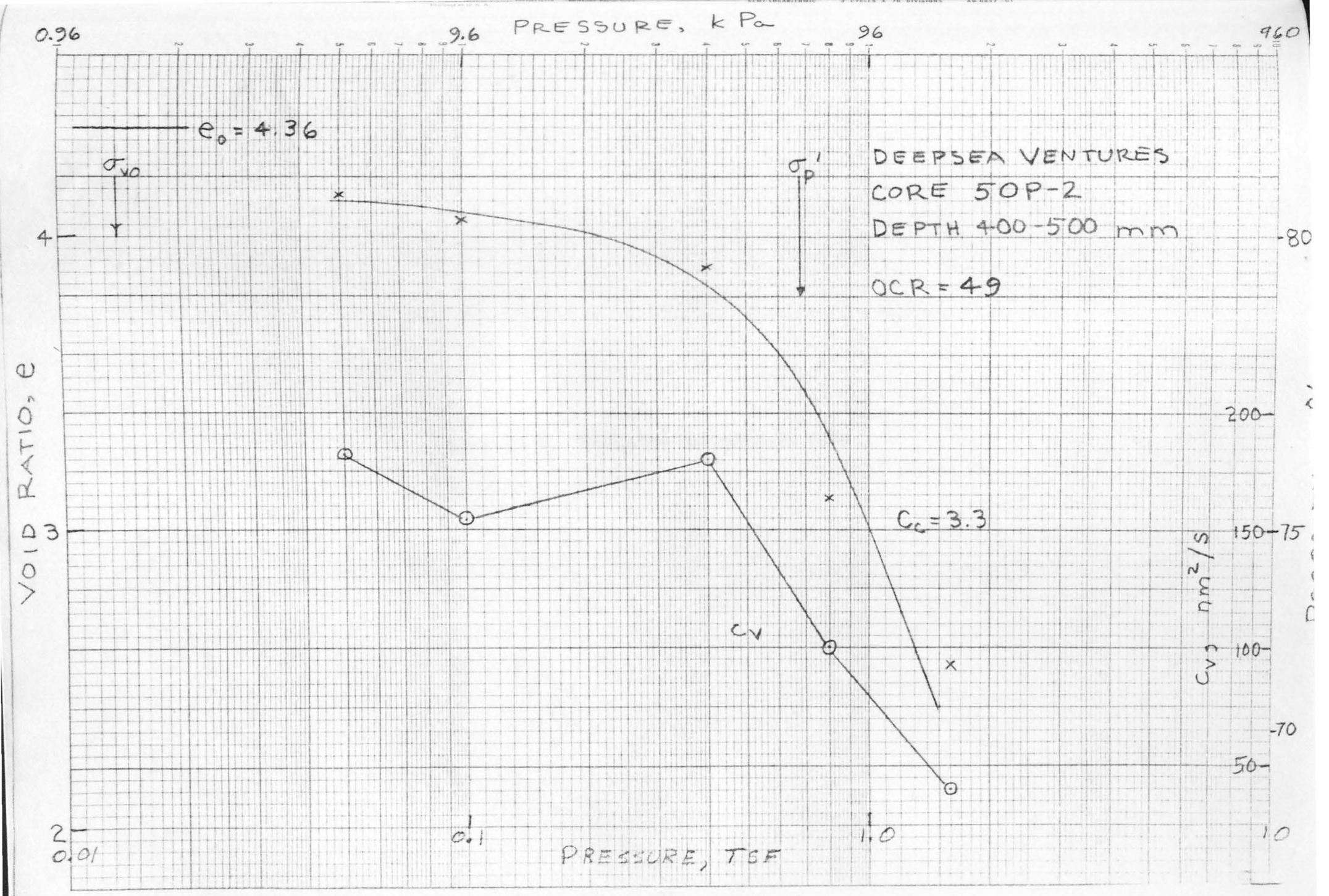

0.96
9.6
PRESSURE, k Pa
96
960
$e_o = 4.36$
σ_{vo}
σ_p'
DEEPSEA VENTURES
CORE 50P-2
DEPTH 400-500 mm
OCR = 49
$C_c = 3.3$
C_v
VOID RATIO, e
C_v, m^2/s
4
3
2
80
75
70
50
200
150
100
10
0.01
0.1
1.0
PRESSURE, TSF

FIGURE 6

Appendix 1. Tabulated Geotechnical Data

Deepsea Ventures Mining Claim

Core 50P-1

Specific Gravity = 2.22*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					196	4.35	81									
25								121	76	45	2.5				33	0
38					183	4.06	80					4.49	1.33	3.38		
50					158	3.50	79									
75				1.33	161	3.57	78									
113	25	7	8.4		147	3.26	77									
138					159	3.52	78					10.49	3.45	3.04		
175				1.38	132	2.93	75	128	53	75	1.1				33	0
373					141	3.13	76									
390	6	2	8.2					108	58	50	1.4				32	0
400					115	2.56	72					23.55	7.77	3.03		
420					115	2.56	72									

* Values questionable, see text.

Deepsea Ventures Mining Claim

Core 50P-2

Specific Gravity = 2.59

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					188	4.87	83									
38					174	4.51	82	145	68	77	1.4	2.38	0.91	2.7		<5
70				1.29	173	4.48	82									
138					190	4.92	83					4.57	0.85	5.4		
170	18	38	7.86	1.29												
190					176	4.56	82									
400					174	4.51	82									

Deepsea Ventures Mining Claim

Core 50P-3

Specific Gravity = 2.29*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					192	4.40	81									
25															34	
38					192	4.40	81					6.55	2.09	3.13		
75				1.28	185	4.24	81									
100	6	20	8.1					131	77	54	2.0					
113					169	3.87	79									0
138					167	3.82	79					19.60	4.87	4.02		
175				1.32	166	3.80	79									
200															34	
213					164	3.76	79									
235					164	3.76	79					20.59	4.99	4.13		
275				1.32	168	3.85	79									
300								128	73	55	1.7					0
338					168	3.85	79					16.37	3.66	4.47		
350					167	3.82	79									
475				1.32	169	3.87	79									
480								128	75	53	1.8				34	0
500	12	8	7.6													
505					170	3.89	80									

* Values questionable, see text.

Deepsea Ventures Mining Claim

Core 50P-5

Specific Gravity = 2.11*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					235	4.96	83									
20															34	
25								128	72	56	2.8					0
38					216	4.56	82					6.09	1.60	3.81		
75				1.26	210	4.43	82									
100	5	28	8.2													
113					210	4.43	82									
138					217	4.56	82					7.43	1.97	3.77		
175				1.26	219	4.62	82									
200								128	71	57	2.4				34	
213					196	4.13	81									0
238					188	3.97	80					11.60	3.46	3.35		
440					169	3.57	78									
475				1.33	168	3.54	78	127	67	60	1.7					
490															34	0
513					164	3.57	78									
538					164	3.46	78					18.68	3.43	5.45		

---

* Values questionable, see text.

Core 50P-6

Specific Gravity = 2.31*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					239	5.52	85									
25	18	7	8.0					127	78	49	3.1				33	
38					220	5.08	84					5.80	1.59	3.65		<5
75				1.22	205	4.74	83									
113					210	4.85	83	129	66	63	2.3					
138					207	4.78	83					10.85	2.51	4.32		0
175				1.26	209	4.83	83									
213	7	7	7.9		197	4.55	82									
238					194	4.48	82					9.75	2.55	3.82		
275				1.30	185	4.27	81									
313					180	4.16	81									
338					180	4.16	81					18.04	3.63	4.97		
350															33	0
375				1.30	182	4.20	81	100	67	33	3.5					
413					167	3.86	79									
438					167	3.86	79					21.58	10.53	2.05		
475				1.29	171	3.95	80									
513					176	4.07	80								33	
535								125	69	56	1.9					0
538	12	0	8.0		173	4.00	80					13.14	2.55	5.15		
560					171	3.95	80									

* Values questionable, see text.

Deepsea Ventures Mining Claim

Core 50P-8

Specific Gravity = 2.34 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					205	4.80	83									
25															34	
38					216	5.05	83					8.93	2.67	3.34		
75				1.30	192	4.49	82									0
100	30	12	8.6					127	66	61	2.2					
113					204	4.77	83									
138					196	4.59	82					12.18	3.24	3.76		
175				1.27	192	4.49	82									
200															33	
213					192	4.49	82									
238					184	4.30	81					15.84	4.99	3.17		
275				1.30	180	4.21	81									
300	19	7	8.4					131	58	73	1.7					0
313					179	4.19	81									
338					174	4.07	80					18.62	4.69	3.97		
375				1.31	176	4.12	80									
400															33	
413					179	4.19	81									
438					178	4.17	81					17.29	4.35	3.97		
475				1.30	178	4.17	81									
483								132	70	62	1.7					0
505					177	4.14	81									

* Values questionable, see text.

Deepsea Ventures Mining Claim

Core 50P-9

Specific Gravity = 2.40 *

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
13					212	5.01	84	128	76	52	2.6					
25																
38					211	5.06	84								34	0
75				1.28	197	4.73	83					6.21	1.80	3.45		
100	20	10	8.4													
113					210	5.04	83									
138					200	4.80	83									
175				1.28	193	4.63	82					11.14	2.85	3.91		
213					180	4.32	81									
220								130	65	65	1.9					
238					185	4.44	82								34	
260					181	4.34	81					10.44	1.63	6.40		0
280					175	4.20	81									
475				1.32	163	3.91	80									
500	25	8	8.5					128	69	59	1.6					
513					161	3.86	79								33	
538					156	3.74	79					4.18	1.74	2.40		0

* Values questionable, see text.

Core 50P-10

Specific Gravity = 2.69

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					173	4.65	82									
38				1.27	183	4.92	83									
63					175	4.73	83									
88					178	4.81	83									
115				1.27	182	4.90	83									
163	35	33	7.06		176	4.73	83									0
188					177	4.76	83	132	59	73	1.6	8.76	2.90	3.0		
413					203	5.46	85									
452					177	4.78	83									
490					176	4.73	83									

Core 50P-11

Specific Gravity = 2.69

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					167	4.49	82									
38					179	4.82	83					4.25	1.13	3.8		
75				1.29	176	4.73	83	137	82	55	1.7					0
100				1.26												
113					175	4.71	82					5.95	1.00	6.0		
170				1.30	161	4.33	81									0
173					159	4.28	81	137	60	77	1.3					
213					157	4.27	81					7.24	0.91	8.0		
238	23	33	7.93		156	4.20	81									
350					132	3.55	78									
400					130	3.50	78									
445				1.23	130	3.50	78	162	97	65	0.5					
450					129	3.47	78									
460					127	3.42	77									

Core 50P-13

Specific Gravity = 2.41*

Depth, mm	%< 2μm	%> 60μm	Median grain diam., φ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio *	Porosity, % *	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					193	4.65	82									
25								130	62	68	1.9				33	0
38					191	4.60	82					9.74	2.38	4.09		
75				1.29	189	4.55	82									
113					205	4.94	83									
138					201	4.84	83					10.01	3.05	3.28		
175				1.27	204	4.92	83									
200	20	25	8.5					129	86	40	3.0				33	
213					205	4.94	83									0
238					195	4.70	82					12.58	2.85	4.41		
275				1.29	192	4.63	82									
313					181	4.36	81									
338					173	4.17	81					18.94	4.26	4.45		
375				1.30	175	4.22	81									
400	20	35	8.4													
413					176	4.24	81									
438					171	4.12	80					20.16	4.90	4.11		
450				1.31												
475					172	4.15	81									
500															33	
513					180	4.34	81									

* Values questionable, see text.

Deepsea Ventures Mining Claim

Core 53P-C-5

Specific Gravity = 2.72

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight #	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
13					161	4.38	81									
38					165	4.49	82					7.48	1.12	6.7		
63					165	4.49	82									
88				1.30	166	4.52	82									
125					163	4.43	82					7.70	1.30	5.9		
175					162	4.41	82	132	59	73	1.4					0
225				1.31	166	4.52	82									
413	35	39	7.14		168	4.57	82									
438					174	4.73	83					6.91	1.46	4.7		

Core desiccated; compare water content values from shipboard samples: MINI-CORE 53P-5

Deepsea Ventures Mining Claim

Core MINI-CORE 53P-5 (Special water content samples)

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate, %
Mini-Core																
20					233											
50					215											
60					207											
100					197											
110					193											
150					178											
160					181											
200					177											
210					183											
250					174											
260					185											
350					177											
360					179											
450					171											
460					178											
Bottom					174											
Mini-Core, homogenized samples																
50					227											
100					201											
150					182											
200					177											
250					174											
350					172											
450					175											
Bottom					173											

Deepsea Ventures Mining Claim

Core MINI-CORE 53P-9 (Special water content samples: no regular core)

Depth, mm	%< 2µm	%> 60µm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/oo	Calcium Carbonate, %
Mini-Core																
0					-											
10					216											
50					198											
60					191											
100					216											
110					210											
150					197											
160					192											
200					197											
210					197											
250					190											
260					186											
350					178											
360					170											
450					172											
460					168											
Bottom					164											
Mini-Core, homogenized sample																
0					-											
5					205											
10					208											
15					207											
20					195											
25					194											
35					179											
45					173											
Bottom					178											

Deepsea Ventures Mining Claim

Core 54P-8

Specific Gravity = 2.82

Depth, mm	%< 2μm	%> 60μm	Median grain diam., ϕ	Bulk density, Mg/m^3	Water Content, % dry weight	Void ratio	Porosity, %	Liquid limit, %	Plastic limit, %	Plasticity index, %	Liquidity index,	Shear strength, undist., kPa	Shear strength remolded, kPa	Sensitivity	Salinity, °/₀₀	Calcium Carbonate %
13					199	5.61	85									
38					180	5.08	84	179	81	98	1.0	9.20	1.43	6.4		
63					331	9.33	90									
88				1.12	370	10.43	91									
113					337	9.50	90									
138					151	4.26	81									
163	25	36	7.51		124	3.50	78									
188					115	3.24	76					15.38	4.13	3.7		
213					116	3.27	77									66
225				1.40												
238					114	3.21	76									