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Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

Report to
GULF CANADA RESOURCES INC.
on
BEAUFORT SEA GEOTECHNICAL INVESTIGATION
1981

AKPAK

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ABSTRACT

This report summarizes the results of a 1981 preliminary subsurface investigation at the Akpak site in the Beaufort Sea. The investigation involved putting down two boreholes to depths of 16.3 m and 46.9 m below sea bed. The water depth at the borehole locations was 38 - 39 m.

The following is a summary of subsoil stratigraphy:

0 to 3 m* (approx.) (Unit 1)	Soft clayey silt to silty clay
3 to 42.6 m (Unit 2)	Compact to very dense sands with ice rich clayey silt zone >3.6 m thick and thin clay layers
3 - 12.6 m (2A)	Compact to dense silty sand
12.6 - 25.9 m (2B)	Dense to very dense medium sand
25.9 - 42.6 (2C)	Ice bonded medium sand
42.6 to >46.9 m (Unit 3)	Ice bonded clayey silt

The surficial clays are soft and unsuitable for the foundation support for gravity structures. The underlying sands are competent and short term settlements within these materials should be modest. However, thawing of ice rich clayey zones, including the basal clay deposit could result in significant (differential) thaw settlements and reduced shear strength.

*Depth below sea bed

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1.0 INTRODUCTION

Golder Associates has been retained by Gulf Canada Resources Inc. (GCRI) to carry out subsurface investigations in 1981 at seven (7) sites in the Beaufort Sea which have been identified as potential locations for oil and gas exploration (Figure 1). It is understood that the Mobile Arctic Caisson (MAC) may be used as a temporary exploration structure at these locations. The purpose of the investigations was to define the general subsurface conditions and properties of the various soil strata at the individual sites. Based on the data obtained at each site, geotechnical parameters for foundation design of the Mobile Arctic Caisson were to be provided together with an assessment of the suitability of in-situ materials as borrow for berm construction and for filling the caisson.

This report presents the results of the subsurface investigation at the Akpak site*. Because of the limited scope of the investigation at this site and the understanding that the actual MAC location may be at some distance from the borings, the foundation design parameters and borrow assessment contained in this report should be considered as preliminary. More detailed investigations will be required for final design purposes.

2.0 SUMMARY OF INVESTIGATION PROGRAM

2.1 Field Work

The Akpak site area is approximately 3 x 3 km in plan area. The results of a 1980 geophysical survey** of this area was supplemented by two borings put down during the 1981 investigation program. Borehole 1 was

*A draft report presenting the results of this investigation was submitted to GCRI in February, 1982.

**Geoterrex report dated September, 1980, "Marine Bottom and Subbottom Survey, Akpak Wellsite, Beaufort Sea".

advanced using sonic (i.e. vibratory/rotary methods) to a depth of 16.3 m below the sea bed on August 11, 1981. Continuous but highly disturbed samples are obtained using this approach. Borehole 2 was put down to 46.9 m depth below sea bed on October 15 and 16, 1981 using conventional rotary mud drilling methods. The choice of location for the sampled boreholes was based on a review of the available geophysical data which indicated an absence of anomalous permafrost conditions, together with relatively thin soft surficial deposits and relatively homogeneous stratigraphy. The location of the 1980 geophysical survey lines, and 1981 boreholes are shown on Figure 2. The Record of Borehole Sheets for the boreholes follow the text of this report. A detailed description of the fieldwork procedures used for in situ testing and sampling in the borings is given in Appendix I.

Geotechnical drilling, sampling and in situ testing was carried out from the Frank Broderick which was also equipped with an on-board geotechnical laboratory. Positioning for this vessel was provided by Canadian Engineering Surveys. Selection of the foundation investigation locations, supervision of drilling and laboratory testing was carried out by Golder Associates. Drilling from the Frank Broderick at the Akpak site was carried out by Foundex Explorations acting as subcontractors to Golder Associates. Liaison and coordination was provided by M.J. O'Connor and Associates who also acted as GCRI on-board representative.

2.2 Laboratory Testing

A detailed description of test techniques is given in Appendix II. In summary, laboratory tests were carried out to determine the grain size distribution and index properties of the samples obtained from the boreholes. These test results are summarized on the Record of Borehole Sheets, Table 1 and Figure 3. Laboratory shear strength measurements were made only on one sample as the remainder of the samples were either too soft for testing (surficial soils) or were ice-bonded.

3.0 SUBSURFACE CONDITIONS

3.1 Regional Geology

The Beaufort Sea deposits within the overall project area, have resulted from sedimentation by the MacKenzie River between late Tertiary and Recent times. The present river is building out a delta into MacKenzie Bay; pro-delta silts and clays extend well beyond the delta into the Beaufort Sea and are also carried eastwards by the littoral drift to partially cover the shelf within the project area. These Recent deposits are being laid down over older deltaic deposits which were laid down by the MacKenzie river in pre-Wisconsin times when the main branch of the river entered the sea via Liverpool Bay. These older deltaic deposits largely cover the project area. Because the western part of the area shows a predominantly clayey sequence, it is possible that these clayey deposits represent the pro-delta muds of the old delta beyond the limit of more granular deltaic deposits.

The thickness of the Recent sediments is not only dependent on the distance from the sediment source and the strength/direction of the ocean currents, but also on the submarine topography at the time of deposition. During the Wisconsin period, the sea level was about 60 to 90 m below the existing level. Therefore, the old delta surface was exposed and subject to permafrost development and later partial thawing. Distributaries were present across the delta, and during the marine transgression which accompanied the melting of the ice, erosion and reworking of the delta surface occurred. Moreover, deep meltwater channels developed across, or at the limits of the delta as exemplified by the MacKenzie Canyon and Kugmallit Channel. For these reasons, the thickness of the Recent sediments is variable. At the eastern end of the overall project area, the Recent sediments may be absent and it is possible that bottom currents may be presently eroding the surface of the old delta. The Recent sediments predominantly comprise soft to firm, possibly overconsolidated silts and clays. Locally, sands are found as well as gravels, and have probably resulted from the reworking of glacial sediments.

The Pleistocene-Tertiary delta has been investigated only to a limited extent to date. In the eastern portion of the overall project area, the deltaic deposits consist primarily of granular soils with subsidiary clays. A continuous sand layer which appears to represent an older deltaic sequence, extends over the eastern part of the 1981 investigation area at about 95 to 100 m below existing sea level. The surface of this layer is relatively smooth with occasional minor channels and dips to the northewest indicating an easterly or southeasterly material source. The overlying sediments appear to represent a younger sequence of deltaic deposits and generally consist of about 20 - 30 m of clayey silt overlain by up to 30 m of fine to medium sand. These sands are overlain by thin surficial soils deposited by the current McKenzie Delta. In the central part of the 1981 project area the interbedded clays are thicker and, in the west, sands are secondary to the silts and clays. The deltaic sediments are variable both laterally and in depth. They may contain a fraction of organic material and lenticular beds are common. The deposits are generally dense or overconsolidated, although weaker materials have been described at depth, possibly due to sample disturbance.

A series of highly variable sediments may be found between the Pleistocene deltaic beds and the overlying Recent silts and clays. They represent channel infillings, glacial deposits and the materials deposited by the transgressive sea. They are localized and may comprise lacustrine silts, fluvial sands and gravels and disturbed tills.

Various post-depositional influences have been operative on both Recent and older sediments. These include ice-scouring from the deep keels of initial and multi-year ice which has affected deposits of both ages, permafrost in the older deposits, gas seepage, consolidation by ground water or surface water level changes, wave activity, ice loading, seismic loading, changes in pore water chemistry, and peripheral effects such as the development of pingos or thermokarst. Some of these processes have served to strengthen the materials and others to disturb them, and they may not all have occurred in the project area.

3.2 Stratigraphy

The Akpak site lies on the west side of the Kugmallit Channel and the water depth across the site is 38 - 39 m. Based on the 1980 geophysical survey results and the 1981 geotechnical drilling data, the area is underlain by three main stratigraphic units as follows:

0 - 3 m (approx.) - recent deltaic clayey deposits (Unit 1)

3 - 42.6 m - older deltaic sand deposits (Unit 2)

42.6 - >46.9 m - older deltaic clayey silt deposits (Unit 3)

Another deeper sand unit underlying Unit 3 was detected by drilling and/or geophysical surveys at other sites in the eastern half of the overall 1981 investigation area. This lower sand deposit was undefined at Akpak due to the screening effect of extensive shallow acoustic permafrost.

Unit (1) is a thin layer of recent MacKenzie Delta sediment. It consists of up to 3.2 m of very soft, dark grey clayey silt to silty clay.

Unit (2) consists of a fine to medium, compact to dense, brown sand. At the borehole locations this unit is about 40 m thick and contains clayey and organic layers. In Borehole 1 an ice-rich clayey silt zone was encountered (but not fully penetrated) indicating that a greater local variability of deltaic sediments exists than at sites closer to shore. The surface of Unit 2 is a strong seismic reflector and may have been previously eroded to some degree.

Unit (3) consists of a hard laminated clayey silt. While only 4 m of this deposit was penetrated during drilling at the Akpak site, this unit was up to 25 to 30 m thick at other nearby sites.

Most of the Akpak area has extensive shallow acoustic permafrost at depths greater than 21 to 29 m below sea bed. This is dissected by four pockets, apparently without shallow acoustic permafrost. In Borehole 2, the ice bonded material was encountered 26 m below sea bed. In Borehole 1 permafrost was encountered 15 m below sea bed and in this boring the permafrost was characterized by 12 - 50 mm thick ice layers spaced as close as 150 mm. The upper boundary of frozen material seems to be variable over the site, which is an indication of degrading permafrost.

4.0 PROPERTIES OF MAJOR STRATIGRAPHIC UNITS

The geotechnical properties of each of these major stratigraphic units encountered in the boreholes put down at the Akpak site, are summarized below. Detailed results of in situ and laboratory tests are given on the Record of Borehole sheets and on Table 1.

4.1 Surficial Clays

The water content of the surficial clay ranges from 47 to 64%, and is close to the liquid limit (50 to 58%). The plastic limit of the surficial clays ranges between 21 and 22% and the plasticity index is in the range of 29 to 36%. The undrained shear strength of these materials was not measured but is estimated to be less than 15 kPa. Two temperature measurements in this material indicate in situ temperature of -0.9 and -1.2°C.

4.2 Sand

Although this unit consists predominantly of sands, the character of these materials varies significantly with depth. Therefore, for the purpose of discussion, this unit has been subdivided into three sub-units:

Sub-Unit 2A: The upper 8 - 10 m of Unit 2 consists of fine to medium sand with some silt/clay (Figure 3); the percentage by weight of fines (i.e. silt and clay) varies between 13 and 43%. It is noted that these gradations reflect particle size distribution in mass samples. However, the deposit is stratified with coarse and fine layers; thin clay laminations and traces of organic matter are also present. As indicated on the attached Record of Borehole sheet, the lower 5 - 6 m in Borehole 1 consists of frozen dark grey clayey silt with relatively closely spaced ice lenses which are 12 - 50 mm thick. Based on the results of standard penetration tests, the majority of the sand material comprising Sub-unit 2A is in a compact to dense condition with 'N' values ranging between 18 and 56 blows/300 mm.

Sub-Unit 2B: The sand within this subunit which is about 13 m thick, consists of predominantly medium sand size particles and contains a small percentage of fines (<4% by weight, Figure 3, Table 1). Occasional organic and clayey/silty zones were also evident in this sub-unit. Based on measured 'N' values which range between 30 and 95 blows/300 mm, these sands are in a dense to very dense condition.

Sub-Unit 2C: This sub-unit also consists predominantly of medium sand size particles with 10 - 20% by weight of fine sand sizes. This material is ice bonded. Based on observations during permafrost coring and the results of two Standard Penetration tests which gave 'N' values in excess of 100 blows for 100 and 150 mm penetrations, Sub-unit 2C is in a very dense condition.

4.3 Unit 3 - Lower Clayey Silt

At a depth of 42.6 m below sea bed, Borehole 2 encountered a dark grey clayey silt containing occasional thin sand layers. This material is ice bonded and is at a temperature of -1.7°C. The hard nature of this lower clayey silt is indicated by the high 'N' values of 49 and 52 blows/300 m and undrained shear strengths of in excess of 200 kPa as measured in pocket penetrometer and laboratory fallcone tests. A lower undrained strength value of 94 kPa was measured in a laboratory vane test. In contrast with these strength measurements the water content of the clayey silt (34%) is in excess of the measured liquid limits of 30 and 32%. As a result the liquidity index for this material is in excess of 1 which would suggest a soft consistency. However, it is considered that the ice content within the lower clayey silt is the reason for the relatively high water content and does not properly reflect in situ consistency.

5.0 PRELIMINARY SITE ASSESSMENT FOR MOBILE ARCTIC CAISSON CONSTRUCTION

5.1 Foundation Design Parameters

Because of the limited scope of the 1981 investigation at the Akpak site and the probability that the MAC location at the site will be at some distance from the borehole location, the foundation design parameters given below should be considered as preliminary only. More detailed investigations will be required for final design purposes.

A summary of soil stratigraphy and engineering properties of the various soil strata is given on Figure 4. The following major features are noted:

- The surficial clays within about 3 m below the seabed are soft and not suitable for foundation support for the MAC.
- The sands underlying the surficial clays are competent for foundation support for the MAC and settlements should be modest within this unit in the short term.
- Over the long term and depending on thermal regime, thawing of ice rich lenses of clayey soils could result in significant differential settlements and zones of relatively low shear strength. The potential for problems associated with thawing of ice rich materials should be further investigated particularly for long term structures at this site.

5.2 Borrow Materials

No suitable borrow materials (i.e. relatively clean sands) for berm construction and for filling the caisson were encountered at accessible depths in the boreholes put down at the Akpak site during the 1981 investigation program. Development of the suitable clean sand materials encountered below a depth of about 50 m below sea level would require excessive stripping of overlying unsuitable materials.

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JHAC:JIC:kk

LIST OF ABBREVIATIONS

The abbreviations commonly employed on each "Record of Borehole," on the figures and in the text of the report, are as follows:

I. SAMPLE TYPES

- *AS* auger sample
- *CS* chunk sample
- *DO* drive open
- *DS* Denison type sample
- *FS* foil sample
- *RC* rock core
- *ST* slotted tube
- *TO* thin-walled, open
- *TP* thin-walled, piston
- *WS* wash sample

II. PENETRATION RESISTANCES

Dynamic Penetration Resistance: The number of blows by a 63.5 kg hammer dropped 760mm required to drive a 50mm diameter, 60 degree cone 0.3 m, where the cone is attached to 'A' size drill rods and casing is not used.

Standard Penetration Resistance, *N*: The number of blows by a 63.5 kg hammer dropped 760 mm required to drive a 50mm drive open sampler

WH sampler advanced by static weight—weight, hammer

PH sampler advanced by pressure—pressure, hydraulic

PM sampler advanced by pressure—pressure, manual

III. SOIL DESCRIPTION

(a) *Cohesionless Soils*

Relative Density	*N, blows/0.3 m*
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	over 50

(b) *Cohesive Soils*

Consistency	c_u, kPa
Very soft	Less than 12
Soft	12 to 25
Firm	25 to 50
Stiff	50 to 100
Very stiff	100 to 200
Hard	over 200

IV. SOIL TESTS

- *C* consolidation test
- *H* hydrometer analysis
- *M* sieve analysis
- *MH* combined analysis, sieve and hydrometer[1]
- *Q* undrained triaxial[2]
- *R* consolidated undrained triaxial[2]
- *S* drained triaxial
- *U* unconfined compression
- *V* field vane test
- F fall cone
- L lab vane
- P pocket penetrometer

NOTES:

[1]Combined analyses when 5 to 95 per cent of the material passes the No. 200 sieve.

[2]Undrained triaxial tests in which pore pressures are measured are shown as $\bar{Q}$ or $\bar{R}$.

LIST OF SYMBOLS

I. GENERAL

$\pi = 3.1416$

e = base of natural logarithms 2.7183

$\log_e a$ or $\ln a$, natural logarithm of a

$\log_{10} a$ or $\log a$, logarithm of a to base 10

- t time
- g acceleration due to gravity
- V volume
- W weight
- M moment
- F factor of safety

II. STRESS AND STRAIN

- u pore pressure
- σ normal stress
- σ' normal effective stress ($\bar{\sigma}$ is also used)
- τ shear stress
- ϵ linear strain
- ϵ_{xy} shear strain
- ν Poisson's ratio (μ is also used)
- E modulus of linear deformation (Young's modulus)
- G modulus of shear deformation
- K modulus of compressibility
- η coefficient of viscosity

III. SOIL PROPERTIES

(a) *Unit weight*

- γ unit weight of soil (bulk density)
- γ_s unit weight of solid particles
- γ_w unit weight of water
- γ_d unit dry weight of soil (dry density)
- γ' unit weight of submerged soil
- G_s specific gravity of solid particles $G_s = \gamma_s/\gamma_w$
- e void ratio
- n porosity
- w water content
- S_r degree of saturation

(b) *Consistency*

- w_L liquid limit
- w_P plastic limit
- I_P plasticity index
- w_S shrinkage limit
- I_L liquidity index $= (w - w_P)/I_P$
- I_C consistency index $= (w_L - w)/I_P$
- e_{max} void ratio in loosest state
- e_{min} void ratio in densest state
- D_r relative density $= (e_{max} - e)/(e_{max} - e_{min})$

(c) *Permeability*

- h hydraulic head or potential
- q rate of discharge
- v velocity of flow
- i hydraulic gradient
- k coefficient of permeability
- j seepage force per unit volume

(d) *Consolidation (one-dimensional)*

- m_v coefficient of volume change $= -\Delta e/(1+e)\Delta\sigma'$
- C_c compression index $= -\Delta e/\Delta \log_{10} \sigma'$
- c_v coefficient of consolidation
- T_v time factor $= c_v t/d^2$ (d, drainage path)
- U degree of consolidation

(e) *Shear strength*

- τ_f shear strength
- c' effective cohesion intercept; ϕ' effective angle of shearing resistance, or friction — in terms of effective stress $\tau_f = c' + \sigma' \tan \phi'$
- c_u apparent cohesion*; ϕ_u apparent angle of shearing resistance, or friction — in terms of total stress $\tau_f = c_u + \sigma \tan \phi_u$
- μ coefficient of friction
- S_t sensitivity

*For the case of a saturated cohesive soil, $\phi_u = 0$ and the undrained shear strength $\tau_f = c_u$ is taken as half the undrained compressive strength.

Summary of Ground Ice Descriptive System
(After Pihlainen and Johnston 1963, Linell and Kaplar 1966)

A. ICE NOT VISIBLE[a]

Group Symbol	Subgroup Description	Subgroup Symbol	Field Identification
N	Poorly bonded or friable	Nf	To determine presence of excess ice, use procedure under note[b] and hand magnifying lens as necessary. For soils not fully saturated, estimate degree of ice saturation: medium, low. Note presence of crystals or of ice coatings around larger particles.
	Well-bonded: No excess ice	Nb: Nbn	
	Well-bonded: Excess ice	Nb: Nbe	

B. VISIBLE ICE—LESS THAN 1 INCH THICK[a]

Group Symbol	Subgroup Description	Subgroup Symbol	Field Identification
V	Individual ice crystals or inclusions	Vx	For ice phase, record the following when applicable: Location — Size Orientation — Shape Thickness — Pattern of arrangement Length Spacing Hardness, Structure, Colour — per Group C Estimate volume of visible segregated ice present as percentage of total sample volume.
	Ice coatings on particles	Vc	
	Random or irregularly oriented ice formations	Vr	
	Stratified or distinctly oriented ice formations	Vs	

C. VISIBLE ICE—GREATER THAN 1 INCH THICK

Group Symbol	Subgroup Description	Subgroup Symbol	Field Identification
ICE	Ice with soil inclusions	ICE + soil type	Designate material as ICE[c] and use descriptive terms as follows, usually one item from each group, when applicable: *Hardness*: HARD; SOFT (of mass, not individual crystals) *Structure*[d]: CLEAR; CLOUDY; POROUS; CANDLED; GRANULAR; STRATIFIED *Colour* (Examples): COLOURLESS; GRAY; BLUE *Admixtures* (Examples): CONTAINS FEW THIN SILT INCLUSIONS
	Ice without soil inclusions	ICE	

(a) Frozen soils in the N group may, on close examination, indicate presence of ice within the voids of the material by crystalline reflections or by a sheen on fractured or trimmed surfaces. The impression received by the unaided eye, however, is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of frozen soils in the V group.

(b) When visual methods are inadequate, a simple field test to aid evaluation of volume of excess ice can be made by placing some frozen soil in a small jar, allowing it to melt, and observing the quantity of supernatant water as a percentage of total volume.

(c) Where special forms of ice such as hoarfrost can be distinguished, more explicit description should be given.

(d) Observer should be careful to avoid being misled by surface scratches or frost coating on the ice.

SOIL CLASSIFICATION SYSTEM

GRAIN SIZE SCALE: M.I.T. STANDARD

BOULDERS	Larger than 200 mm
COBBLES	60 mm to 200 mm
GRAVEL	2 mm to 60 mm
SAND	0.06 mm to 2 mm
SILT	0.002 to 0.06 mm
CLAY	Smaller than 0.002 mm

COMPOSITION:

"and"	36 to 50%
"y" or "ey"	21 to 35%
"some"	11 to 20%
"trace"	0 to 10%

EXAMPLE:

Gravel 70%   Sand 22%

Pass #200 Sieve 8%

Sandy Gravel, Trace of Silt

EXCEPTION:

Silt 70%   Clay 30%

And plots above 'A' line

Silty clay <u>not</u> clayey silt

TABLE 1: SUMMARY OF LABORATORY TESTING: BOREHOLE #'s 1 AND 2

BOREHOLE #1: Sonic

Unit #	Description	Sample #	Depth (m) From	-	To	Wn %	W_L %	W_P %	Plasticity Index %	Grain Size Distribution: Sand C	Sand M	Sand F	Fines* --	Silt C	Silt M	Silt F	Clay --	Undrained Shear Strength (kPa)
1	Soft silty clay	1	1.2	-	1.5	61.9	58	22	36									
		2	2.3	-	2.6	47.3	50	21	29									
2A	Fine to medium silty sand	3	4.0	-	4.3						42	45	13					
		6	5.3	-	5.6													
		4	6.9	-	7.2						23	47	30					
		5	8.4	-	8.7													
		7	9.9	-	10.2					1	68	16	15					
2A[1]	Clayey silt, ice rich below 14.9m	8	12.8	-	13.0	27.7												
		11	13.3	-	13.6	23.0	39	18	21			1	99					
		9	14.9	-	15.1	34.6	42	27	15									

BOREHOLE #2: Rotary

Unit #	Description	Sample #	Depth (m) From	-	To	Wn %	W_L %	W_P %	Plasticity Index %	Grain Size Distribution: Sand C	Sand M	Sand F	Fines* --	Silt C	Silt M	Silt F	Clay --	Undrained Shear Strength (kPa)
1	Soft clayey silt	1	0.9	-	1.5	63.6												
2A	Compact to very dense fine to medium silty sand	2	2.4	-	3.1						18	61	21					
		3	4.0	-	4.4													
		4	5.5	-	5.9						20	59	21		SM/SC			
		5	7.0	-	7.5													
		6	8.7	-	9.1					2	28	49	21					
		7	9.9	-	10.4													
		8	11.6	-	12.0						5	52	43					
2B	Dense to very dense medium grained sand	9	13.1	-	13.6													
		10	14.8	-	15.2						72	24	4					
		11	16.2	-	16.6													
		12	18.0	-	18.4					2	88	8	2					
		13	19.1	-	19.5													
		14	20.9	-	21.3					1	87	10	2					
		15	22.3	-	22.7													
		16	23.9	-	24.4					5	84	9	2					
2C	Ice bonded medium grained sand	17	25.3	-	25.8													
		18	26.7	-	27.1													
		19	27.1	-	27.9													
		20	27.9	-	29.4													
		21	29.4	-	30.9													
		22	30.9	-	32.5						90	10						
		23	32.5	-	34.0						81	19						
		24	34.0	-	34.8													
		25	38.0	-	38.4													
		26	40.8	-	41.0													
3	Ice Bonded clayey silt	27	44.2	-	44.7	34.0	32	24	8		12	7		14	40	10	17	P.Pen >215 Fall Cone >250 Lab Vane 94
		28	45.7	-	46.2													
		29	46.3	-	46.9	34.3	30	27	3			1		14	53	14	18	

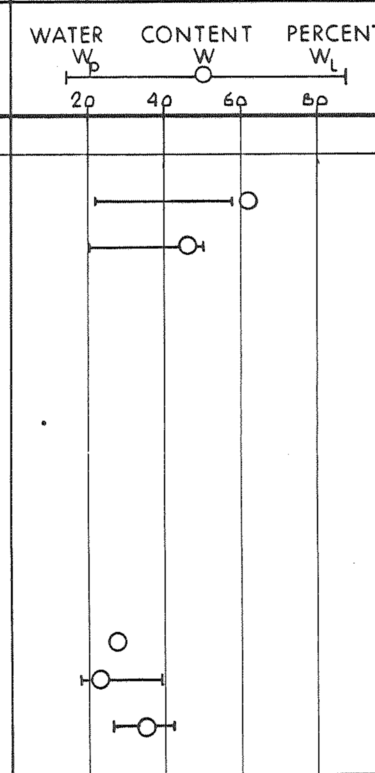
*Fines = silt and clay sizes

RECORD OF BOREHOLE BH 1

LOCATION (See Figure 1.2) N 7 789 264 E 531 559 AKPAK | BORING DATE AUGUST 11 1981 | BOREHOLE DIAMETER 10.2 cm

SAMPLE HAMMER WEIGHT | DROP | DATUM SEA FLOOR

Boring Method	Elev. Depth (m)	Description	Strat. Plot	Sample Number	Sample Type	Blows/300mm		Water Content Percent (W_p, W, W_L)	Additional Lab. Testing	Piezometer or Standpipe Installation
	0.0	SEA FLOOR (WATER DEPTH 38.7 m)								
4 5/8 in O.D. (117.5 mm) DRILL PIPE. SONIC/ROTARY DRILLING *	0.0–3.2	VERY SOFT TO SOFT, DARK GREY TO OLIVE GREEN, SILTY CLAY, TRACE OF SAND, SHELLS AND ORGANICS		1, 2	SAMPLES FROM CONTINUOUS SONIC CORE		RUN #1			
	3.2–3.6	DARK GREY, CLAYEY SILT AND SAND								
	3.6–10.8	DARK GREYISH-BROWN, FINE AND MEDIUM GRAINED SAND AND SILT, THINLY BEDDED OCCASIONAL LAMINATIONS, GRADED BEDDING, TRACE OF ORGANICS		3, 6, 4, 5			RUN #2		M, M, M	
	10.8–11.7	MEDIUM TO COARSE GRAINED SAND SOME SHELLS, TRACE OF FINE ANGULAR GRAVEL		7						
	11.7–12.0	DARK GREY SILT LAMINATED, ORGANIC								
	12.0–12.7	DARK GREY-BROWN ORGANIC SAND		8, 11			RUN #3			
	12.7–14.9	DARK GREY CLAYEY SILT SOME FINE SAND, ORGANICS, CALCAREOUS		9						
	14.9–16.3	PERMAFROST. ICE LAYERS 12-50 mm THICK. ICE IS HARD HOMOGENOUS NO SOIL INCLUSIONS.								
	16.3	END OF BOREHOLE								



(NO ADVANCEMENT POSSIBLE WITH SONIC DRILLING. ROTARY DRILLING WITH TRICONE INSERT RATE OF ADVANCE ~ 150 mm IN TWO HOURS)

* CONDUCTOR STRING

a) 6 5/8 in (168 mm) O.D. RISER CASING FROM 0.6 m BELOW SEA FLOOR TO MOON POOL.

b) 8 5/8 in (219 mm) O.D. OUTER CASING TO 26.8 m BELOW MOON POOL DECK.

c) DRILLING MUD DISCHARGE ONTO SEABED THROUGH SLOTS IN 6 5/8 in CASING.

SCALE 1: 200 | Golder Associates | BOREHOLE No BH 1

RECORD OF BOREHOLE BH 2

LOCATION (See Figure 1.2) N 7 789 256 E 531 670 AKPAK SITE
SAMPLE HAMMER WEIGHT 63.5 KG

BORING DATE OCTOBER 14-16 1981
DROP 0.76 METERS

BOREHOLE DIAMETER 10.2 cm
DATUM SEA FLOOR

Boring Method	Elev. Depth (m)	Description	Sample Number	Type	Blows/300mm	Temperature °C	Additional Lab. Testing
BQ SAMPLING RODS; 4 5/8" OD (117.5 mm) DRILL PIPE WITH CASING SHOE DRILL BIT, MUD SUPPORTED HOLE **	0.0	SEA FLOOR (WATER DEPTH ≈ 38 m)					
		(1) VERY SOFT, DARK GREY, CLAYEY SILT, TRACE OF SAND	1	TO		-1.2	
	2.6	(2A) COMPACT TO VERY DENSE BROWN TO GREY BROWN, FINE TO MEDIUM GRAINED SAND AND SILT. THINLY BEDDED SOME LAMINAE OF SILTY CLAY	2	TO		-0.9	M
			3	DO	42		
			4	DO	56		M
			5	DO	34		
			6	DO	24		M
			7	DO	18		
			8	DO	30		M
	12.6	(2B) DENSE TO VERY DENSE, BROWN, MEDIUM GRAINED SAND. SOME FINE SAND, TRACE SILT, OCCASIONAL ORGANIC AND SILT/CLAY LAYERS.	9	DO	32		
			10	DO	39		M
			11	DO	59		
			12	DO	51		M
			13	DO	94		
			14	DO	95		M
			15	DO	47		
			16	DO	68		M
			17	DO	30		
NQ TRIPLE TUBE CORE BARREL	25.9	(2C) FROZEN (ICE BONDED) BROWN, FINE TO MEDIUM GRAINED SAND	18	DO	100 for 175mm		
			19	PC* #1			
			20	PC #2			
			21	PC #3			
			22	PC #4			M
			23	PC #5			M
			24	PC #6			
BQ SAMPLING RODS; 4 5/8" OD DRILL PIPE, MUD SUPPORTED			25	DO	100 for 150mm		
			26	DO	100 for 100mm		
	42.6	(3) HARD, ICE BONDED, DARK GREY, CLAYEY SILT, OCCASIONAL SAND LAYERS, THINLY BEDDED, NO VISIBLE ICE (Nbe)	27	DO	49	-1.7	MH
			28	DO	52	No recovery	
			29	TO		-1.7	MH
	46.9	END OF BOREHOLE.					

Water content percent (W_p, W, W_L): 20, 40, 60, 80

PERMAFROST CORING DISCONTINUED. NQ RODS FAILED AT END OF 8 5/8" CASING DUE TO MOTION OF SHIP.

NOTE: ALL T.O. SAMPLES WERE 75mm DIA.
ALL D.O. SAMPLES WERE 50mm DIA.

* PERMAFROST CORE (NQ)

** CONDUCTOR STRING
a) NO RISER CASING FROM SEABED
b) 8 5/8 in (219 mm) O.D. OUTER CASING SUSPENDED TO 24.4 m BELOW MOONPOOL DECK.

SCALE 1:200 — Golder Associates — BOREHOLE No BH 2

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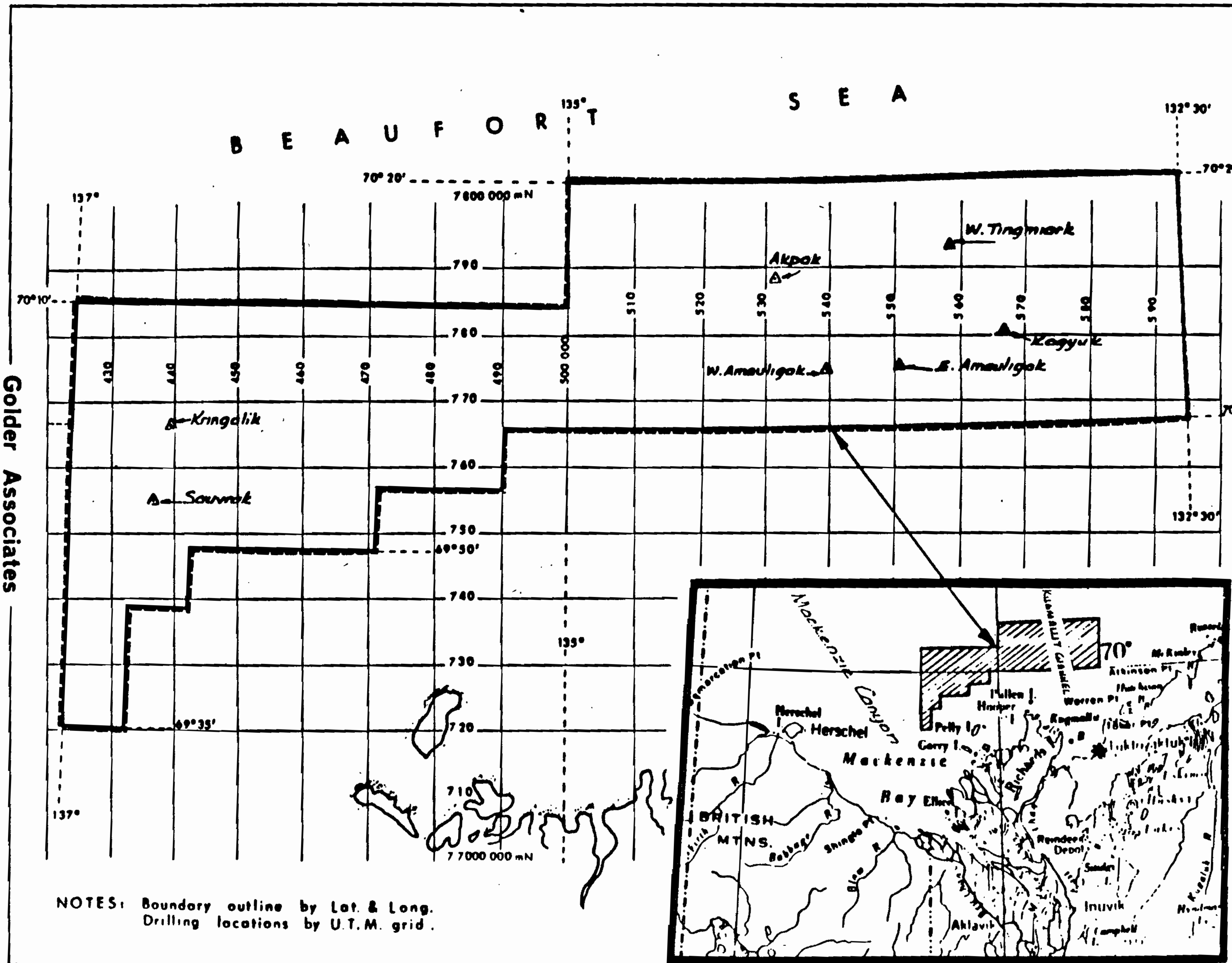


NOTES: Boundary outline by Lat. & Long.
Drilling locations by U.T.M. grid.

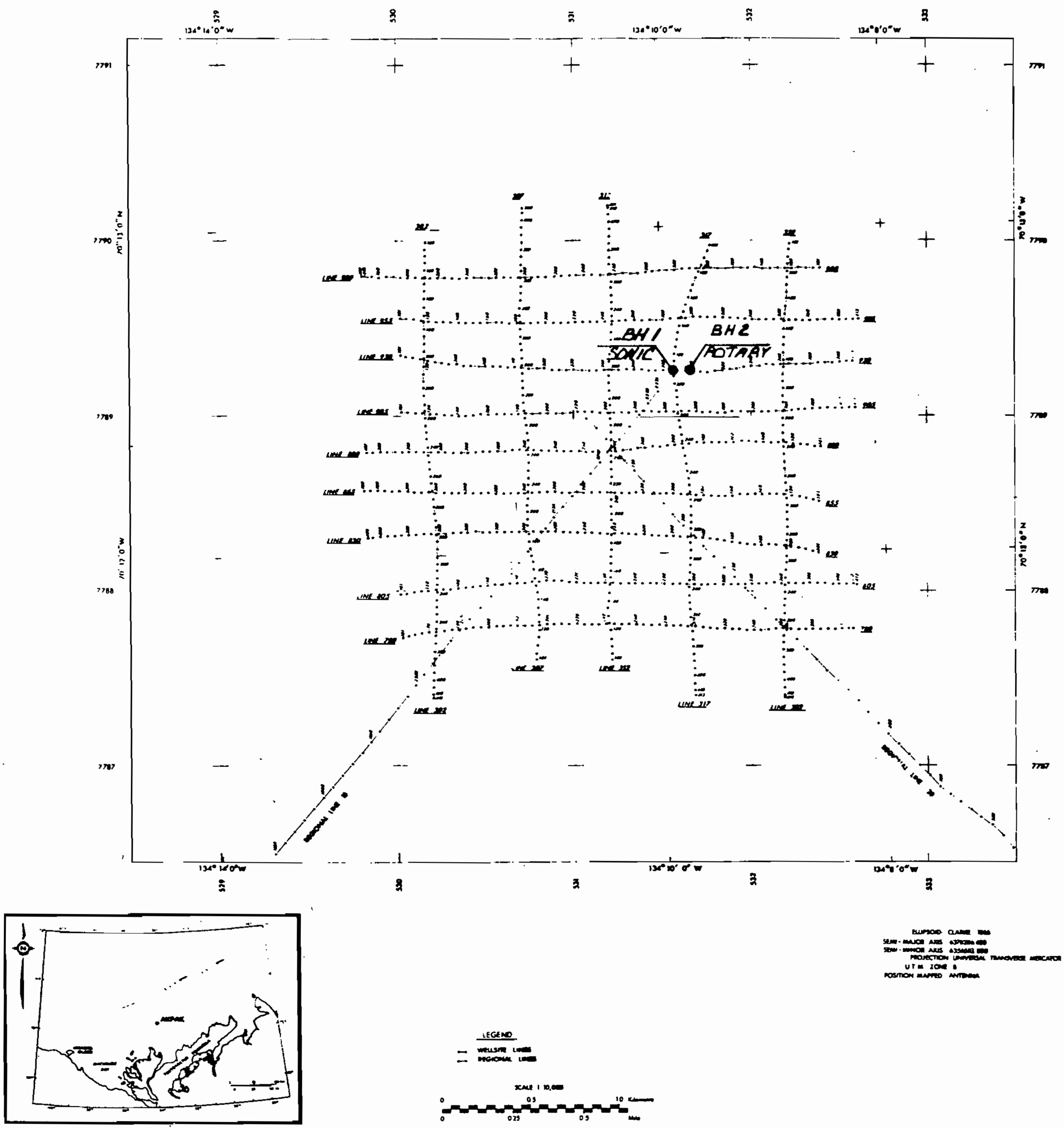
Golder Associates

SITE LOCATION PLAN

Figure 1

GEOPHYSICAL SURVEY LINES AND BOREHOLE LOCATIONS

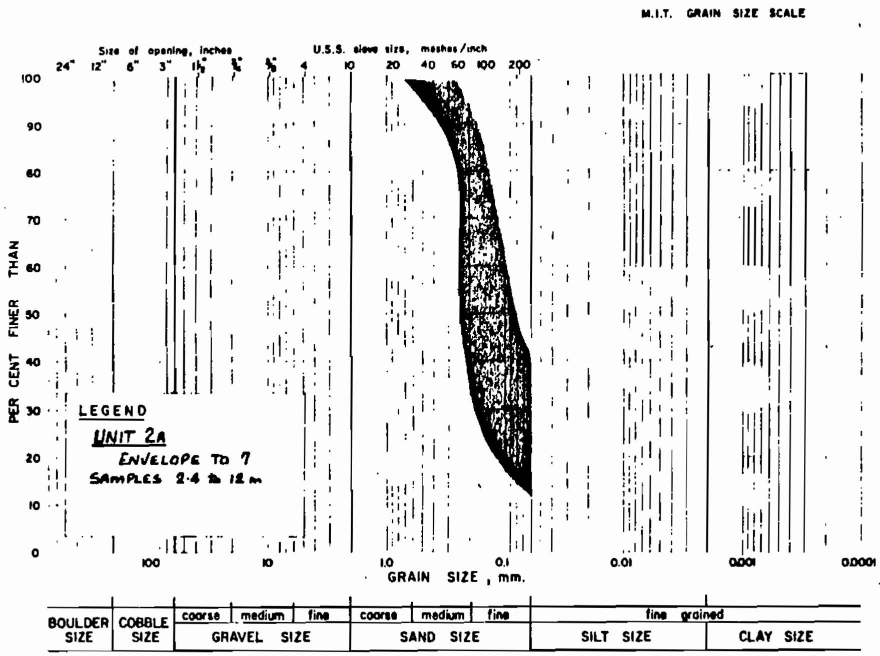
Figure 2

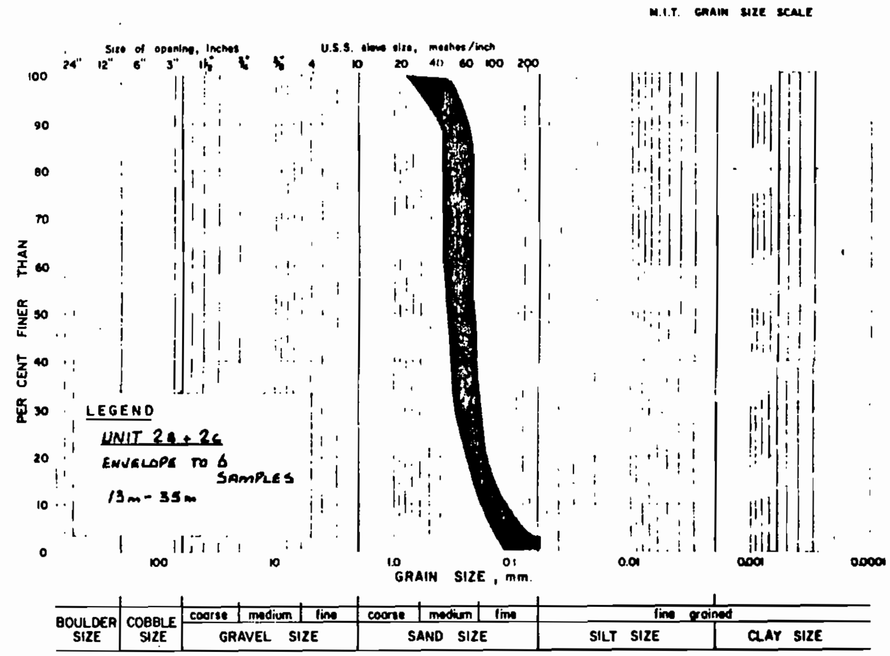


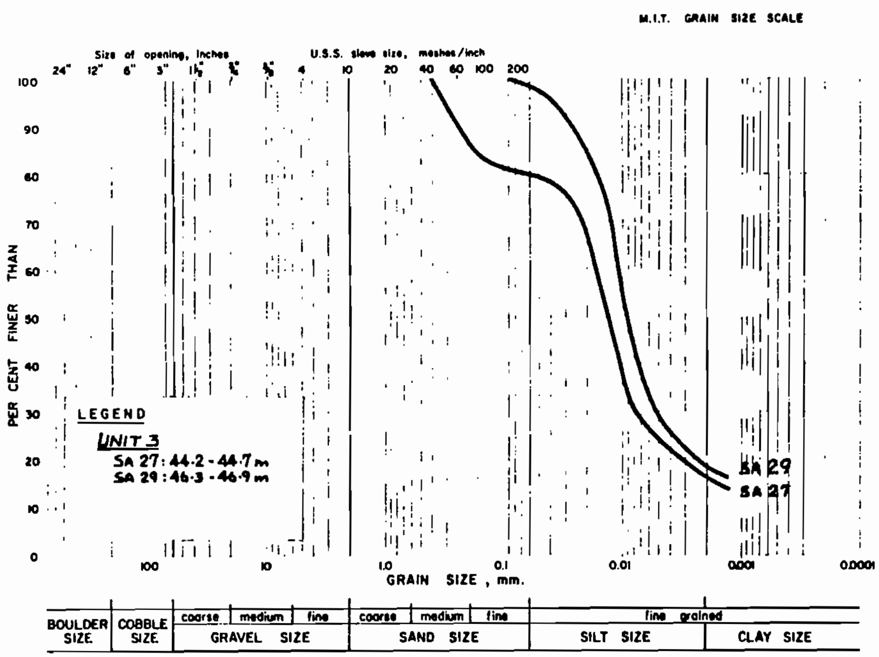
Project No. 812-2102 Drawn DS Reviewed [illegible] Date Nov 82

Golder Associates

Project No. 812-2102 Drawn D.S. Reviewed [initials] Date NOV 82







- DATA FROM BH1 (SONIC) AND BH2 (ROTARY)
- CURVE FROM BH1, SA11 NOT SHOWN. (1% SAND, 99% FINES NOT ANALYSED)

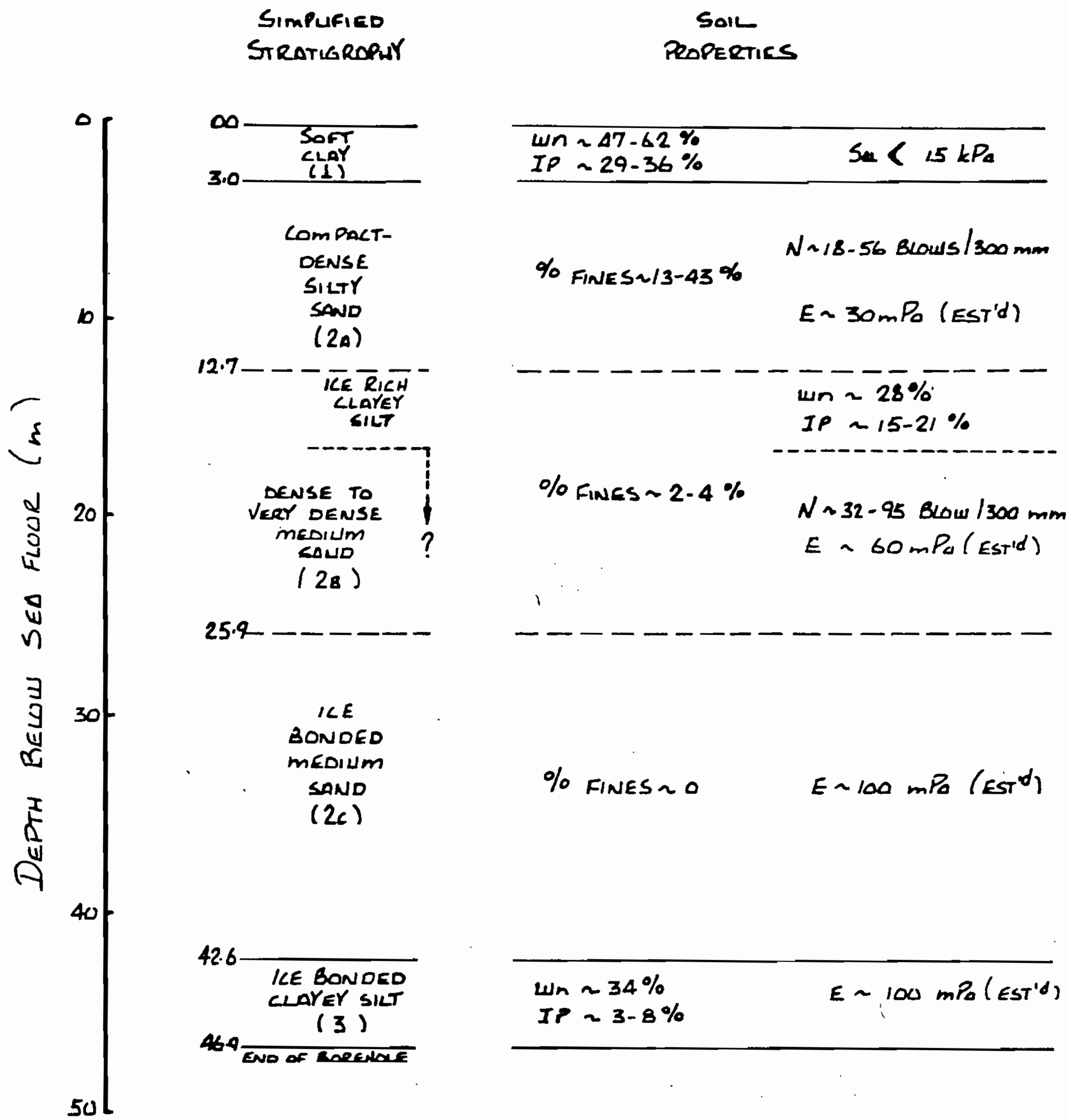
GRAIN SIZE DISTRIBUTION

Figure 3

Golder Associates

SUMMARIZED STRATIGRAPHY AND ENGINEERING PROPERTIES FOR PRELIMINARY DESIGN AKPAK SITE.

Figure 4



NOTE: STRATIGRAPHY AND ENGINEERING PROPERTIES GIVEN ON THIS FIGURE ARE FOR PRELIMINARY DESIGN PURPOSES ONLY.

Project No. 812-2102 Drawn D.S. Reviewed [illegible] Date NOV 82

APPENDIX I

FIELD INVESTIGATION PROCEDURES

812-2102 November, 1982

The initial phase* of the 1981 Field Program was to undertake geophysical traverses (by the Arctic Sounder) at the proposed site areas to determine, on a preliminary basis, the general stratigraphy at the sites. For calibration of the geophysical results and for the preliminary borrow search, a number of vibro-cored boreholes (VC series) were carried out from the same vessel. The vibra-coring carried out from the Arctic Sounder was not performed under the direction of Golder Associates, and details of these operations are therefore not included in this report. The geophysical and vibracore data was reviewed on site for selection of a potential MAC (Mobile Arctic Caisson) site within each site area. Potential MAC sites were selected based on water depth, thickness and consistency of surficial deposits, uniformity of stratigraphy and absence of permafrost.

Each selected MAC site was investigated by means of sampling and in situ testing from the Frank Broderick to verify the suitability of the chosen location from a geotechnical standpoint. Detailed sampled borings were put down from the Frank Broderick. This vessel was equipped with a diesel powered all hydraulic combined sonic/rotary top drive drillrig (modified Simco 5000 WS). The rig was mounted on rails to allow moving the rig and thereby to facilitate handling of casings and conductor pipes.

The casing system consisted of a conductor pipe and two different size casings. The conductor pipe, 203 mm (8") in diameter, was suspended from the moonpool cover to a maximum depth of approximately 27 m, to give additional lateral support to, and allow free vertical movement of, a 152 mm (6") casing, supported on the seafloor by means of a casing footing. The casing footing was equipped with longitudinal slots to allow discharge of the drilling mud onto the sea floor.

*No geophysical surveys or vibracore holes were carried out at the Akpak site during the 1981 investigation program.

Inside the 152 mm (6") casing, 102 mm (4") casing was used for drilling and advanced by means of a wireline casing advancer. Sampling was carried out below the 102 mm (4") casing using split spoon sampling equipment and/or 76 mm (3") Shelby tubes attached to BQ drillrods.

In addition to conventional split spoon and Shelby tube sampling, the rig was also equipped for wireline Shelby tube sampling and down hole standard penetration testing. However, these options were not used due to time and weather constraints.

For the foundation investigation borehole, the sampling intervals were generally 1.5 m down to approximately 30 m below sea floor, 3.0 m between 30 m and 60 m and 4.6 m below 60 m. These sampling intervals applied to both split spoon and Shelby tube sampling.

Despite occasional difficulties in performing the standard penetration test in rough weather conditions, the 'N' values obtained are considered to be reliable. This is supported by the comparison between SPT 'N' value profiles where profiles were drilled within 300 m of one another. All tests were performed using a rope and cathead system for raising the drop-hammer, with BQ drill rod used for sampling.

In situ vane tests were performed with a Nilcon vane borer at selected depths in cohesive soils. This instrument has a limited twist slip coupling between the vane and rods, which allows the vane shear resistance to be distinguished from rod friction. In addition a continuous mechanical trace of torque against rotation is obtained. All tests were carried out using a 100 mm vane, with a rated capacity of 220 kPa. Remoulded tests were generally performed after measurement of peak (undisturbed) strengths. To ensure that the vane remained stationary in the soil, the vane and vane rods were suspended from the 152 mm casing resting on the sea bed. Field vane strengths measured during this investigation have not been modified to account for effects such as strain rate or anisotropy.

In addition to the above techniques Static Cone Penetration Testing was attempted, but no results were obtained due to difficulties in handling the equipment on the ship. The equipment was however tried in shallow water and under ideal weather conditions.

APPENDIX II

LABORATORY TESTING PROCEDURES

812-2102 November, 1982

The geotechnical laboratory on the Frank Broderick was equipped for routine testing of all samples and for preliminary shear strength determination on cohesive soils. The laboratory equipment included the following.

- Hydraulic sample extruder for extrusion of Shelby tube samples.
- Sieves, hydrometers and balances for determination of grain size distribution.
- Oven for water content determination
- Casagrande liquid limit device for determination of liquid limit.
- Pilcon shear vane, pocket penetrometer and Geonor fall cone for determination of undrained shear strength.
- Triaxial apparatus for determination of shear strength by unconfined compression tests, UU (unconsolidated undrained) or CU (consolidated undrained) triaxial tests.
- Thermometers for temperature measurement of samples.
- Microscope for classification of ice bonded soils.

Split spoon samples were classified and a portion of each sample was placed in a sealed container for shipment to Calgary. For most samples, a sieve analysis was carried out on the ship. Hydrometer tests were attempted but were found to give incorrect results due to vibrations and the movements of the ship.

Following extrusion and classification of Shelby tube samples, one portion of each sample was sealed and prepared for shipment to Calgary and another was used for on board testing. On board, laboratory shear strength measurements were made using the fall cone, Pilcon vane and pocket penetrometer. The portions of samples retained onboard were used for determination of moisture content, Atterberg limits and for triaxial testing.

Where temperature measurements indicated the possibility of ice bonding, without visual evidence of ice, the samples were examined under the microscope.

Sample temperatures were taken as soon as the samples arrived in the laboratory by inserting a 1.5 mm diameter probe into the sample. Initially a mechanical dial gauge type reading to the nearest degree Fahrenheit was used. Towards the end of the investigation, an electronic thermometer, accurate to 0.1°C. was used.

Temperatures measured on Shelby tube samples are probably close to the in situ temperature, as ambient temperatures during most of the operation were close to 0°C. Temperatures of split spoon samples should be considered as approximate only as the temperature could be significantly altered when the sampler is driven, particularly as the blowcounts were frequently high.

In general, it appeared that ice or ice bonding was present in samples where the measured temperature was lower than approximately -1.6°C. However, some thawing during the sampling process occurs and this figure may not be representative for the material in situ.

All consolidation tests were performed using a conventional oedometer cell and gravity loading frame. The loading procedure was, however, modified slightly to improve the assessment and interpretation of test results. The vertical stress on the sample was applied in increments up to an effective stress level slightly less than the in situ effective overburden pressure. This load was then removed, allowing the sample to swell back under a nominal load. The purpose of this loading and unloading is to reduce the effects of sample disturbance on the consolidation curve obtained from the subsequent load increments. After the initial loading and rebound, the consolidation tests were performed in the usual manner. Samples were unloaded in increments after the final load increment. Each load was allowed to remain on the sample until primary consolidation was completed, based on Taylor's "square root of time" interpretation. Therefore the void ratio - log stress curves have not been corrected for secondary compression effects.

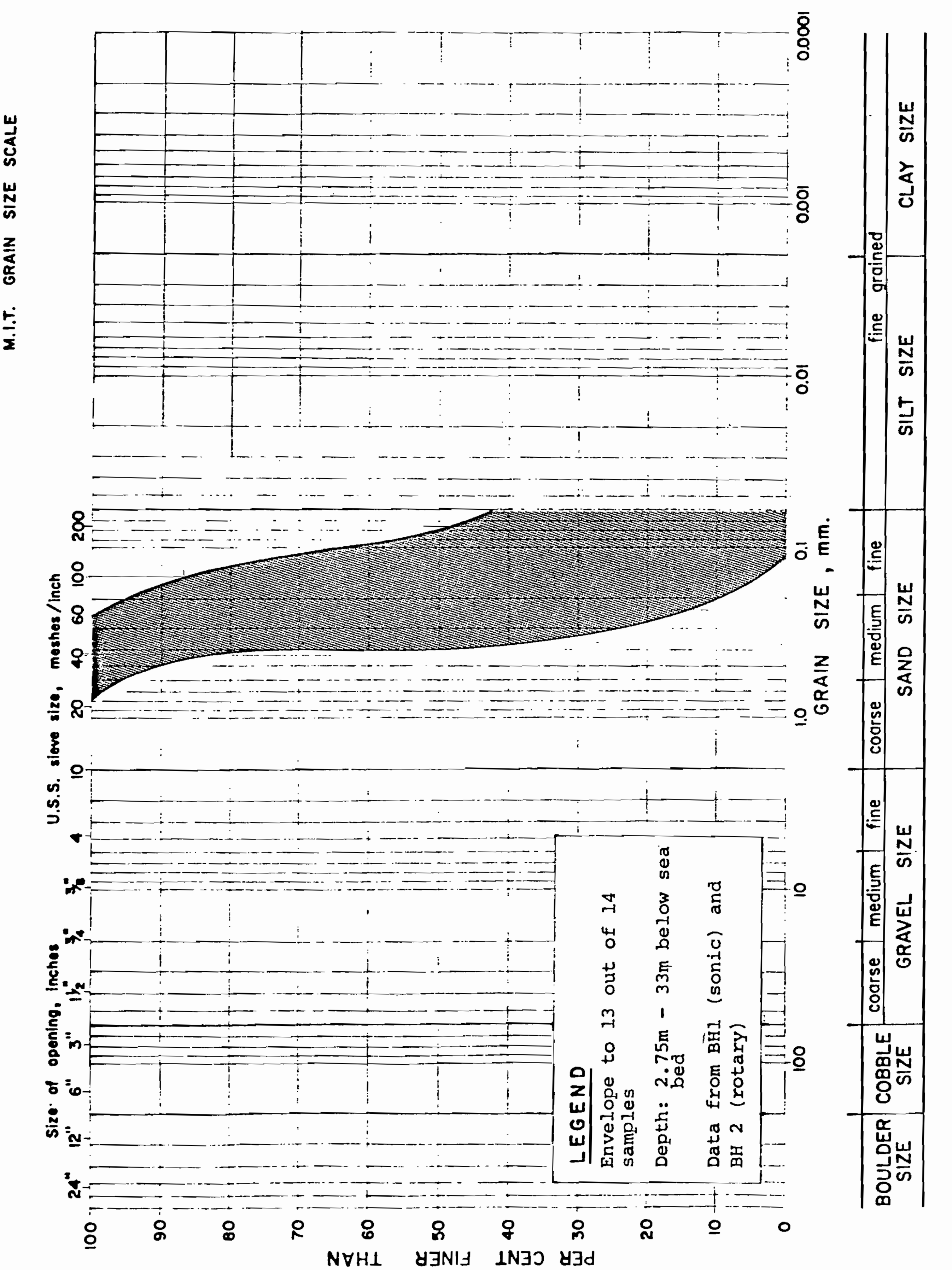
The undrained shear strength of samples was measured using a number of methods. It should be appreciated that rapid methods (i.e. laboratory vane, fall cone and pocket penetrometer tests) provide only approximate values of undrained shear strength since considerable scatter in test results is frequently evident from these various tests on the same sample. This variation is caused by a combination of varying boundary conditions and effective stress paths associated with the various tests. Other factors are also important, such as varying strain rate, and effect of intrinsic anisotropy of the soils being tested together with the small volume of test sample in relation to natural heterogeneity of the soil.

Effective stress strength parameters (c' and Ø') were determined in consolidated undrained triaxial tests with porewater pressure measurement ($\bar{R}$ tests). The triaxial test specimens were 50 or 72 mm in diameter and between 101 and 158 mm high. The tests were carried out on "undisturbed" specimens obtained from the Shelby tube samples. To ensure saturation of the test specimens (B>99%), back pressures were applied. The specimens were consolidated under cell pressures approximately equal to the in situ vertical effective stress. When consolidation was completed, drainage from the test specimen was shut off and undrained shearing carried out at a constant rate of strain. The strain rate of 1 to 3.5%/hr. adopted in these tests allows for equalization of porewater pressure throughout the samples. Water contents, unit weights and Atterberg limits were determined for the majority of triaxial test specimens.

GRAIN SIZE DISTRIBUTION

AKPAK MAC SITE - SUMMARY GRADING CURVE ENVELOPE

Figure 4.2



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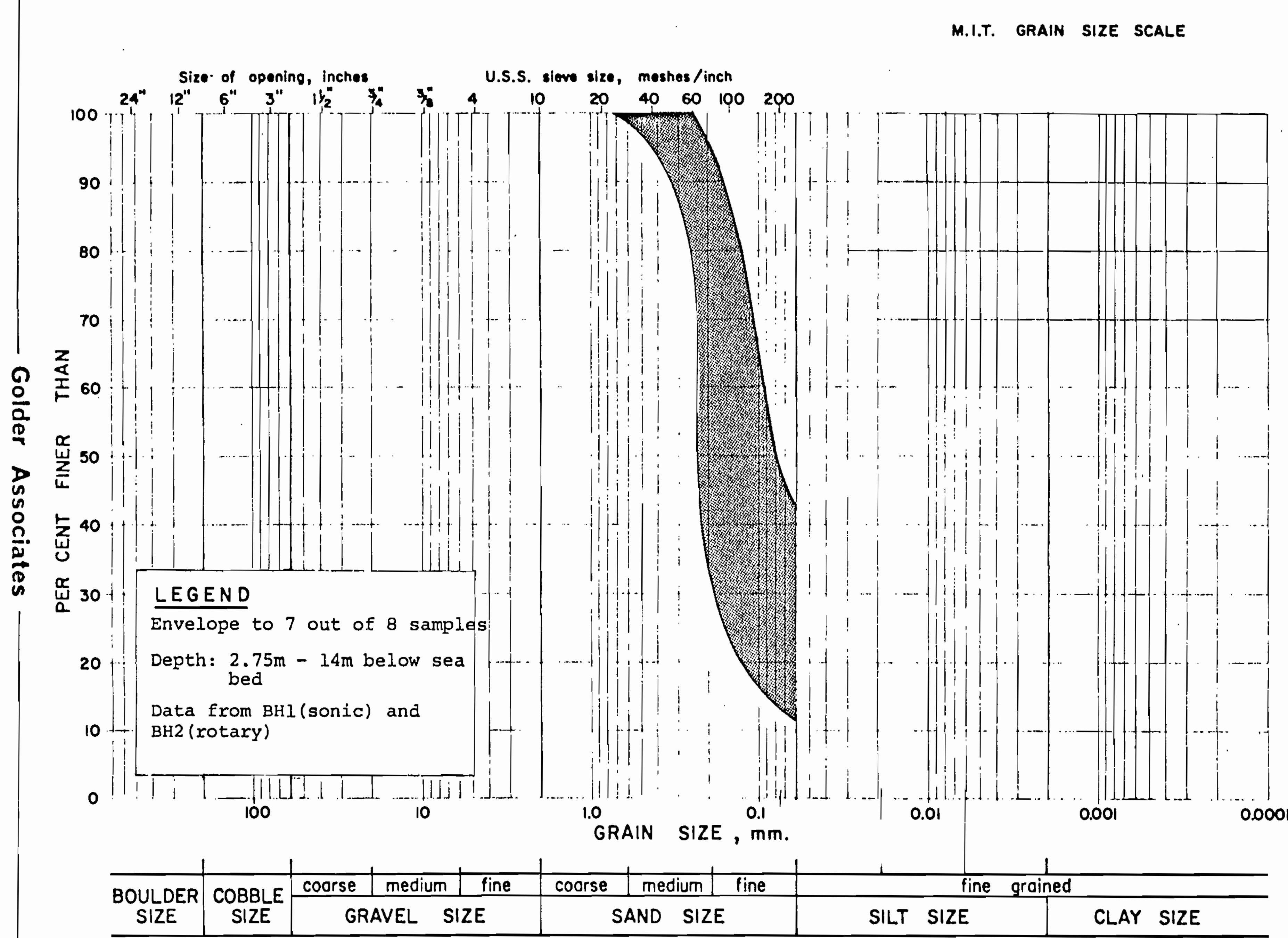

GRAIN SIZE DISTRIBUTION

AKPAK MAC SITE - SUMMARY GRADING CURVE ENVELOPE

Figure 4.3