1984 OFFSHORE GEOTECHNICAL SITE INVESTIGATION

HERSCHEL SILL SITES
YUKON TERRITORY

Submitted to

INDIAN AND NORTHERN AFFAIRS CANADA
GEOLOGICAL SURVEY OF CANADA

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1984 12 03

Geological Survey of Canada
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Job No. 101C-4133

Attention: Kate Moran
Environmental Marine Geology

Dear Kate:

Subject: Geotechnical Investigation - Herschel Sill Sites

This report presents a summary of the geotechnical data collected at the Herschel Sill for the Geological Survey of Canada (GSC) and Indian and Northern Affairs (INA) Canada. The information was obtained during the 1984 offshore geotechnical program conducted by EBA Engineering Consultants Ltd. (EBA) in conjunction with Beaudril Ltd. The general location of the site (HS Series Holes) is shown in Figure 1. The investigation was performed to determine the distribution, thickness and quality of potential sand and gravel deposits on the Herschel Sill, and the general stratigraphy and geotechnical properties of the area. Field testing was carried out from the Arctic Kiggiak on October 11, 1984. An operational calendar presented as Figure 2 indicates the duration of the investigation with respect to the 1984 GSC/INA program.

Field Investigation

The field investigation at the Herschel Sill site involved drilling of a series of holes along the short axis of a small, elongated bathymetric high. The total investigation comprised two sampled boreholes to depths of 19.7 m and 5.7 m, respectively, two shallow probeholes to delineate the gravel thickness, and four shallow test pits. Hole locations were selected by GSC/INA.

A summary of the fieldwork carried out at the site is presented in Table 1. The locations of the boreholes and probeholes drilled are summarized in Table 2, and presented on Figure 3.

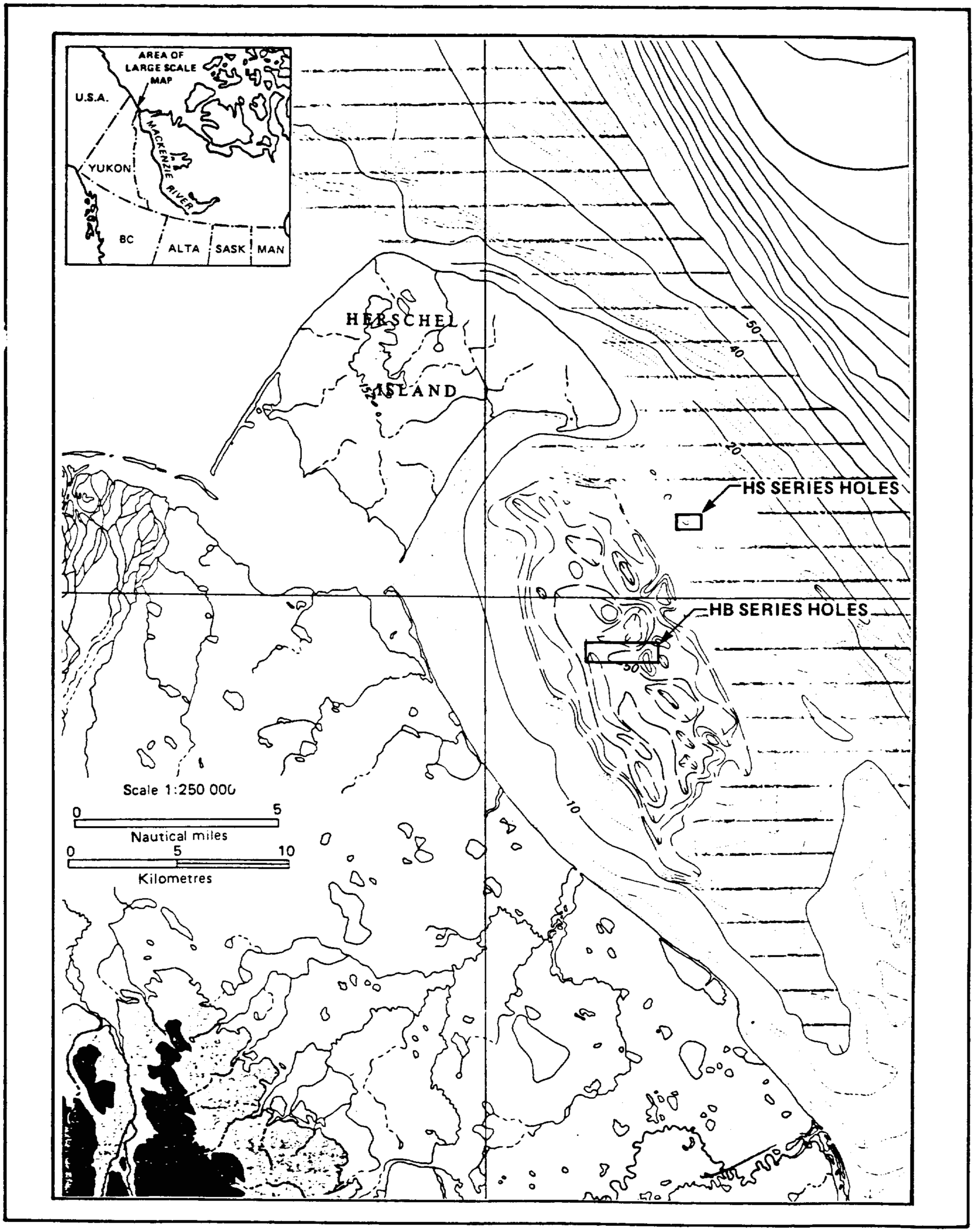


FIGURE 1 GENERAL LOCATION MAP

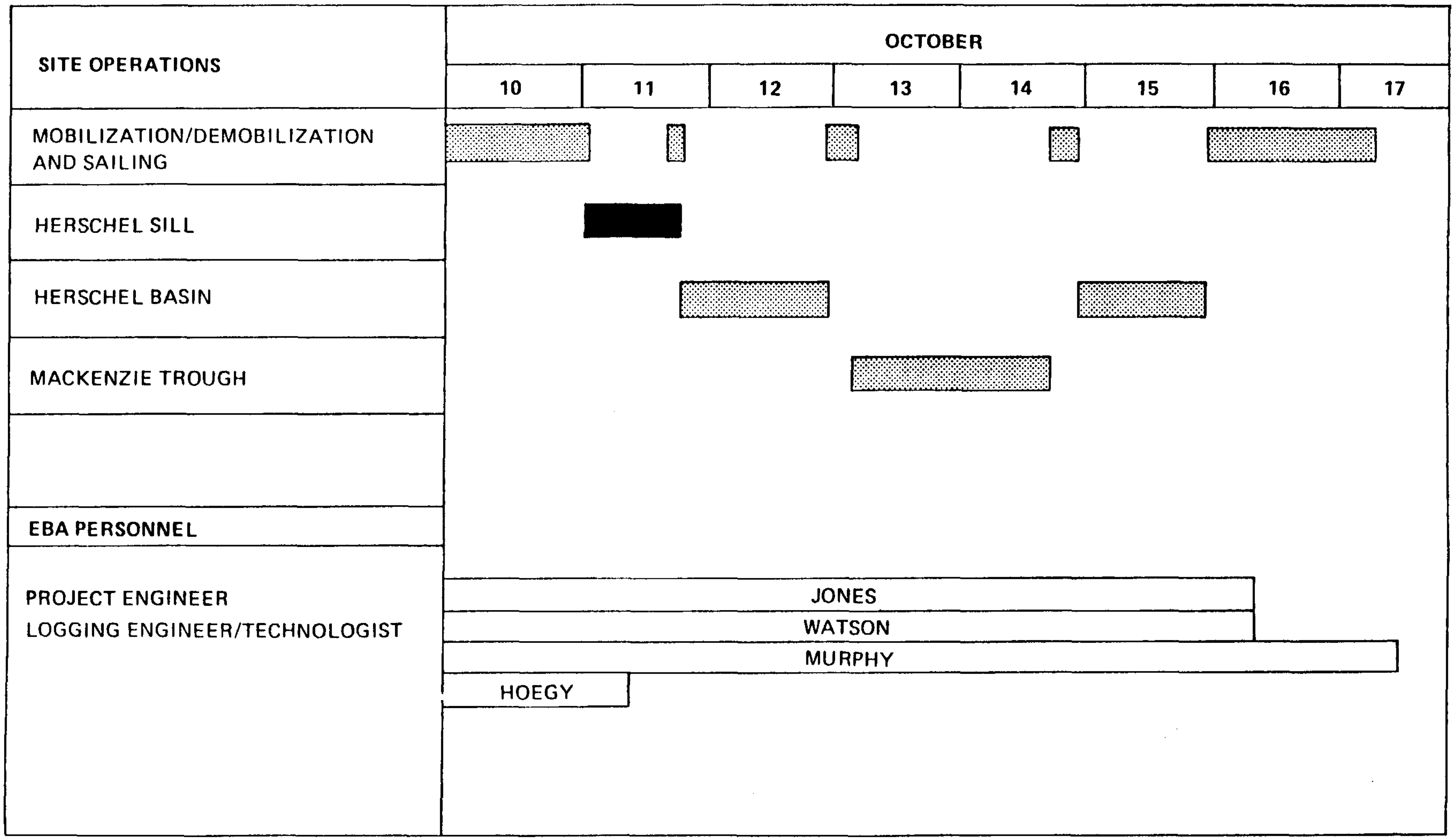


FIGURE 2 1984 OFFSHORE FIELD OPERATIONS SUMMARY – GSC/INA PROGRAMS

TABLE 1 OPERATIONAL CALENDAR
HERSCHEL SILL SITES

October 10, 1984

0000 - 1700	Enroute to Herschel Island.
1700 - 2400	Arrive at Gulf Beaufort. Loading water and enroute to Herschel Sill sites.

October 11, 1984

0000 - 0100	Enroute to Herschel Sill sites.
0100 - 0400	Setting anchors at borehole location HS01.
0400 - 1030	Drilling and sampling borehole HS01 to 19.7 m penetration, 13 samples recovered. Test pitting and sampling with clam shell bucket, 3 samples recovered.
1030 - 1040	Pulling out of hole and moving to borehole HS02.
1040 - 1230	Drilling and sampling borehole HS2 to 5.7 m penetration, 5 samples recovered. Test pitting and sampling with clam shell bucket, 1 sample recovered.
1230 - 1305	Pulling out of hole.
1305 - 1315	Moving to probehole location HS03.
1315 - 1400	Drilling probehole HS03 to bottom of sand at 1.52 m penetration. Test pitting and sampling with clam shell bucket, 2 samples recovered.
1400 - 1415	Moving to probehole location HS04.
1415 - 1425	Drilling probehole HS04 to bottom of sand at 2.0 m penetration. Testpitting and sampling with clam shell bucket, 1 sample recovered.
1425 - 1435	Preparing to leave Herschel Sill sites.
1435 - 1445	Pulling out of hole.
1445 - 1650	Pulling anchors and preparing to sail.
1650 - 1845	Sailing to Herschel Basin sites.

TABLE 2 BOREHOLE AND PROBEHOLE LOCATIONS

BOREHOLE/ PROBEHOLE	UTM COORDINATES (ZONE 7)		GEOGRAPHIC COORDINATES		DATE	SEABED PENETRATION
	mN	mE	LATITUDE	LONGITUDE	(YR-MO-DA)	(metres)
HS01	7 715 205	587 000	69°31'59"	138°46'13"	84-10-11	19.7
HS02	7 715 255	587 095	69°32'00"	138°46'04"	84-10-11	5.7
HS03	7 715 295	587 130	69°32'02"	138°46'01"	84-10-11	1.5+
HS04	7 715 160	586 975	69°31'57"	138°46'15"	84-10-11	2.0+

NOTE: 1. All coordinates supplied by CES. The borehole/probehole locations were established with a Syledis system.

2. Coordinates reported to nearest 5.0 metres in accordance with expected accuracy of survey equipment.

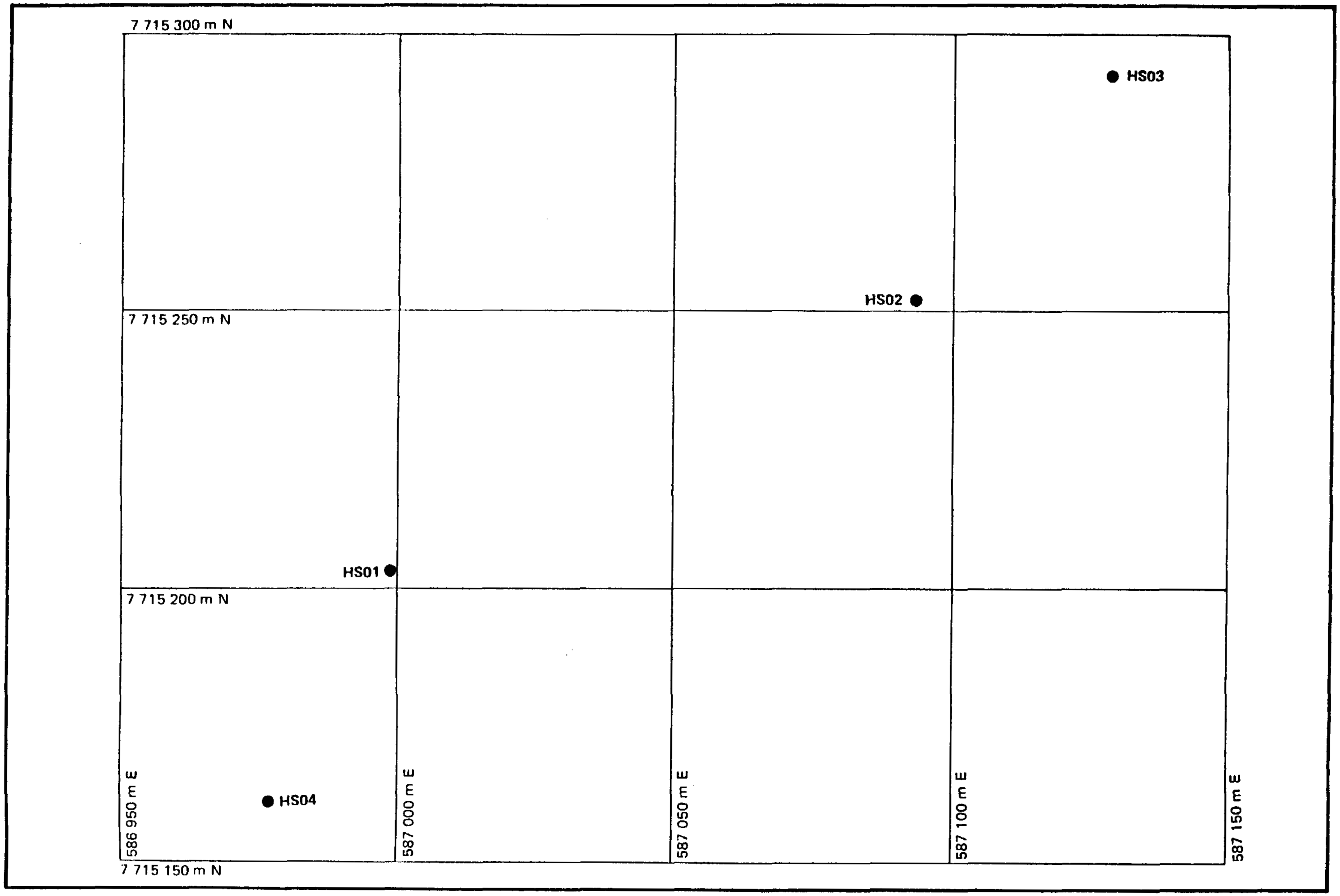


FIGURE 3 BOREHOLE LOCATION PLAN
HERSCHEL SILL INVESTIGATION

Drilling and Sampling

All subsurface testing was conducted from the barge "Arctic Kiggiak", a 114 m-long by 33 m-wide vessel converted for geotechnical fieldwork. The barge deployed a six-point anchor pattern during most tests. The testholes were drilled through a 80 m^2 moonpool situated amidships, approximately half-way along its length. A modified Simco 5000 WS diesel top-drive rotary drilling rig, mounted on rails adjacent to the moonpool, was used for all drilling and sampling operations.

The drilling operation was conducted without use of down-hole casing. The hole was advanced using open-centre, tungsten carbide drag bits, mounted on the core barrel assembly, especially adapted to receive the latch-in wireline samplers. The drill rod was 114 mm O.D. by 102 mm I.D. ("four inch") bottleneck drill pipe.

In each of the sampled boreholes, samples were obtained at approximately 1.0 m to 1.5 m intervals. Non-cohesive soils were sampled with a 65 mm I.D., heavy-walled, sampling tube operating on a 75 kilogram wireline hammer. Samples recovered in this zone varied from 0.25 m to 0.4 m in length. Cohesive soils were sampled using 76.2 mm, internal diameter, thin-walled stainless steel sampling tubes. To advance the tubes, a latch-in wireline system, which uses the weight of the drill string to push the sampling tube, was employed. Samples recovered varied from 0.2 metres to 0.8 metres in length.

Depending upon the nature of the soil observed in the end of the sampling tube, a series of standard procedures were carried out as described in the following.

Immediately upon recovery of the sampling tube from the borehole, the temperature of the sampled soil was determined using a thermistor probe accurate to ±0.01°C, inserted up to 50 mm into the end of the sample. If the sample consisted of cohesive soils, the undrained shear strength was also determined with a "Pilcon" hand vane inserted into the sample. The sample temperature and strength data is presented on the borehole logs in Appendix A.

Granular materials were extruded from the tubes and subsampled for onboard moisture content, gradation, and salinity analyses. Approximately 5 cm to 15 cm of the cohesive soils was extruded for onboard testing of moisture content, bulk density and porewater salinity. The remaining portions of cohesive samples were sealed in the tubes. The remaining samples were stored in wooden boxes or pails and shipped to the Inuvik Scientific Research Centre, or EBA's Edmonton laboratory.

At each of the probehole locations, the hole was advanced, without sampling, until the surficial granular materials had been penetrated.

A shallow test pit was excavated at each borehole or probehole location using a clam shell bucket operated from the deck crane on the Kiggiak. Grab samples of the granular materials recovered were obtained from the bucket for onboard gradation analysis.

General Geological History

The location of Herschel Sill relative to the major physiographic regions that have been identified on the Canadian Beaufort Shelf is shown on Figure 4. The study area lies on the Natsek Plain, an area for which little subsea information is available. The discussion that follows is based on published information on the Yukon/Alaska Coastal Plain and previous discussions with Mr. Phil Hill of the Geological Survey of Canada.

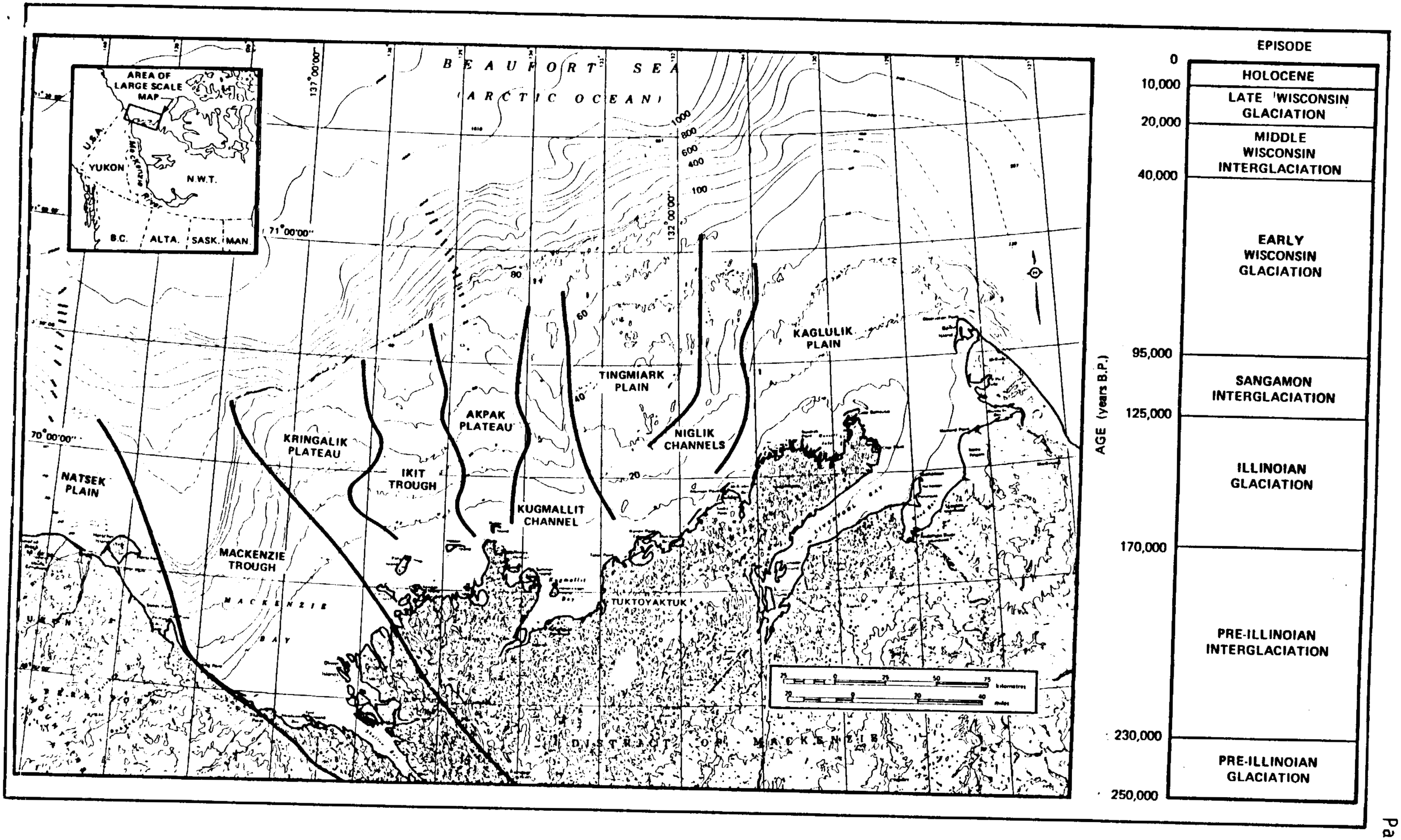


FIGURE 4 PHYSIOGRAPHIC REGIONS OF THE BEAUFORT SEA AND GEOLOGIC TIME SCALE

Exposures on the Yukon/Alaska Coastal Plain reveal sediments which are thought to predate the early Wisconsin (Buckland) glaciation. Hopkins (1973), and more recently, Rampton (1982), have suggested that these pre-Buckland sediments were deposited during the nonglacial interval immediately preceding the early Wisconsin (see geological time scale on Figure 4).

Sections of the pre-Buckland sediments exposed on Herschel Island reveal complex marine, deltaic, fluvial, lacustrine and even terrestrial depositional environments. Three marine units have been identified on Herschel Island (Rampton, 1982). These consist of marine clays overlying "mixed sediments from shallow marine and brackish retreat during this period". Radiocarbon analysis of wood and peat recovered from the pre-Buckland sediments dates the material as being older than 51,100 years (reported in Rampton, 1982).

The Buckland glaciation, which is thought to have occurred greater than 40,000 years ago, is likely responsible for a major ice-thrusting event at Herschel Island. The Mackenzie Trough probably influenced the movement of the early Wisconsin ice sheet, forming a lobe of ice to the northwest. This lobe is thought to have thrust sediments from Herschel Basin to form Herschel Island (Mackay, 1959).

Herschel Basin is confined on the seaward side by a narrow submerged ridge extending southeast from the eastern tip of Herschel Island. This ridge, which includes Herschel Sill, is thought to be an intact remnant of the original pre-Buckland marine sequence which escaped removal by the ice-thrusting event (Phil Hill, personal communication). Localized folding and thrusting of the sediments is, however, possible along the margin of the position of the ice lobe. The thin surficial deposit of granular material on Herschel Sill may therefore be a marine lag deposit derived from moraine deposited during the Buckland glaciation, or small glaciofluvial or ice-contact features laid down during the ice retreat from the area.

During and immediately following this glaciation, when sea levels were depressed at least 60 metres below present levels, the shelf sediments were exposed to a periglacial environment. Permafrost aggradation likely occurred while this cooler climate prevailed.

Post-Buckland, Wisconsin deposition appears to have been largely absent from the Herschel area, unlike the area east of the Mackenzie Trough, where an extensive deltaic sequence developed. It is postulated that, in the study area, only minor coastal reworking of thin glacial and preglacial deposits has generally occurred, producing numerous spits, baymouth bars, and beach ridges at varying elevations. The granular deposits on Herschel Sill, however, are likely to have experienced more extensive reworking. The area appears to have been unaffected by the late Wisconsin glacial advance.

Modern marine deposition appears limited to extension of bars and spits by longshore drift, although active deposition continues near the mouths of the Mackenzie, Firth and Malcolm rivers.

Stratigraphy

The stratigraphy of the Herschel Sill site, as revealed by the present investigation, is summarized in Table 3.

This sequence appears to be consistent with the description of the ice-thrust exposures on Herschel Island (Rampton, 1982) and with the stratigraphy defined by other investigations conducted by EBA in the same general area. Local glacial outwash, extensive marine reworking and longshore drift account for most discrepancies.

TABLE 3 LITHOSTRATIGRAPHIC UNITS OF HERSCHEL SILL

UNIT	THICKNESS (metres)	DESCRIPTION
Ia	1.2 - 2.2	GRAVEL and SAND, (GW-GP) - trace of silt, sub-rounded to angular gravel, maximum diameter varies from 20 mm to 40 mm, dense, dark grey.
Ib	0.3 - 1.2	SAND, (SP-SM) - trace of silt to silty, traces of clay and gravel, uniform fine-grained, becoming laminated, dark grey.
IIa	3.0	CLAY (CI-CH) - silty to some silt, trace of fine grained sand, trace organics, peat, and coal, very thinly laminated, firm to stiff, moist, high to medium plasticity, dark grey.
IIb	(13.3+)	CLAY (CL) - trace of silt, trace of shell fragments, slightly blocky, very stiff to hard, dry, low plasticity, dark grey.

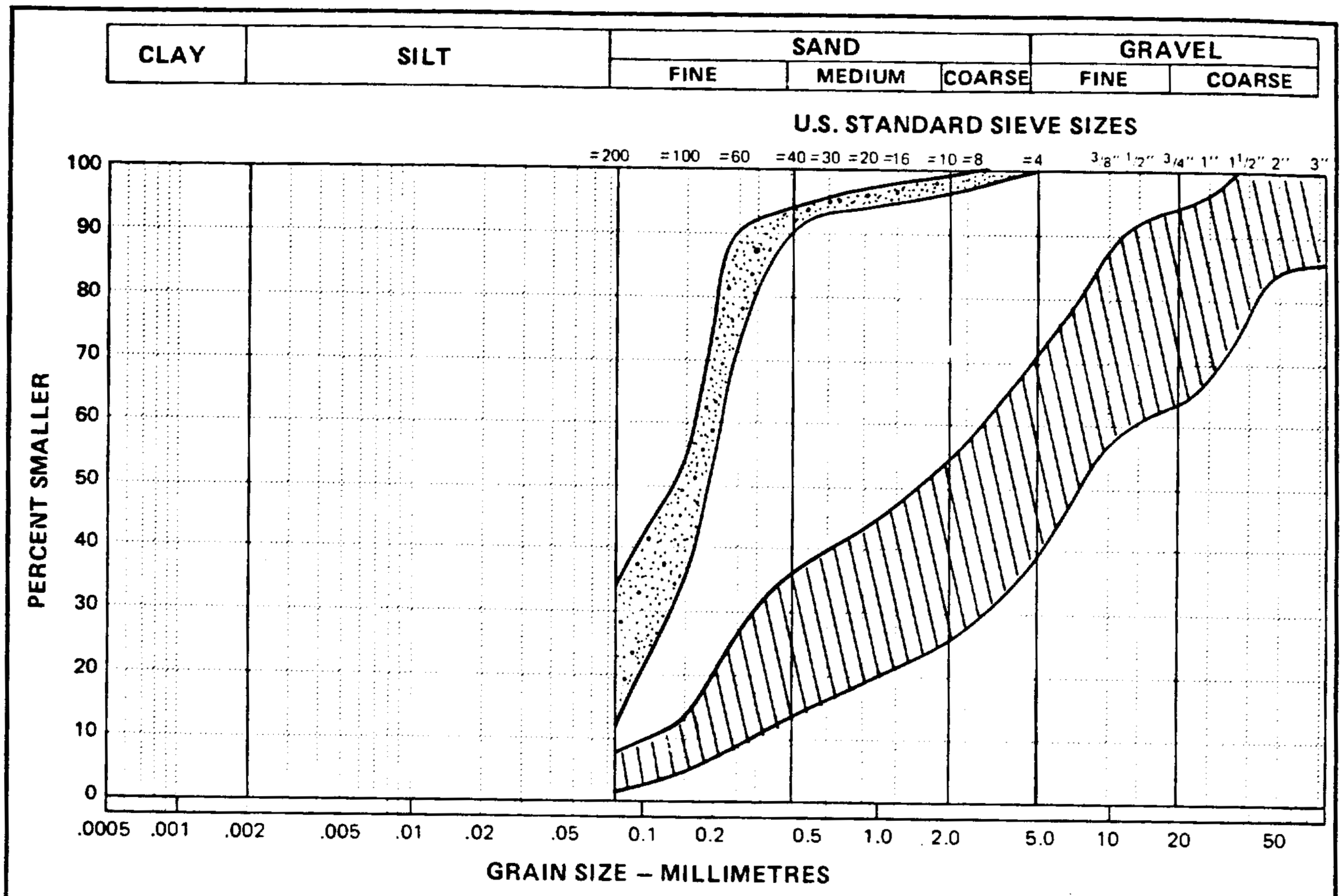
The granular deposit (Unit I), ranged in thickness from 1.52 m to 3.4 m at the locations drilled. The deposit reflects the bathymetry of the feature, reaching its maximum thickness near the centre and thinning on the flanks of the ridge. The surficial GRAVEL and SAND (subunit Ia) is more than 2.1 m thick at borehole HS01 but is only slightly over 1.0 m thick at the other locations drilled. The subunit is also coarser at borehole HS01, and becomes SAND and GRAVEL (SP), containing occasional shell fragments, on the flanks of the bathymetric feature. The underlying silty SAND (subunit Ib) is approximately 1.0 m thick at the sampled boreholes, (HS01 and HS01) but is believed to thin to about 0.3 m to 0.4 m thick towards the probehole locations (HS03 and HS04).

The underlying fine-grained sediment (Unit II) is known to be at least 16.3 m thick at borehole HS01, however, because drilling was terminated at this depth, its maximum extent was not determined. This clay unit probably correlates with the upper marine clay exposed on Herschel Island. The upper portion of the CLAY (subunit IIa), sampled at boreholes HS01 and HS02, is approximately 3.0 m thick. This subunit is generally moist but the composition, consistency and plasticity of the clay is variable. The deeper CLAY (subunit IIb) is typically very stiff and dry.

Detailed descriptions of textural variations, consistency, and colour for each unit are given on the borehole logs presented in Appendix A.

Soil Properties

The engineering properties of the seabed soils penetrated can be summarized on the basis of the stratigraphic units described above. The soil properties described below are based on limited onboard laboratory testing. Pertinent engineering properties measured are summarized in Appendices A and B, and in Figure 5.



SYMBOL	BOREHOLE NUMBER	DEPTH (m)	DESCRIPTION				Cu	Cc	U.S.C.
			CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)			
▨	UNIT Ia	8 SAMPLES		2-8	35-66	30-63			GP/SP-SM
░	UNIT Ib	2 SAMPLES		11-30	70-89	0			SM

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FIGURE 5 GRADATION ENVELOPES FOR GRANULAR MATERIALS
HERSCHEL SILL

EBA Engineering Consultants Ltd.

The surficial GRAVEL and SAND (subunit Ia) is well-graded to poorly-graded and contains 2% to 8% silt-sizes, 35% to 66% sand-sizes and 30% to 63% gravel-sizes. D_{50} values range from 1500 to 7300 microns. Gradations of the disturbed samples, obtained from the clam shell bucket (Figure B.2 in Appendix B), were consistently finer than undisturbed samples from the boreholes (Figure B.1). A single moisture content determination for this unit yielded a value of 12%. From observations made during drilling, the materials appear to be dense to very dense.

The SAND layer (subunit Ib) was found to contain uniform fine-grained sands with 11% to 30% of silt-sizes. The D_{50} values ranged from 120 microns to 170 microns. Limited testing revealed a moisture content of 22%, a bulk density of 1.88 Mg/m^3 and porewater salinity of 24 parts per thousand (ppt).

Samples of the upper CLAY (subunit IIa) recovered from the two boreholes were found to be firm to stiff in consistency, with undrained shear strengths, as determined by the Pilcon vane, ranging from 28 kPa to 99 kPa. The undrained shear strength was observed to increase with depth. Moisture contents were generally in the order of 35% ± 3%, and wet bulk densities ranged from 1.65 Mg/m^3 to 1.76 Mg/m^3. Porewater salinities ranged from 11 ppt to 18 ppt, and showed a tendency of decreasing salinity with depth. The clay is classified as intermediate to high plasticity, but Atterberg limit and hydrometer testing has not been completed to verify these field classifications.

The lower CLAY (subunit IIb) was sampled only in borehole HS01. Moisture contents within the layer decreased with depth from about 30% near the top of the unit to about 20% near the termination depth of the borehole.

Bulk densities in the order of 1.50 Mg/m^3 to 1.60 Mg/m^3 were measured near the top of the subunit, but values of 1.88 Mg/m^3 to 2.00 Mg/m^3 were obtained at depth. Undrained shear strengths were consistently greater than 120 kPa, but as most values were beyond the range of the Pilcon vane (>130 kPa), no indication of the variation of strength with depth is available. The clay is described as being of very stiff consistency throughout. The lower clay is classified as being of low plasticity, but Atterberg limit and hydrometer testing have not been completed.

Permafrost and Ground Ice

"Permafrost" is defined as any earth material that has been at 0°C or less for a prolonged period of time without any regard to the phase composition of moisture present in the pore spaces. The typical marine sediments from the Beaufort Sea have porewater salinities between 30 and 40 ppt, resulting in a freezing point depression of close to 1.5°C. As a result soil can exist at temperatures below 0°C but exhibit no significant ice bonding or segregated ice. For the purposes of this field program, soil has been designated "frozen" only if visible ice and/or ice bonding was encountered. "Frozen" soil is therefore distinguished from "permafrost" as permafrost conditions are not necessarily of engineering significance.

Isolated, thin layers and pockets of frozen material are thought to be present near the seabed, within the surficial granular deposits. Clam shell samples recovered from a depth of 0.6 m to 0.7 m in the test pit at location HS01 contained frozen material. However, frozen soils were not detected in any of the boreholes or probeholes, and sample temperatures were consistently higher than -1.0°C. As a result of the measured salinities of 11 ppt to 24 ppt, freezing point depression of between 0.6C° and 1.4C° would be expected for the pore fluids. Frozen material, with traces of stratified ice (Vs) and ice crystals (Vx) has been observed below 11.0 m seabed penetration during other investigations conducted by EBA in the same general area.

Closure

The geotechnical information contained in this letter report was obtained from seabed soil samples collected during the 1984 geotechnical program carried out for the Geological Survey of Canada and Indian and Northern Affairs Canada.

The geotechnical data obtained during the Herschel Sill site investigation indicates that thin deposits of clean gravel and sand are present at the seabed in small, ridge-like features. The base of the granular deposit consists of silty sands. Although the deposit contains isolated frozen material, it is believed that these materials could be recovered by dredging if sufficient quantities are proven in the the area.

The underlying clays are thought to represent the intact pre-Buckland sediments not scoured by the ice-thrusting event at Herschel Island. The clays are believed to be similar to the upper part of marine sequence exposed on Herschel Island.

EBA Engineering Consultants Ltd. has appreciated the opportunity to work on this project and would like to acknowledge the cooperation and guidance provided by all other parties involved in this program.

Respectfully submitted,

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MACKAY, J.R., 1959. Glacier Ice-thrust Features of the Yukon Coast. Geographical Bulletin, No. 13, pp. 5-21.

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SYSTEM INTERNATIONAL UNITS

QUANTITY	NAME	SYMBOL	EXPRESSED IN TERMS OF OTHER SI UNITS	EXPRESSED IN TERMS OF BASE AND SUPPLEMENTARY UNITS
SI UNITS				
length	metre	m		
mass	kilogram	kg		
time	second	s		
electric current	ampere	A		
thermodynamic temperature	kelvin	K		
amount of substance	mole	mol		
luminous intensity	candela	cd		
SI SUPPLEMENTARY UNITS				
plane angle	radian	rad		
solid angle	steradian	sr		
EXAMPLES OF SI DERIVED UNITS WITH SPECIAL NAMES				
frequency	hertz	Hz	1/s	s^{1}
force	newton	N	$m \cdot kg/s^2$	$m \cdot kg \cdot s^{2}$
pressure, stress	pascal	Pa	N/m^2	$m^{1} \cdot kg \cdot s^{2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{3}$
EXAMPLES OF SI DERIVED UNITS WITHOUT SPECIAL NAMES				
velocity - linear	metre per second		m/s	$m \cdot s^{1}$
- angular	(radian per second)		rad/s	$rad \cdot s^{1}$
acceleration - linear	(metre per second) per second		m/s^2	$m \cdot s^{2}$
- angular	(radian per second) per second		rad/s^2	$rad \cdot s^{2}$
concentration (of amount of substance)	mole per cubic metre		mol/m^3	$mol \cdot m^{3}$
dynamic viscosity	pascal second		$Pa \cdot s$	$m^{1} \cdot kg \cdot s^{1}$
moment of force	newton metre		$N \cdot m$	$m^2 \cdot kg \cdot s^{2}$
surface tension	newton per metre		N/m	$kg \cdot s^{2}$
heat flux density, irradiance	watt per square metre		W/m^2	$kg \cdot s^{3}$
heat capacity, entropy	joule per kelvin		J/K	$m^2 \cdot s^{2} \cdot K^{1}$
specific heat capacity, specific entropy	joule per kilogram kelvin		$J/(kg \cdot K)$	$m^2 \cdot s^{2} \cdot K^{1}$
specific energy	joule per kilogram		J/kg	$m^2 \cdot s^{2}$
thermal conductivity	watt per metre kelvin		$W/(m \cdot K)$	$m \cdot kg \cdot s^{3} \cdot K^{1}$

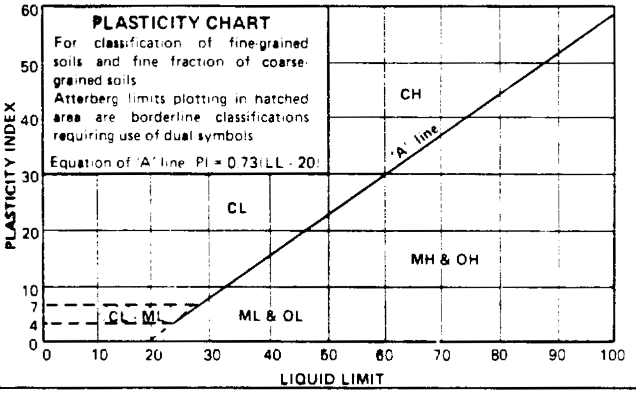
OTHER UNITS PERMITTED FOR USE WITH SI

QUANTITY	NAME	SYMBOL	DEFINITION
time	minute	min	1 min = 60 s
	hour	h	1 h = 3,600 s
	day	d	1 d = 86,400 s
	year	a	
plane angle	degree	°	1° = (π/180) rad
	minute	′	1′ = (π/10,800) rad
	second	″	1″ = (π/648 000) rad
area	hectare	ha	1 ha = 10,000 m^2
volume	litre	L	1,000 L = 1 m^3
temperature	degree Celsius	C	0 C = 273.15 K
			temperature interval 1 C 1 K
mass	tonne	t	1 t = 1,000 kg = 1 Mg

MULTIPLYING FACTOR	PREFIX	SYMBOL	MULTIPLYING FACTOR	PREFIX	SYMBOL
1,000,000,000,000,000,000 = 10^{18}	exa	E	0.1 = 10^{1}	deci*	d
1,000,000,000,000,000 = 10^{15}	peta	P	0.01 = 10^{2}	centi*	c
1,000,000,000,000 = 10^{12}	tetra	T	0.001 = 10^{3}	milli	m
1,000,000,000 = 10^{9}	giga	G	0.000,001 = 10^{6}	micro	μ
1,000,000 = 10^{6}	mega	M	0.000,000,001 = 10^{9}	nano	n
1,000 = 10^{3}	kilo	k	0.000,000,000,001 = 10^{12}	pico	p
100 = 10^{2}	hecto*	h	0.000,000,000,000,001 = 10^{15}	femto	f
10 = 10^{1}	deca*	da	0.000,000,000,000,000,001 = 10^{18}	atto	a

* *to be avoided where possible*

UNIFIED SOIL CLASSIFICATION†

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	CLASSIFICATION CRITERIA		
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve*	**GRAVELS** 50% or more of coarse fraction retained on No. 4 sieve	**CLEAN GRAVELS**	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	Classification on basis of percentage of fines Less than 5% pass No. 200 sieve More than 12% pass No. 200 sieve 5% to 12% pass No. 200 sieve GW, GP, SW, SP GM, GC, SM, SC Borderline classification requiring use of dual symbols	$C_u = D_{60}/D_{10}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines		Not meeting both criteria for GW	
		GRAVELS WITH FINES	GM	Silty gravels, gravel-sand-silt mixtures		Atterberg limits plot below 'A' line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			GC	Clayey gravels, gravel-sand clay mixtures		Atterberg limits plot above 'A' line and plasticity index greater than 7	
	SANDS More than 50% of coarse fraction passes No. 4 sieve	**CLEAN SANDS**	SW	Well-graded sands and gravelly sands, little or no fines		$C_u = D_{60}/D_{10}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			SP	Poorly-graded sands and gravelly sands, little or no fines		Not meeting both criteria for SW	
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures		Atterberg limits plot below 'A' line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures		Atterberg limits plot above 'A' line and plasticity index greater than 7	
FINE-GRAINED SOILS 50% or more passes No. 200 sieve*	**SILTS AND CLAYS**	Liquid limit 50% or less	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands	 **PLASTICITY CHART** For classification of fine-grained soils and fine fraction of coarse-grained soils Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols Equation of 'A' line: PI = 0.73(LL - 20)		
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silty clays of low plasticity			
	SILTS AND CLAYS	Liquid limit greater than 50%	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts			
			CH	Inorganic clays of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity			
HIGHLY ORGANIC SOILS			PT	Peat, muck and other highly organic soils	*Based on the material passing the 3 in. (75 mm) sieve †ASTM Designation D 2487, for identification procedure see D 2488		

GROUND ICE DESCRIPTION

ICE NOT VISIBLE

GROUP SYMBOLS	SYMBOLS	SUBGROUP DESCRIPTION	
N	Nf	Poorly-bonded or friable	▨
	Nbn	No excess ice, well-bonded	■
	Nbe	Excess ice, well - bonded	■

NOTE:

1. *Dual symbols are used to indicate borderline or mixed ice classifications*
2. *Visual estimates of ice contents indicated on borehole logs ± 5%*
3. *This system of ground ice description has been modified from NRC Technical Memo 79, Guide to the Field Description of Permafrost for Engineering Purposes*

LEGEND

Soil ■ Ice ■

VISIBLE ICE LESS THAN 50% BY VOLUME

GROUP SYMBOLS	SYMBOLS	SUBGROUP DESCRIPTION	
V	Vx	Individual ice crystals or inclusions	■
	Vc	Ice coatings on particles	▨
	Vr	Random or irregularly oriented ice formations	■
	Vs	Stratified or distinctly oriented ice formations	■

VISIBLE ICE GREATER THAN 50% BY VOLUME

ICE	ICE + Soil Type	Ice with soil inclusions	■
	ICE	Ice without soil inclusions (greater than 25 mm (1 in.) thick)	■

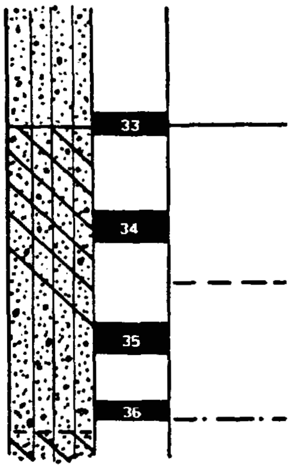
SYMBOLS AND ABBREVIATIONS USED ON BOREHOLE LOGS

SOIL SAMPLE

- represented by sample identification number which increase sequentially from the top of the hole, thickness of block is equivalent to sample recovery

SOIL BOUNDARIES

- have been indicated using the following system
- stratum boundary observed within sample
- stratum boundary assumed to occur within ± 0.5 m of the marked level and is probably gradational between the two samples
- stratum boundary assumed to occur within ±1.0m of the marked level
- stratum boundary notation for both depth below seabed (41.5 m) and elevation below sealevel (uncorrected for tides) (-64.6m. Elevation)



41.5 (-64.6 El.)

SOIL DESCRIPTION

UNIFIED SOIL CLASSIFICATION USC

- determined in accordance with chart on following page

TEXTURAL DESCRIPTION

- material named after its principal component
- name is modified by other components as follows:

Presence of Component "XXX"	Modifier
> - 35%	and XXX
21 - 35%	XXX-ey
11 - 20%	Some XXX
1 - 10%	Trace of XXX

- Modifiers are always recorded in order of decreasing amounts.
- Classification may be modified as information regarding plasticity, grain size distribution, etc., is made available from lab test results.

e.g. FROZEN	28.1°C
- Nf - Nbn	
- poorly to slightly bonded	
SAND: Nbn	28.5°C
CLAY: not frozen	

TEST RESULTS

- see legend at bottom of borehole log

CONSISTENCY

Fine-Grained Soils

Major portion passing No. 200 Sieve. Includes (1) inorganic and organic silts and clays, (2) gravelly, sandy, or silty clays, and (3) clayey silt. Consistency is rated according to undrained shear strength, as indicated by cone penetrometer reading or miniature vane and triaxial test results.

Descriptive Term	Undrained Shear Strength (ksf)
Very Soft	less than 0.25
Soft	0.25 to 0.50
Firm	0.50 to 1.00
Stiff	1.00 to 2.00
Very Stiff	2.00 to 4.00
Hard	4.00 and higher

Coarse-Grained Soils

Major portion retained in No. 200 Sieve. Includes (1) clean gravels and sands, and (2) silty or clayey gravels and sands. Condition is rated according to relative density, as determined by laboratory tests.

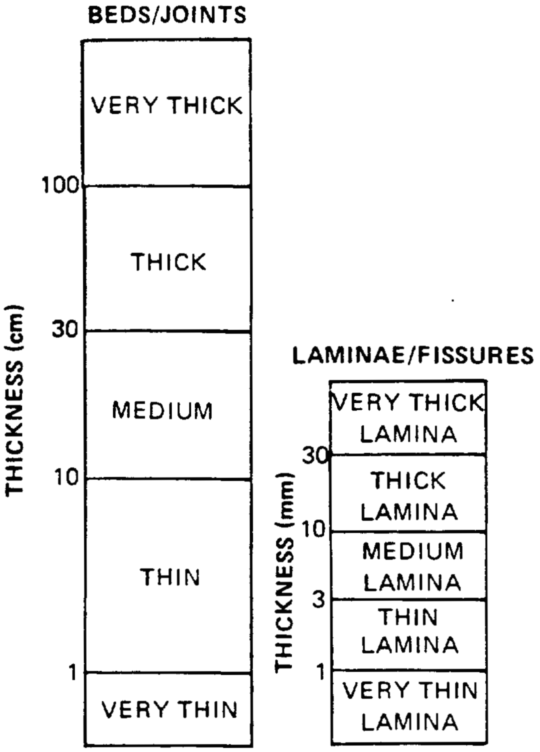
Descriptive Term	Relative Density
Very Loose	0 - 20%
Loose	20 - 40%
Compact or Medium	40 - 75%
Dense	75 - 90%
Very Dense	90 - 100%

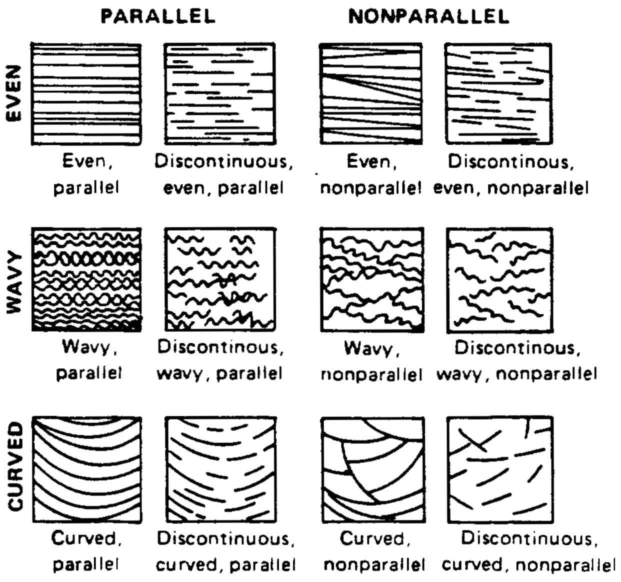
PLASTICITY

L Low - Liquid limit less than 35
I Intermediate - Liquid limit between 35 and 50
H High - Liquid limit greater than 50

DESCRIPTION OF SEDIMENTARY STRUCTURES

BEDS	SEDIMENTATION UNITS DEPOSITED UNDER ESSENTIALLY CONSTANT PHYSICAL CONDITIONS, SEPARATED BY BEDDING PLANES WHICH ARE RECOGNIZABLE BY TEXTURAL OR COMPOSITIONAL CHANGES RESULTING FROM PERIODS OF NON-DEPOSITION OR EROSION, OR ABRUPT CHANGES IN DEPOSITIONAL CONDITIONS. BEDS MAY BE INTERNALLY HOMOGENEOUS, OR COMPOSED OF SMALLER UNITS-LAMINAE
LAMINAE	THE SMALLEST MEGASCOPIC LAYERS IN A SEDIMENTARY SEQUENCE, REPRESENTING MINOR FLUCTUATIONS IN PHYSICAL CONDITIONS DURING THE DEPOSITION OF BEDS. LAMINAE ARE RELATIVELY UNIFORM IN TEXTURE AND COMPOSITION AND GENERALLY LACK MEGASCOPIC INTERNAL LAYERING.





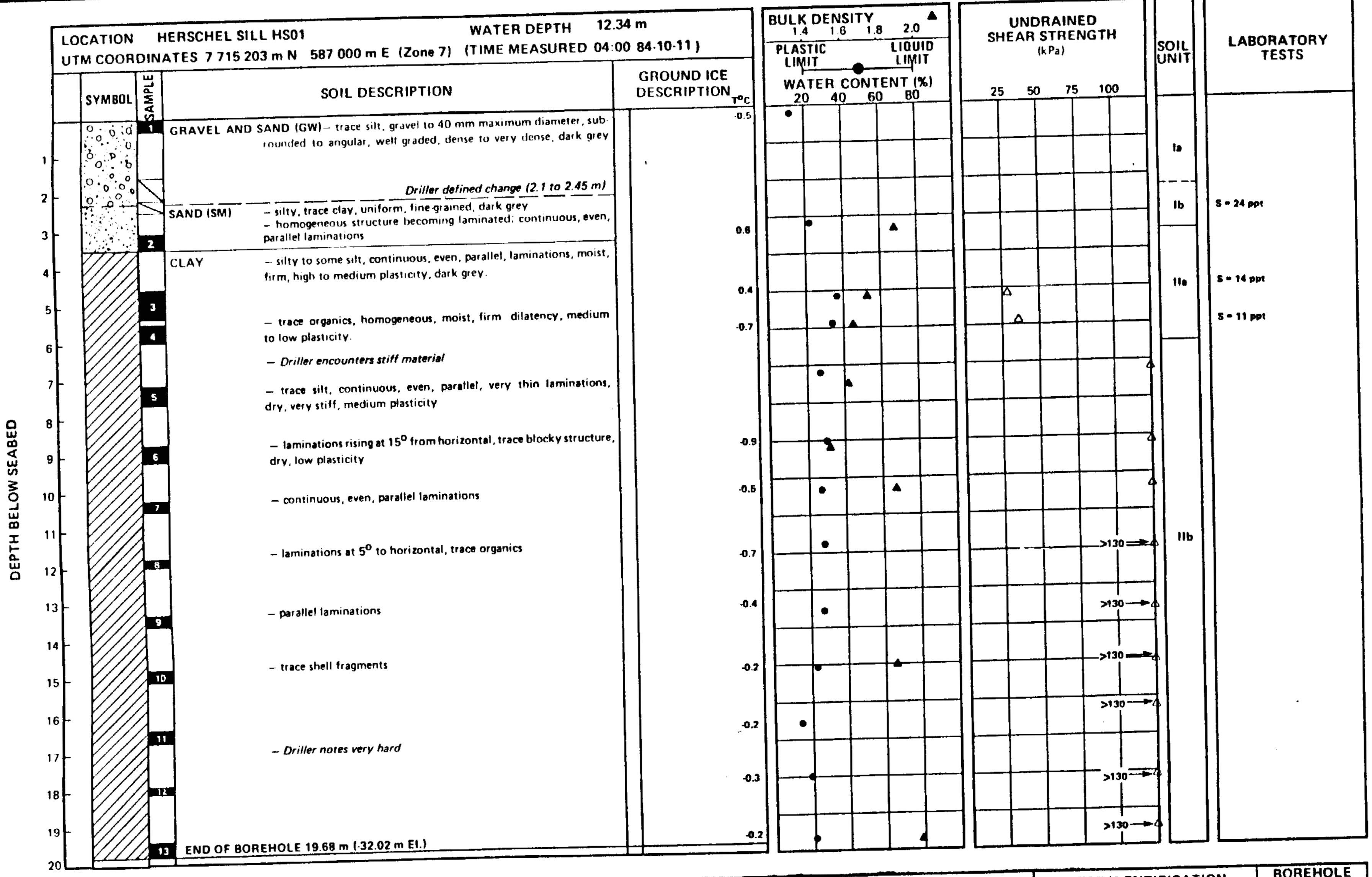
e.g. Thick bed
Thickly spaced joint

e.g. Thin lamina
Thinly spaced fissures

(After Campbell, 1967)

*(Modified after Ingram, 1954
and Campbell, 1967)*

LOCATION HERSCHEL SILL HS01 WATER DEPTH 12.34 m
UTM COORDINATES 7 715 203 m N 587 000 m E (Zone 7) (TIME MEASURED 04:00 84-10-11)



GRAVEL AND SAND (GW) – trace silt, gravel to 40 mm maximum diameter, subrounded to angular, well graded, dense to very dense, dark grey

Driller defined change (2.1 to 2.45 m)

SAND (SM) – silty, trace clay, uniform, fine-grained, dark grey
– homogeneous structure becoming laminated; continuous, even, parallel laminations

CLAY – silty to some silt, continuous, even, parallel, laminations, moist, firm, high to medium plasticity, dark grey.

– trace organics, homogeneous, moist, firm dilatency, medium to low plasticity.

– *Driller encounters stiff material*

– trace silt, continuous, even, parallel, very thin laminations, dry, very stiff, medium plasticity

– laminations rising at 15° from horizontal, trace blocky structure, dry, low plasticity

– continuous, even, parallel laminations

– laminations at 5° to horizontal, trace organics

– parallel laminations

– trace shell fragments

– *Driller notes very hard*

END OF BOREHOLE 19.68 m (-32.02 m El.)

PROJECT NUMBER 101C-4133 DRILLING COMPLETED 84-10-11 TERMINATION DEPTH 19.7 m DRILLING RIG SIMCO 5000 LOG COMPILED BY MLH/KWJ	**SOIL SYMBOLS**	**SAMPLE TYPE**	**SHEAR STRENGTH**	**TEST IDENTIFICATION**		**BOREHOLE NUMBER** HS01
	Gravel Sand	Thin Wall Tube Split Spoon Liner	+ Torvane × Mini Vane △ Pilcon Vane ⦶ In Situ Vane	C Consolidation TS Thaw Strain DS Direct Shear DSS Direct Simple Shear	T Triaxial Shear S P.W.Salinity G Gas Analysis	PAGE 1 OF 1
	Silt Clay	Core Disturbed No Recovery	▲ UU Triaxial ▽ Fall Cone			

HERSCHEL SILL HS01

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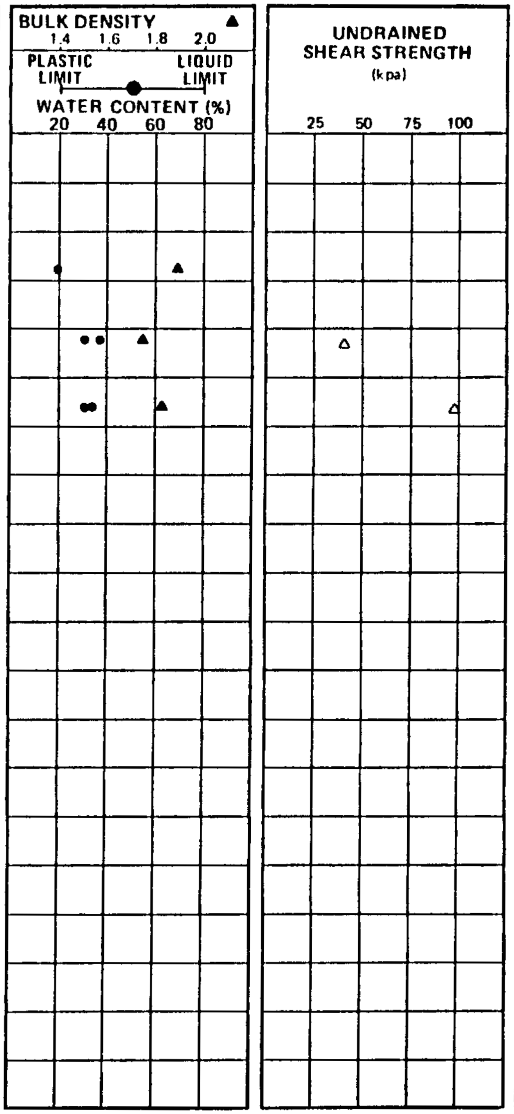
BOREHOLE LOG AND LABORATORY TEST RESULTS

LOCATION HERSCHEL SILL HS02 WATER DEPTH 12.5 m

UTM COORDINATES 7 715 255 m N 587 095 m E (Zone 7) (TIME MEASURED 84-10-11)

DEPTH BELOW SEABED	SYMBOL	SAMPLE	SOIL DESCRIPTION	GROUND ICE DESCRIPTION T°C	SOIL UNIT	LABORATORY TESTS
0		1	**GRAVEL AND SAND (GP)**– trace silt, subrounded, mainly coarse gravel to 50 mm maximum diameter, poorly-graded, dark to olive grey			
1		2	**SAND** –trace silt, uniform, fine to medium grained – becoming gravelly below 1.57 m. *Driller defined change at 2.14 m (-14.64 m El.)*		Ib	
2–3		13	**CLAY** – silty, interbedded, trace fine sand in silt beds, very thinly laminated, continuous, parallel, occasional organic laminae, lens of coal and peat at 2.50 m.		IIa	S = 18 ppt
4		14	– trace silt, very thin, continuous, even parallel laminations, firm, medium plasticity.			S = 15 ppt
5		15	– mottled olive grey and dark grey.	-0.7		
6			END OF BOREHOLE 5.73 m (-18.23 m El.)		IIb	



PROJECT NUMBER	101C-4133
DRILLING COMPLETED	84-10-11
TERMINATION DEPTH	5.73 m
DRILLING RIG	SIMCO 5000
LOG COMPILED BY	KWJ

SOIL SYMBOLS

- Gravel
- Sand
- Silt
- Clay

SAMPLE TYPE

- Thin Wall Tube
- Split Spoon
- Liner
- Core
- Disturbed
- No Recovery

SHEAR STRENGTH

- \+ Torvane
- × Mini Vane
- △ Pilcon Vane
- ⌽ In Situ Vane
- ▲ UU Triaxial
- ▽ Fall Cone

TEST IDENTIFICATION

C	Consolidation
TS	Thaw Strain
DS	Direct Shear
DSS	Direct Simple Shear
T	Triaxial Shear
S	P.W.Salinity
G	Gas Analysis

BOREHOLE NUMBER HS02

PAGE 1 OF 1

HERSCHEL SILL HS02

EBA Engineering Consultants Ltd.

BOREHOLE LOG AND LABORATORY TEST RESULTS

APPENDIX B

CLASSIFICATION AND INDEX TEST RESULTS

LABORATORY TEST PROCEDURES

1. CLASSIFICATION AND INDEX TESTS

These tests are routine and the standard ASTM procedures employed are listed below:

TEST	ASTM DESIGNATION
Moisture Content	D 2216
Liquid Limit (1)	D 423
Plastic Limit and Plasticity Index	D 424
Grain Size	D 421 & 422
Unified Soil Classification	D 2487

NOTE: 1. All liquid limits reported are obtained from 3 point determinations.

2.1 Particle Size Distribution

2.1.1 Sieving Method

This test was performed in the field laboratory on 10 samples in accordance with ASTM standard designation D-421-63 (Re-approved 1982). When necessary, the material was divided by using a riffle-box to obtain samples of standard mass. The particle-size distribution curves obtained are presented in Appendix B.

2.1.2 Hydrometer Method

This test will be carried out at EBA's laboratory in Edmonton in accordance with ASTM standard designation D-422-63 (Reapproved 1982). The results of these analyses will be presented in Appendix B in the final report.

2.2 Atterberg Limits

Atterberg limits will be determined in EBA's laboratory in Edmonton. Results including the calculated Plasticity Index, will presented on the borehole logs in Appendix A, and summary sheets in Appendix B in the final report.

2.2.1 Liquid Limit

Liquid limits will be determined in accordance with ASTM standard designation D-423-66 (Reapproved 1982), utilizing a three-point method.

2.2.2 Plastic Limit

The plastic limit test will be carried out in accordance with ASTM standard designation D-424-59 (Reapproved 1971.)

3. "PILCON" VANE

Sample was retained in the thin wall sampling tube during the test. Vane is inserted into sample and vane is rotated. Peak and post-peak shear strengths are produced in the field.

4. POREWATER SALINITY TESTS

Sample is trimmed to remove disturbed material. Porewater is extruded from thawed sample and filtered. The salinity content (NaCl) of the extruded porewater in % is determined using a hand-held refractometer. Several drops of porewater are placed on the reflecting plate and a reading is taken through the eyepiece. Results are reported to the nearest parts per thousand (ppt).

SUMMARY OF TEST RESULTS

Borehole Number: HS01

Sample Number	Sample Type	Depth (metres) *Sample Photographed	Unified Soil Classification	Ground Ice Description (%)	Temp. (°C)	Moisture Content (%)	Frozen Moisture Content (%)	Bulk Density (Mgm⁻³)	ATTERBERG LIMITS Liquid Limit (%)	ATTERBERG LIMITS Plastic Limit (%)	GRAIN SIZE DISTRIBUTION Clay (%)	GRAIN SIZE DISTRIBUTION Silt (%)	GRAIN SIZE DISTRIBUTION Sand (%)	GRAIN SIZE DISTRIBUTION Gravel (%)	GRAIN SIZE DISTRIBUTION D_{50} (μm)	SHEAR STRENGTH Test	SHEAR STRENGTH Shear Strength (kPa)	SHEAR STRENGTH Failure Strain (%)	SHEAR STRENGTH Consistency	CONSOLIDATION CHARACTERISTICS P_o (kPa)	CONSOLIDATION CHARACTERISTICS P_c (kPa)	CONSOLIDATION CHARACTERISTICS C_c	TEST RESULTS TABULATED SEPARATELY
--	C	0.0 - 0.3	SP								--	5	56	39	2300								
1A	B	0.00 - 0.31	GW		-0.5	12					--	2	35	63	7300								
--	C	0.5 - 0.6	GM-GP								--	8	45	47	3300								
--	C	0.7 - 0.8	GP								--	4	44	52	5000								
2A	B	3.05 - 3.40			+0.6	22/21		1.88															S=24ppt
3A	T	4.57 - 5.20				36										PV	28						
3B	B	5.20 - 5.36			+0.4	35		1.73															S=14ppt
4A	T	5.49 - 5.80														PV	36						
4B	B	5.80 - 5.95			-0.7	34/35		1.65															S=11ppt
5A	T	7.16 - 7.50														PV	124						
5B	B	7.50 - 7.62			-0.7	27/28		1.62															
6A	T	8.69 - 9.05														PV	124						
6B	B	9.05 - 9.15			-0.9	30/30		1.53															
7A	B	10.30 - 10.44				29		1.88								PV	122						
7B		10.3			-0.5	27																	
8A	B	11.73 - 11.90						--								PV	130+						
8B		11.90 - 11.95			-0.7	29																	
9A	T	13.26 - 13.52						--								PV	130+						
9B	B	13.52 - 13.54			-0.4	28																	
10A	B	14.78 - 15.04			-0.2	24/30		1.88								PV	130+						

LEGEND AND NOTES

B Bag Sample
G Gas Sample
L Liner Sample
P Piston Sample
NR No Recovery
NS No Sample Remaining

PF - Permafrost Sample
PW - Porewater Sample
T - Sample Stored in Tube
W - Waxed Sample
RC Radiocarbon Sample
C - Clam Shell Sample

MV - Minivane
FC - Fall Cone
TV - Torvane
PV - Pilcon Vane
RV - Remote Vane

UU - Unconsolidated Undrained Triaxial
UUp - UU Triaxial with Pore Pressure Measurements
CU - Consolidated Undrained Triaxial
CUp - CU Triaxial with Pore Pressure Measurements
CD - Consolidated Drained Triaxial

O - Organic Content
S - Salinity
TS - Thaw Strain
SG - Specific Gravity

1984 OFFSHORE GEOTECHNICAL
SITE INVESTIGATION

HERSCHEL SILL - BEAUFORT SEA

Project Number: 101C-4133

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HS01

SUMMARY OF TEST RESULTS

Borehole Number									ATTERBERG LIMITS		GRAIN SIZE DISTRIBUTION					SHEAR STRENGTH				CONSOLIDATION CHARACTERISTICS			
Sample Number	Sample Type	Depth (metres) *Sample Photographed	Unified Soil Classification	Ground Ice Description (%)	Temp. (°C)	Moisture Content (%)	Frozen Moisture Content (%)	Bulk Density (Mgm^{-3})	Liquid Limit (%)	Plastic Limit (%)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	D_{50} (μm)	Test	Shear Strength (kPa)	Failure Strain (%)	Consistency	P_o (kPa)	P_c (kPa)	C_c	TEST RESULTS TABULATED SEPARATELY
11A	T	16.31 - 16.64									-	5	6	9		PV	130+						
11B	B	16.64 - 16.66			-0.2	16		--															
12A	B	17.83 - 18.00			-0.3	20										PV	130+						
13A	T	19.35 - 19.67														PV	130+						
13B	B	19.67 - 19.68			-0.2	22/21		2.00															

LEGEND AND NOTES

B - Bag Sample
G - Gas Sample
L - Liner Sample
P - Piston Sample
NR - No Recovery
NS - No Sample Remaining

PF - Permafrost Sample
PW - Porewater Sample
T - Sample Stored in Tube
W - Waxed Sample
RC - Radiocarbon Sample
C - Clam Shell Sample

MV - Minivane
FC - Fall Cone
TV - Torvane
PV - Pilcon Vane
RV - *Remote Vane*

UU - Unconsolidated Undrained Triaxial
UUp - UU Triaxial with Pore Pressure Measurements
CU - Consolidated Undrained Triaxial
CUp - CU Triaxial with Pore Pressure Measurements
CD - Consolidated Drained Triaxial

O - Organic Content
S - Salinity
TS - Thaw Strain
SG - Specific Gravity

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Page 2 of 2

HS02, HS03, HS04

SUMMARY OF TEST RESULTS

Borehole Number Sample Number	Sample Type	Depth (metres) *Sample Photographed	Unified Soil Classification	Ground Ice Description (%)	Temp. (°C)	Moisture Content (%)	Frozen Moisture Content (%)	Bulk Density (Mgm^{-3})	ATTERBERG LIMITS Liquid Limit (%)	Plastic Limit (%)	GRAIN SIZE DISTRIBUTION Clay (%)	Silt (%)	Sand (%)	Gravel (%)	D_{50} (μm)	SHEAR STRENGTH Test	Shear Strength (kPa)	Failure Strain (%)	Consistency	CONSOLIDATION CHARACTERISTICS P_o (kPa)	P_c (kPa)	C_c	TEST RESULTS TABULATED SEPARATELY
HS-2																							
1A	B	0.00 - 0.25	GP								--	3	46	51	5000								
--	C	0.0 - 0.4	SP								--	4	57	39	2300								
2A	B	1.37 - 1.67	SM								--	11	89	0	170								
3A	B	2.46 - 2.90				21	1.90																S=18ppt
4A	T	3.81 - 4.40														PV	42						
4B	B	4.40 - 4.43			-0.7	33/38	1.76																
5A	T	5.33 - 5.72														PV	99						S=15ppt
5B	B	5.73 - 5.13			-0.7	33/35	1.84																
HS-3																							
--	C	0.0 - 0.4	SP								--	4	66	30	1500								
--	C	0.9 - 1.2	SM								--	30	70	0	120								
HS-4																							
--	C	0.0 - 0.4	SP-SM								--	7	49	44	2300								

LEGEND AND NOTES

B - Bag Sample
G - Gas Sample
L - Liner Sample
P - Piston Sample
NR - No Recovery
NS - No Sample Remaining

PF - Permafrost Sample
PW - Porewater Sample
T - Sample Stored in Tube
W - Waxed Sample
RC - Radiocarbon Sample
C - Clam Shell Sample

MV - Minivane
FC - Fall Cone
TV - Torvane
PV - Pilcon Vane
RV - Remote Vane

UU - Unconsolidated Undrained Triaxial
UUp - UU Triaxial with Pore Pressure Measurements
CU - Consolidated Undrained Triaxial
CUp - CU Triaxial with Pore Pressure Measurements
CD - Consolidated Drained Triaxial

O - Organic Content
S - Salinity
TS - Thaw Strain
SG - Specific Gravity

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HERSCHEL SILL - BEAUFORT SEA

Project Number: 101C-4133

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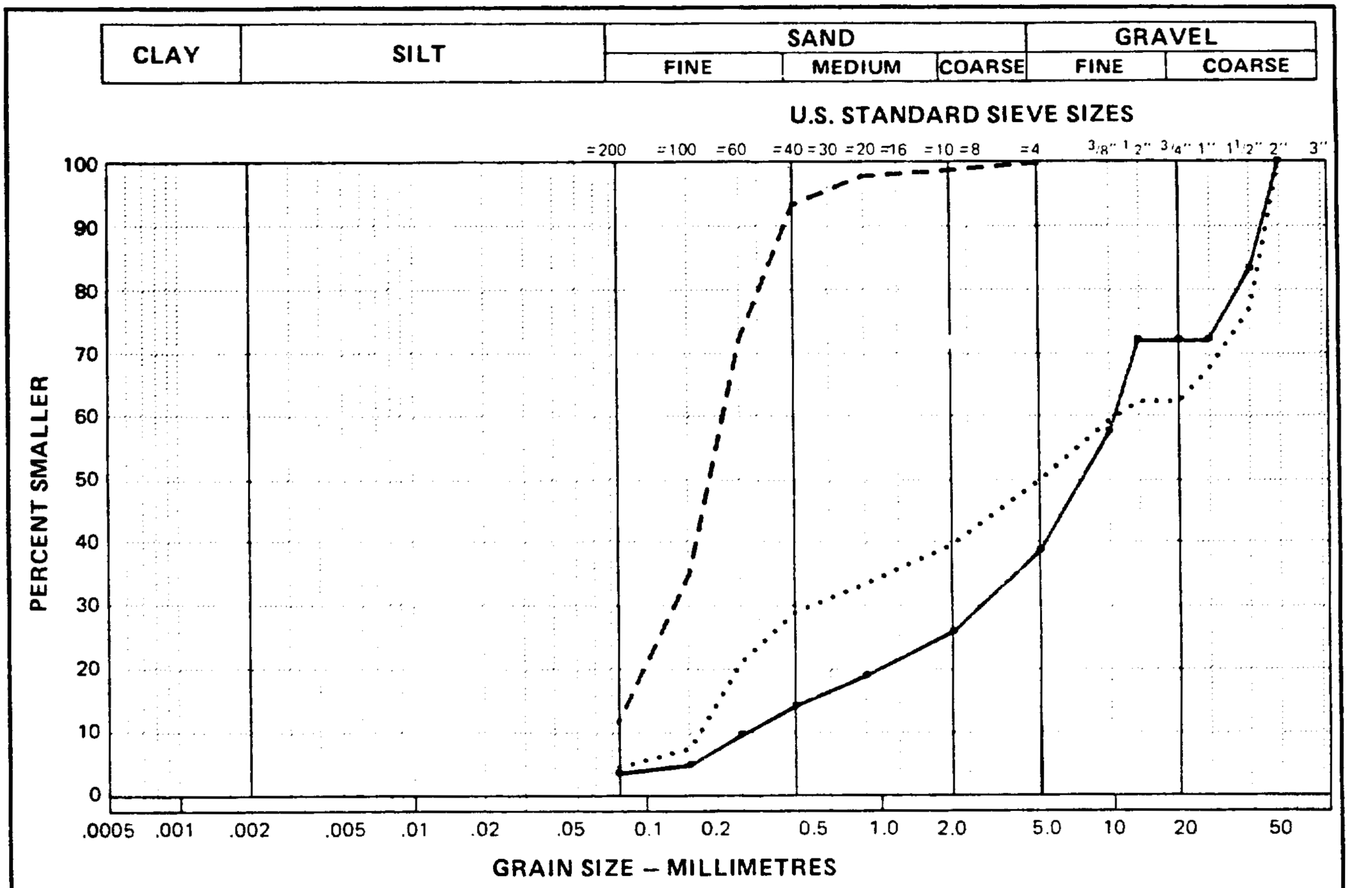
PARTICLE - SIZE ANALYSIS OF SOILS



SYMBOL	BOREHOLE NUMBER	DEPTH (m)	DESCRIPTION				Cu	Cc	U.S.C.
			CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)			
______	HS1	0.00 - .30	-	2.3	35.3	62.4	33.8	2.7	GW
......	HS2	0.00 - .25	-	3.4	45.6	51.0	63.1	.2	GP
— — —	HS2	1.37 - 1.67	-	10.7	89.3	0.0	-	-	-

JOB NO. 101 -4133 **DATE** 84-10-11

FIGURE B-1 BOREHOLE SAMPLES
HERSCHEL SILL

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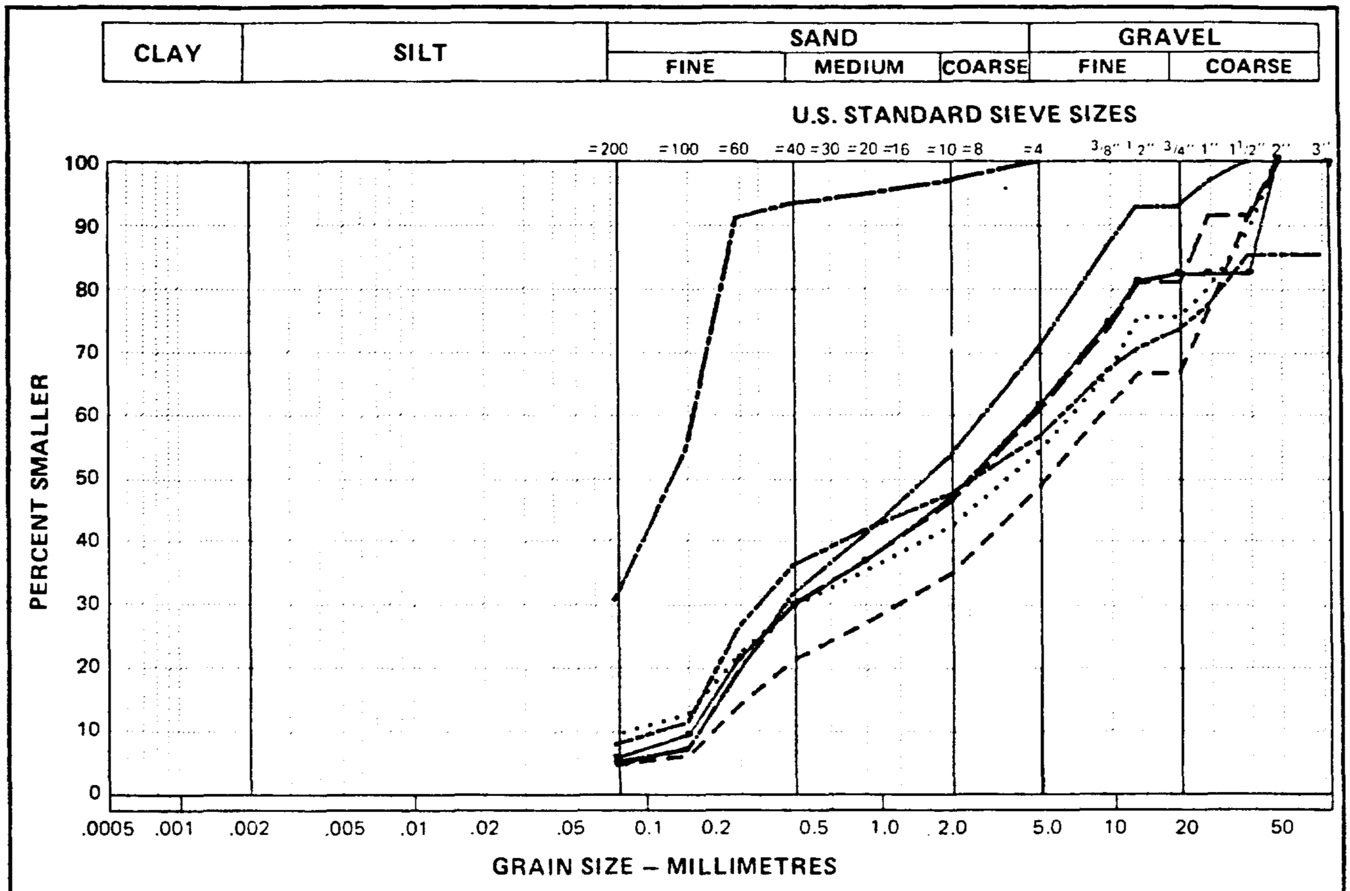
PARTICLE - SIZE ANALYSIS OF SOILS



SYMBOL	BOREHOLE NUMBER	DEPTH (m)	DESCRIPTION				Cu	Cc	U.S.C.
			CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)			
———	HS1	0.00 - .30	-	4.5	56.1	39.4	28.6	.3	SP
·····	HS1	.50 - .60	-	8.5	44.8	46.7	67.1	.3	GP-GM
– – –	HS1	.70 - .80	-	3.6	44.1	52.3	44.4	.9	GP
—— ——	HS2	0.00 - .40	-	3.7	56.8	39.5	27.1	.2	SP
——·—	HS3	0.00 - .40	-	3.9	66.0	30.1	16.3	.3	SP
——--	HS3	.90 - 1.20	-	30.0	70.0	0.0	-	-	-
——---	HS4	0.00 - .40	-	6.8	49.0	44.2	44.9	.1	SP-SM

JOB NO. 101 -4133 **DATE** 84-10-13

FIGURE B-2 CLAM-SHELL SAMPLES
HERSCHEL SILL