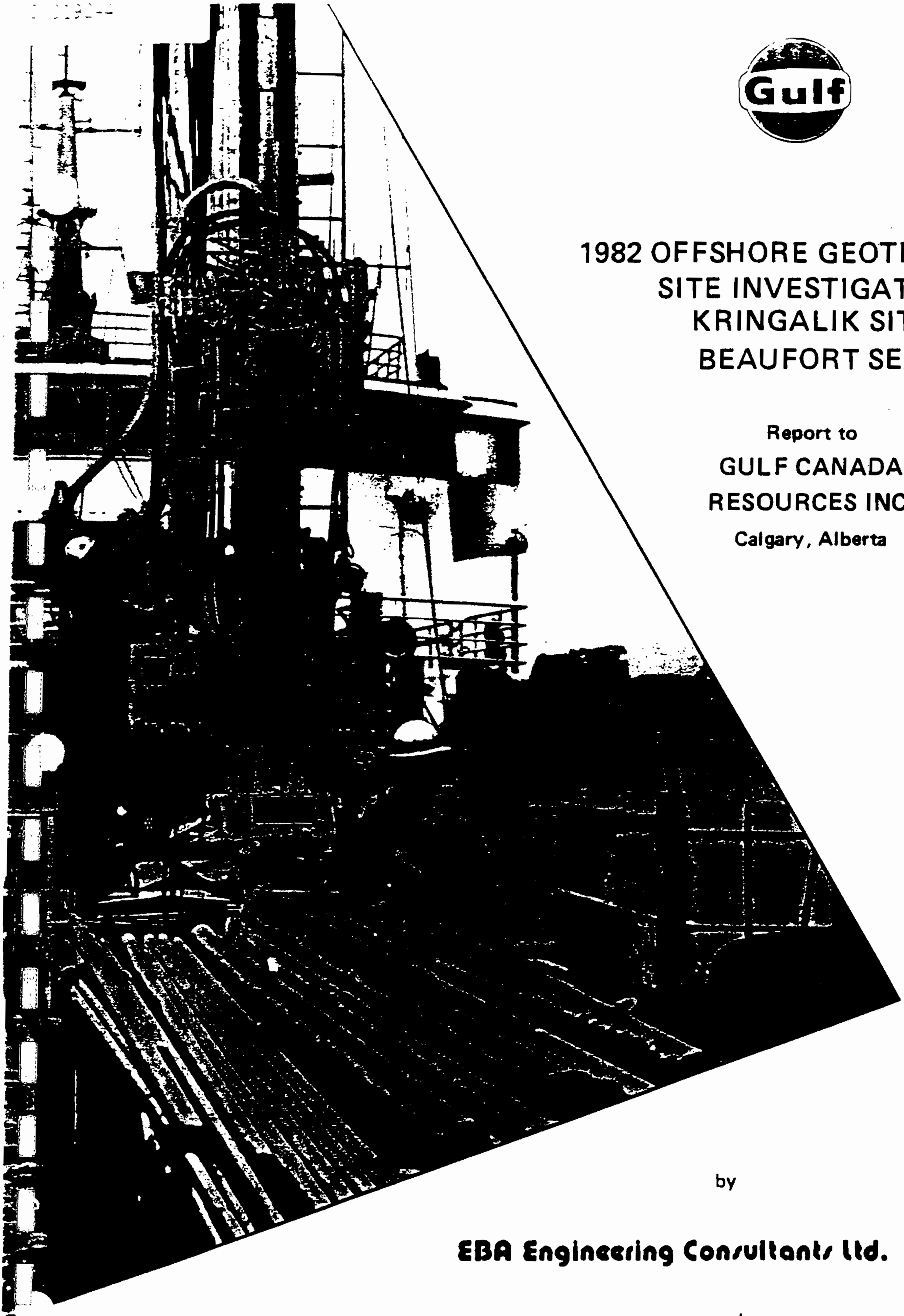

# 1982 OFFSHORE GEOTECHNICAL SITE INVESTIGATION KRINGALIK SITE BEAUFORT SEA

Report to

GULF CANADA
RESOURCES INC.
Calgary, Alberta

by

**EBA Engineering Consultants Ltd.**

and

**McClelland engineers, inc.**

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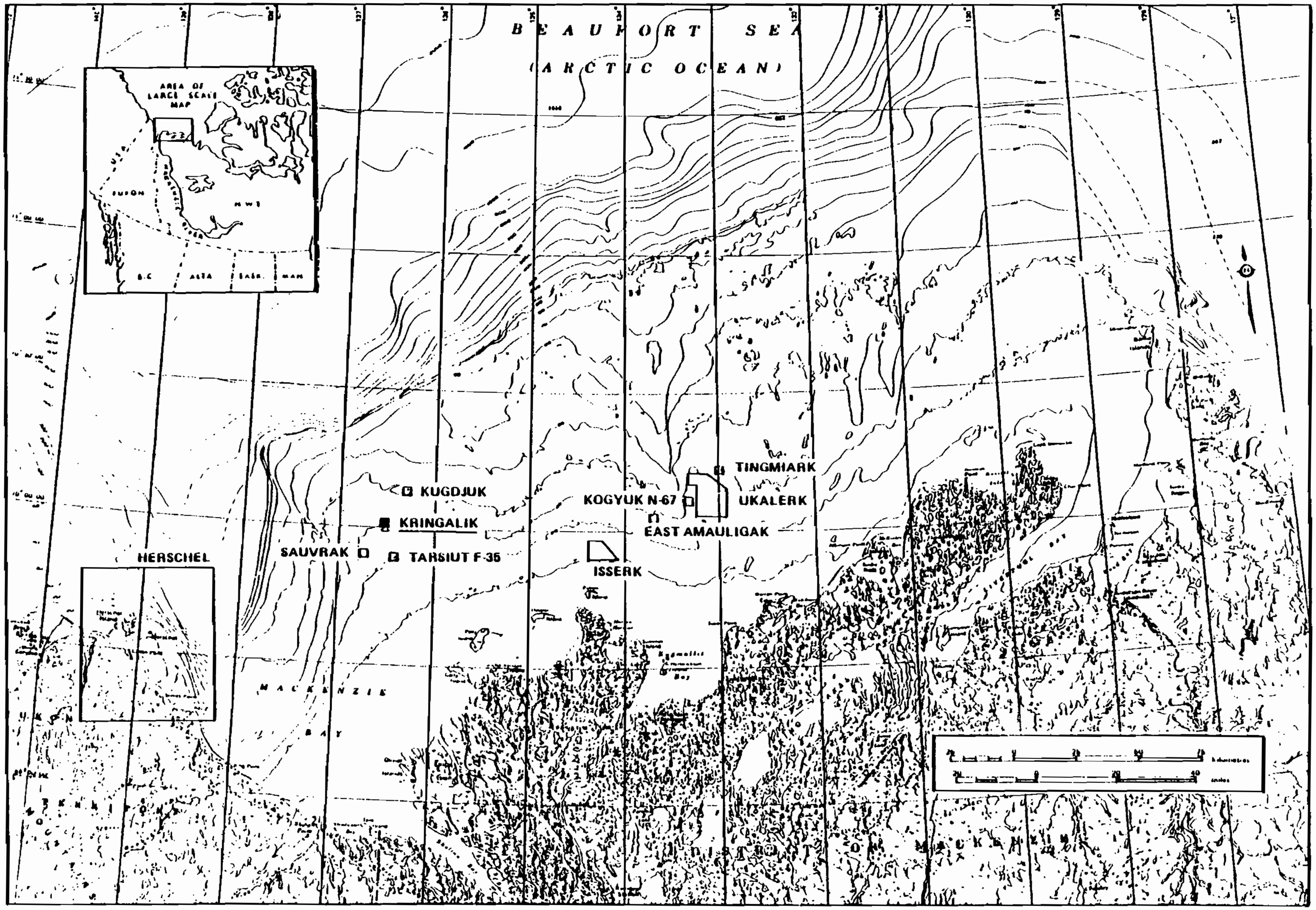
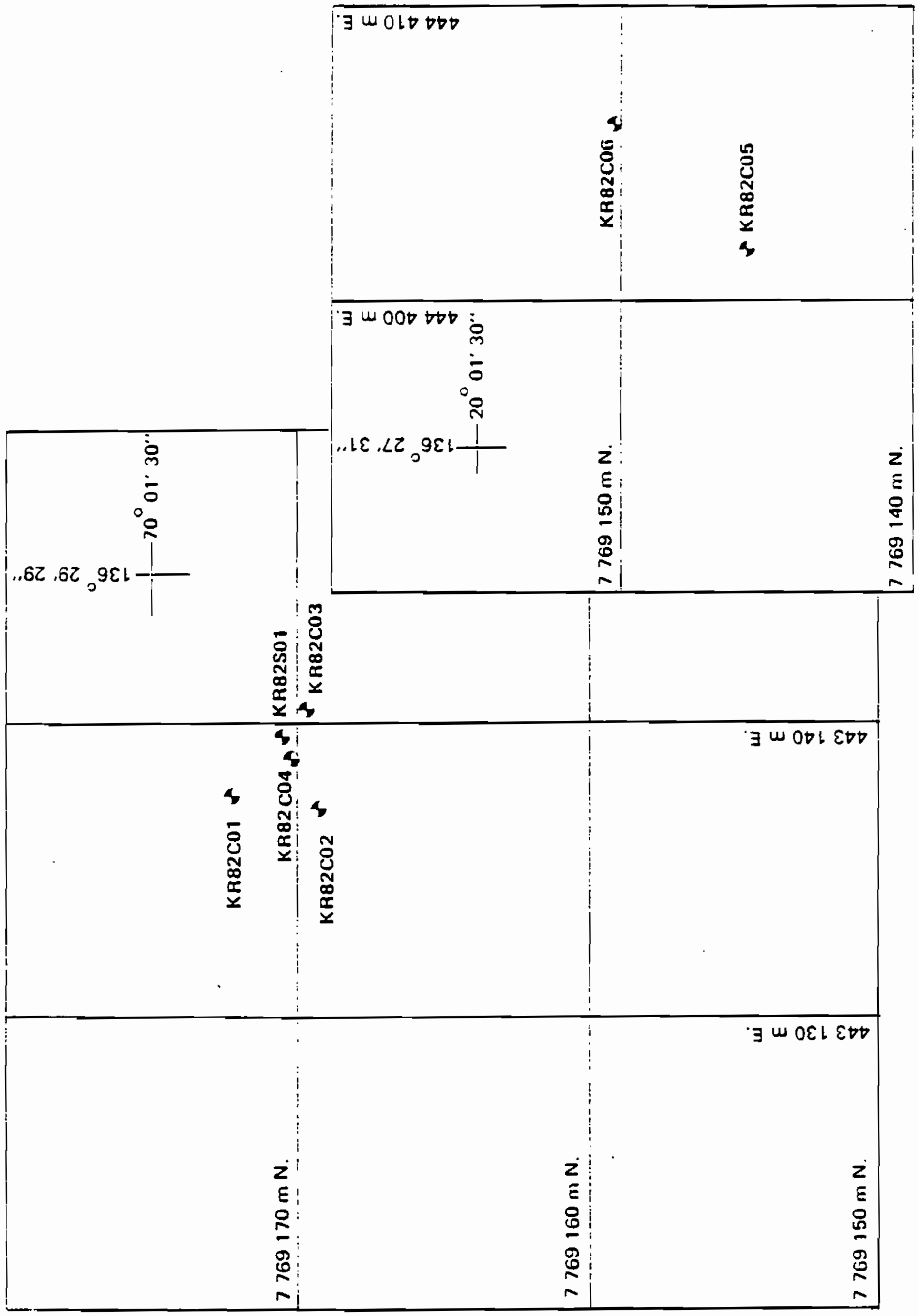


FIGURE 1 GENERAL LOCATION MAP



Note: *Locations provided by Canadian Engineering Surveys Co. Ltd.*

FIGURE 2 TEST HOLE LOCATION PLAN KRINGALIK SITE

## TABLE 1

### Stratigraphy of Site

The materials encountered in the geotechnical investigation at Kringalik were predominantly fine-grained marine deltaic sediments, presumed to have been deposited subsequent to the late Wisconsin glacial retreat. The stratigraphy of the site can be summarized as follows:

| | LITHOSTRATIGRAPHIC UNIT | DEPTH |
|---|---|---|
| UNIT (I) | Soft SILTY CLAY of high plasticity<br>[Recent deltaic sediments remoulded] | 0 - 3.0 |
| UNIT (II) | Partially remoulded, firm to stiff SILTY CLAY of low plasticity and fine-grained SAND<br>[Deltaic sediments reworked and possibly ice-scoured] | 3.0 - 5.2 |
| UNIT (III) | Firm to very stiff SILTY CLAY<br>[Deltaic sediments deposited between the late Wisconsin and present] | 5.2 - 25.0 |
| UNIT (IV) | Stiff SILT with some clay and occasionally sand<br>[Deltaic sediments deposited between the late Wisconsin and present] | 25.0 - 30.7 |

101-3658
February 1983

## TABLE 2 SUMMARY OF BOREHOLE/PROBEHOLE LOCATIONS

| BOREHOLE/PROBEHOLE | UTM COORDINATES (ZONE 8) | | DATE | SEABED PENETRATION AT COMPLETION (metres) |
|---|---|---|---|---|
| KR82S01 | N 7 769 170 | E 443 140 | 82-08-31 | 31 |
| KR82C01 | N 7 769 170 | E 443 140 | 82-08-29 | 71 |
| KR82C02 | N 7 769 170 | E 443 140 | 82-08-29 | No data |
| KR82C03 | N 7 769 170 | E 443 140 | 82-08-30 | 19 |
| KR82C04 | N 7 769 170 | E 443 140 | 82-08-31 | 7 |
| KR82C05 | N 7 769 145 | E 444 400 | 82-09-01 | 25 |
| KR82C06 | N 7 769 150 | E 444 405 | 82-09-02 | 43 |

Note: 1. All coordinates supplied by CES Ltd.

2. "KR82" denotes a borehole/probehole at the KRINGALIK site drilled/tested in 1982. "S" refers to "sampled", "R" refers to "Remote Vane", "C" refers to "static cone", and "P" refers to "pressuremeter". The number following the letter designation is the borehole/probehole number.

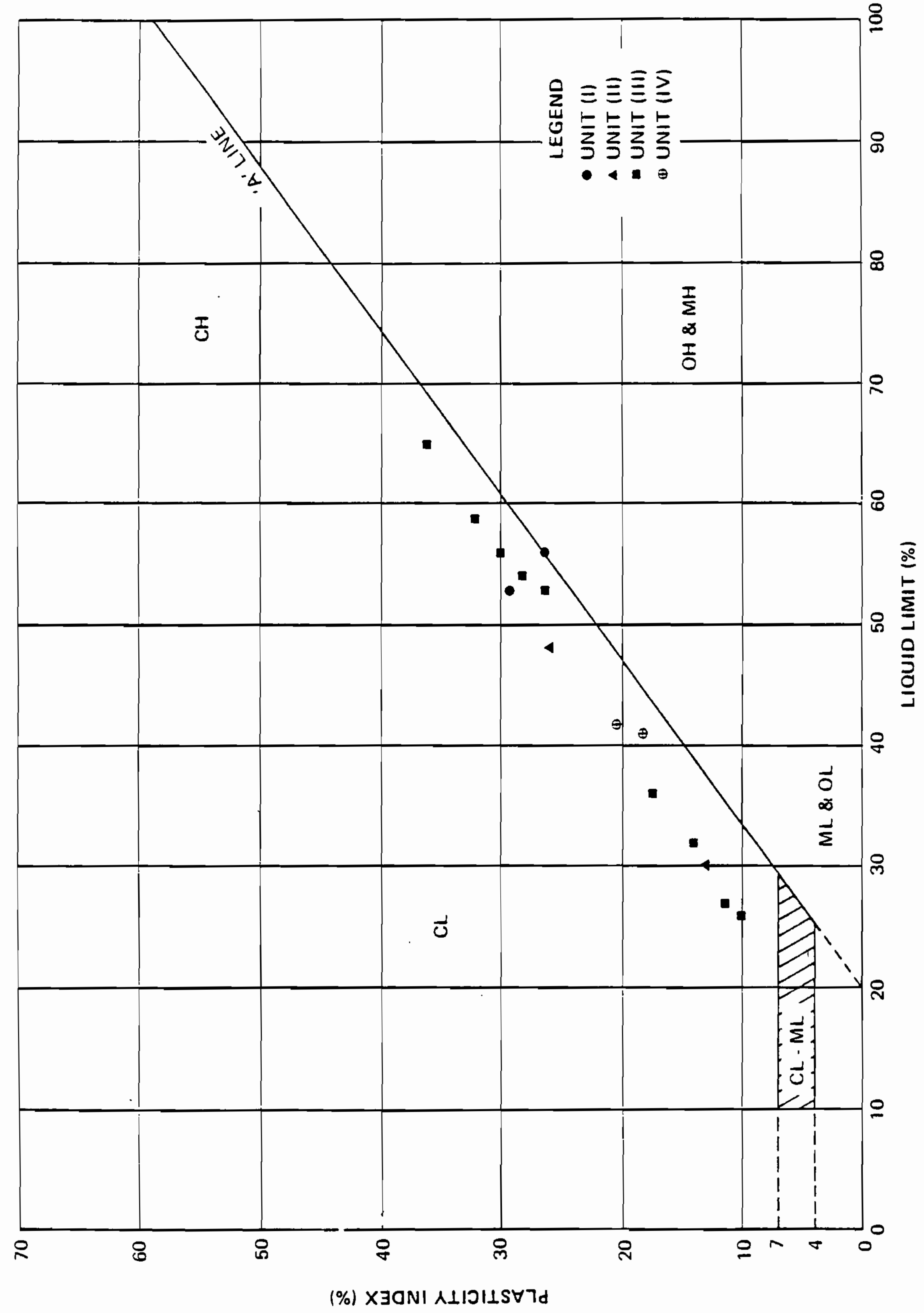


FIGURE 3 PLASTICITY CHART, KRINGALIK AREA

# APPENDIX A

## Borehole Logs

# 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 | $m^2 \cdot s^{-2}\ K^{-1}$ |
| 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 | | $W/(m \cdot K)$ | $m \cdot kg \cdot s^{-3} \cdot K^{-1}$ |

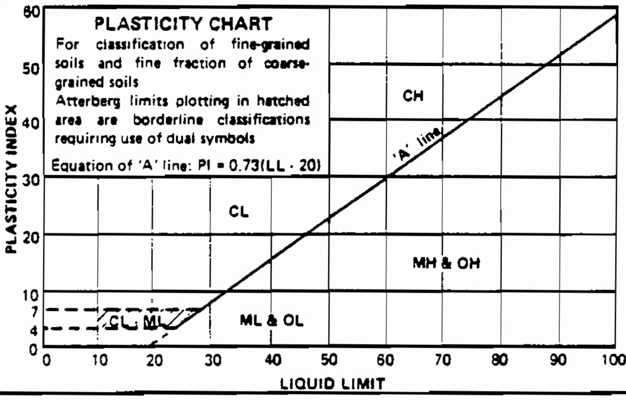
# OTHER UNITS PERMITTED FOR USE WITH SI

| 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° = (°/180) rad |
| | minute | ′ | 1′ = (°/10,800) rad |
| | second | ″ | 1″ = (°/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 | - |
| 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<br>More than 50% retained on No. 200 sieve* | GRAVELS<br>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<br>Less than 5% pass No. 200 sieve GW, GP, SW, SP<br>More than 12% pass No. 200 sieve GM, GC, SM, SC<br>5% to 12% pass No. 200 sieve Borderline classification requiring use of dual symbols | $C_u = D_{60}\ D_{10}$ Greater than 4<br>$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ 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<br>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<br>$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ 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<br>50% or more passes No. 200 sieve* | SILTS AND CLAYS<br>Liquid limit 50% or less | | ML | Inorganic silts, very fine sands, rock flour, silty or clayey fine sands |  | | |
| | | | 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<br>Liquid limit greater than 50% | | MH | Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts | | | |
| | | | CH | Inorganic silts 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<br>†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 | ▨ |

## 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<br>(greater than 25 mm (1 in.) thick) | ■ |

*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*

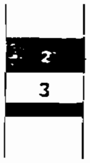
LEGEND

Soil ☐ Ice ■

# SYMBOLS AND ABBREVIATIONS USED ON BOREHOLE LOGS

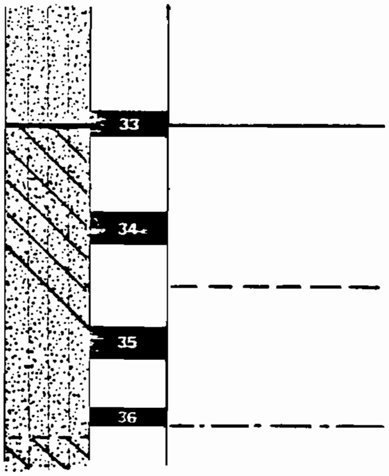
**SOIL SAMPLE**

- 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 ± 0.5m 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 metres) and elevation below sealevel (uncorrected for tides) (-64.6 metres El.)

41.5 (-64.6 El.)

**SOIL DESCRIPTION**

**UNIFIED SOIL CLASSIFICATION** — USC

- determined in accordance with chart on following page

**TEXTURAL DESCRIPTION**

- determined in accordance with attached sheet and used to augment Unified Soil Classification

Special terms used include:

e.g. - "becoming trace of/with some CLAY" indicating an overall change in a feature of the stratum not sufficient to change the total description

- "trace of/with some CLAY" indicating small feature displayed in that sample only

**MUNSELL COLOUR DESIGNATION**

- describing wet grey soil, e.g. (5Y 4/2)
- describing dry grey soil, e.g. (10YR 6/1)

GROUND ICE DESCRIPTION

- determined in accordance with chart on following page. extra effort has been made to better describe the degree and extent of soil bonding and also a value of core temperature (°C) at that level

- see also definition of terms in text

| | |
|---|---|
| e.g. FROZEN | -2.3 |
| - Nf - Nbn | |
| - poorly to slightly bonded | |
| SAND: Nbn | -2.8 |
| 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 shear strength, as indicated by penetrometer readings or vane shear readings.

| Descriptive Term | Unconfined Compressive Strength kPa | Equivalent Blows per Foot (N) |
|---|---|---|
| Very Soft | less than 25 | 0 - 2 |
| Soft | 25 to 50 | 2 - 4 |
| Firm | 50 to 100 | 4 - 8 |
| Stiff | 100 to 200 | 8 - 16 |
| Very Stiff | 200 to 400 | 15 - 50 |
| Hard | 400 and higher | >50 |

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 | Equivalent Blows per foot (N) |
|---|---|---|
| Very Loose | 0 - 20% | 0 - 4 |
| Loose | 20 - 40% | 4 - 10 |
| Compact or Medium | 40 - 75% | 10 - 30 |
| Dense | 75 - 90% | 30 - 50 |
| Very Dense | 90 - 100% | 50 + |

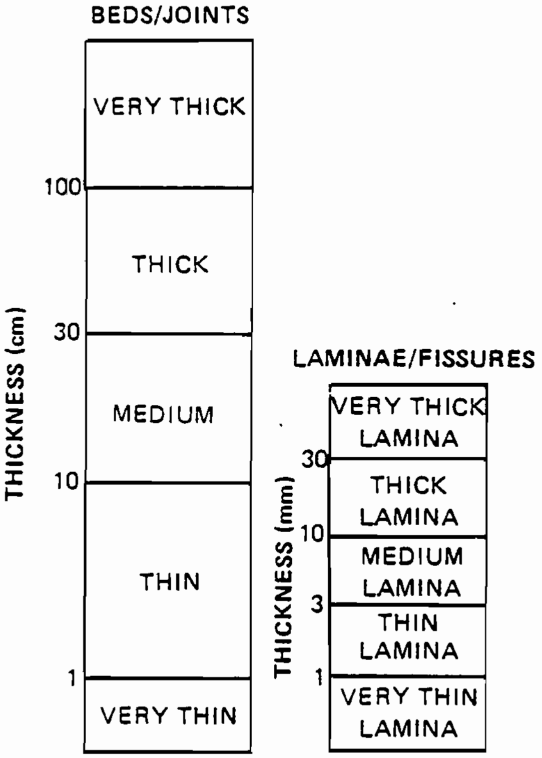
The number of blows (N) on a 2" O.D. split spoon sampler by a 140 lbs. weight falling 30" required to drive the sample a distance of 1' (in accordance with ASTM D1586).

## PLASTICITY

Low - Liquid limit less than 50
High - Liquid limit greater than 50

# DESCRIPTION OF SEDIMENTARY STRUCTURES

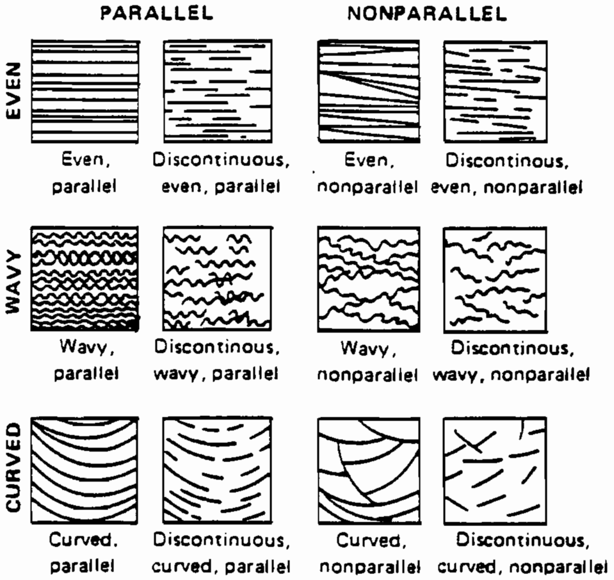
| | |
|---|---|
| **BEDS** | SEDIMENTATION UNITS DEPOSITED UNDER ESSENTIALLY CONSTANT PHYSICAL CONDITIONS, SEPARATED BY BEDDING PLANES WHICH ARE RECOGNIZABLE BY TEXTURAL OR COMPOSITIONAL CHANGES RESULTING FROM PERIODS OF NON-DEPOSITION OR EROSION, OR ABRUPT CHANGES IN DEPOSITIONAL CONDITIONS. BEDS MAY 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

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

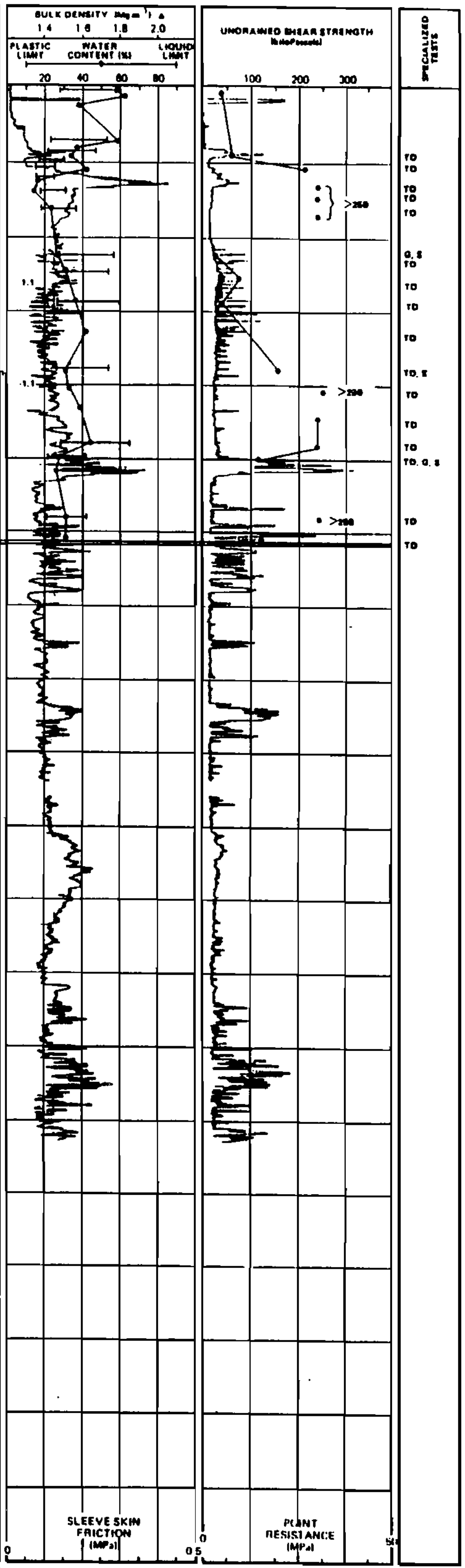


*(After Campbell, 1967)*

LOCATION: KRINGALIK
UTM COORDINATES: 7 769 170 m N. 443 140 m E. WATER DEPTH: 34.1 m

| SOIL DESCRIPTION | | GROUND ICE | T°C |
|---|---|---|---|
| **SILTY CLAY (CL)** - soft to very soft, featureless dark olive grey | | NOT FROZEN | +0.8<br>+1.4 |
| 3.0 m (-37.1 m El.) | | | +0.6 |
| **SILTY CLAY (CL)** - firm to stiff, low plasticity, grey interlayered with<br>**SAND** trace of silt, fine grained, sub-angular, brown-grey to yellow brown | | | +0.7<br>+1.0 |
| **SILTY CLAY (CL)** - some sand, trace of gravel, stiff to very stiff low plasticity, dark grey<br>grading to: | | | |
| 8.8 m (-43.8 m El.) | | PARTIALLY FROZEN | |
| **SILTY CLAY (CL)** with discontinuous, nonparallel curved laminae, firm to very stiff when thawed, high plasticity, dark grey<br>becoming high plasticity | 10.8<br>11.2<br>12.8 | Vs, horizontal + Vr 5% ICE, clear with vertical bubble trains, fresh water, horizontal<br>Vx 10 - 15% throughout | |
| | 14.0<br>14.2 | Vx 10% (inclusions up to 10 mm ϕ)<br>Excluded salt on laminations | -1.3 |
| | | | -1.0 |
| | | Vs 5%, lenses to 20 mm horizontal, clear, fractured, fresh water, excluded salt on laminations | |
| - some silt | | | -0.2<br>0.2 |
| 26.0 m (-59.3 m El.) | | | |
| **SILT and SAND (SM)** - fine grained, dense, dark grey<br>grading to: | | Nbn FROZEN | |
| 26.7 m (-60.8 m El.) | | | |
| **SILT (ML)** clayey, trace of fine grained sand, with very thin continuous even horizontal laminae, low plasticity, very stiff when thawed | | | |
| with occasional faint black bedding | | Vx trace?<br>Nbn | -1.0<br>-1.2 |
| **END OF BOREHOLE** 30.7 m (-64.8 m El.) | | | |

DEPTH BELOW SEABED (metres)



JOB No.: 101 - 3668
DRILLING COMPLETED: 82/09/01
BOREHOLE DEPTH: 30.7 m (-64.8 m EL)
DRILLING RIG: S5000/MV BRODERICK
LOG COMPILED BY: JPR

**LEGEND**

SOIL SYMBOLS: ▨ SAND, ▥ SILT, ▧ CLAY

SHEAR STRENGTH
- ◆ Torvane
- ▪ Min. Vane
- ♦ Pilcon Vane
- ○ Halibut Vane
- ● Fall Cone
- ▲ UU Triaxial
- ■ CU Triaxial

TEST IDENTIFICATION
- C Consolidation
- DS Direct Shear
- TD TDR
- Ca Calorimetry
- T Triaxial Shear
- S - P.W. Salinity
- G Gas Analysis

BOREHOLE NUMBER KR 82 S01

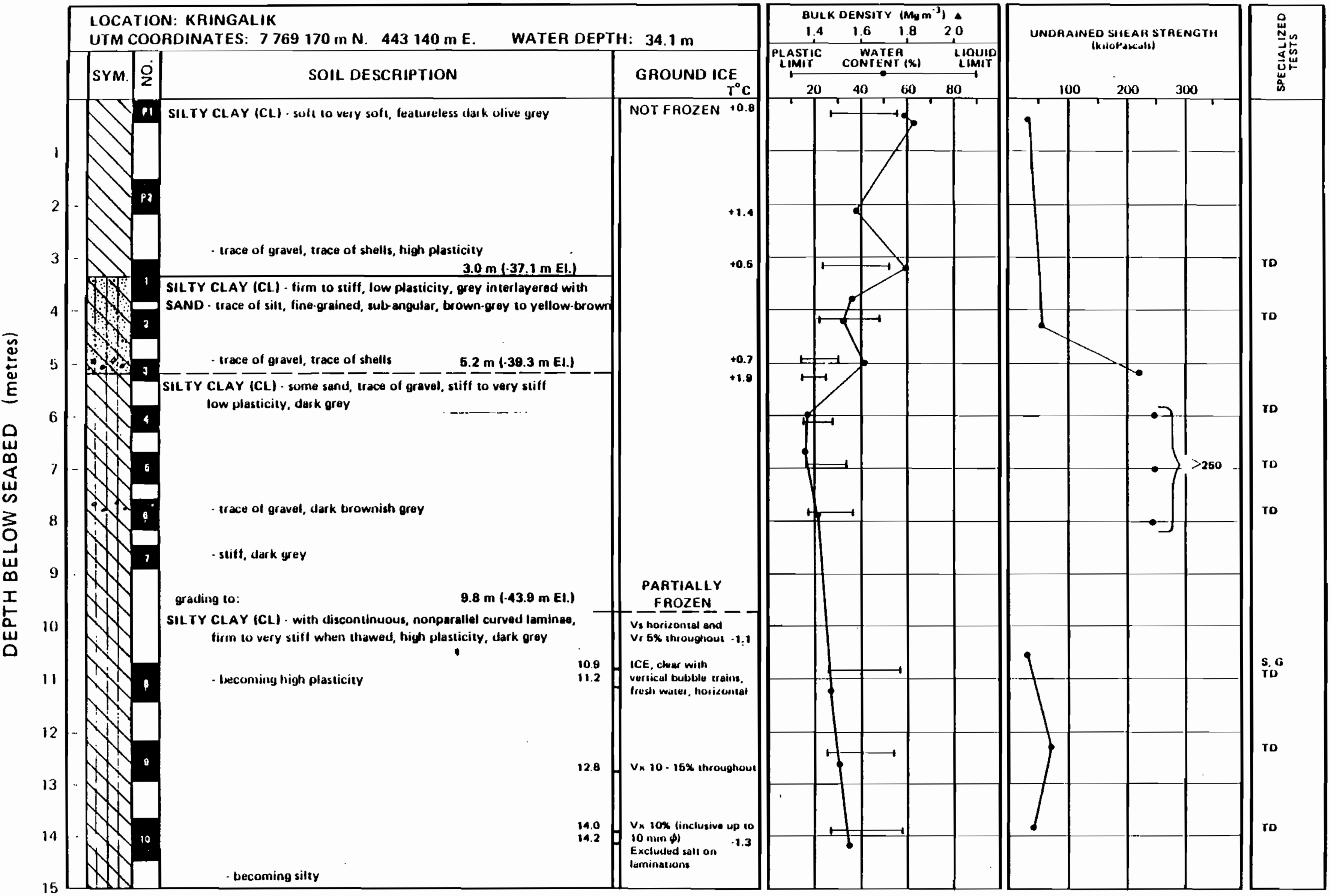
PAGE 2 OF 2

Geosystems

# BOREHOLE LOG AND LABORATORY TEST RESULTS
## CONE PENETRATION TEST DATA

PENETRATION TEST KH82:01

LOCATION: KRINGALIK
UTM COORDINATES: 7 769 170 m N. 443 140 m E. WATER DEPTH: 34.1 m



SOIL DESCRIPTION

SILTY CLAY (CL) - soft to very soft, featureless dark olive grey

- trace of gravel, trace of shells, high plasticity

3.0 m (-37.1 m El.)

SILTY CLAY (CL) - firm to stiff, low plasticity, grey interlayered with
SAND - trace of silt, fine-grained, sub-angular, brown-grey to yellow-brown

- trace of gravel, trace of shells 5.2 m (-39.3 m El.)

SILTY CLAY (CL) - some sand, trace of gravel, stiff to very stiff low plasticity, dark grey

- trace of gravel, dark brownish grey

- stiff, dark grey

grading to: 9.8 m (-43.9 m El.)

SILTY CLAY (CL) - with discontinuous, nonparallel curved laminae, firm to very stiff when thawed, high plasticity, dark grey

- becoming high plasticity

- becoming silty

GROUND ICE T°C

NOT FROZEN +0.8

+1.4

+0.5

+0.7

+1.9

PARTIALLY FROZEN

Vs horizontal and Vr 5% throughout -1.1

10.9
11.2 ICE, clear with vertical bubble trains, fresh water, horizontal

12.8 Vx 10 - 15% throughout

14.0
14.2 Vx 10% (inclusive up to 10 mm $\phi$) -1.3 Excluded salt on laminations

eba

JOB No.: 101 - 3658
DRILLING COMPLETED: 82/09/01
BOREHOLE DEPTH: 30.7 m (-64.8 m El.)
DRILLING RIG: S5000/MV BRODERICK
LOG COMPILED BY: JPR

LEGEND

SOIL SYMBOLS

| ▨ | ▥ | ▧ |
|---|---|---|
| SAND | SILT | CLAY |

SHEAR STRENGTH

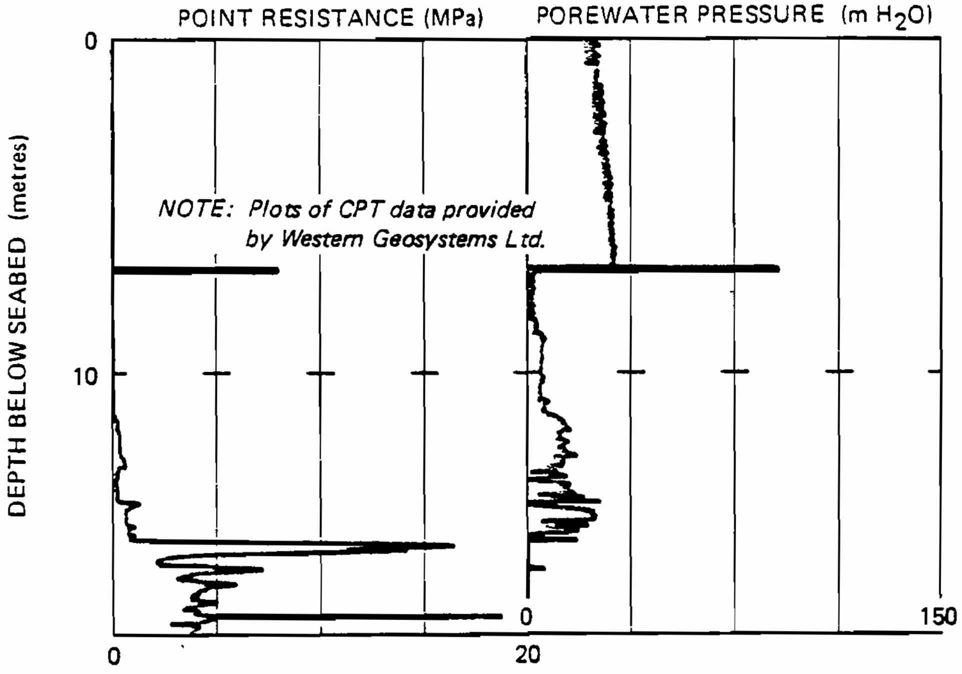
| | |
|---|---|
| + Torvane | ● Fall Cone |
| × Mini Vane | ▲ UU Triaxial |
| • Pilcon Vane | ■ CU Triaxial |
| ○ Halibut Vane | |

TEST IDENTIFICATION

| | |
|---|---|
| C Consolidation | T Triaxial Shear |
| DS Direct Shear | S P W Salinity |
| TD TDR | G Gas Analysis |
| Ca Calorimetry | |

BOREHOLE NUMBER
KR 82 S01

# BOREHOLE LOG AND LABORATORY TEST RESULTS



NOTE: Plots of CPT data provided by Western Geosystems Ltd.

FIGURE A.1 CONE PENETRATION TEST PROFILE
TEST KR82C03 - KRINGALIK

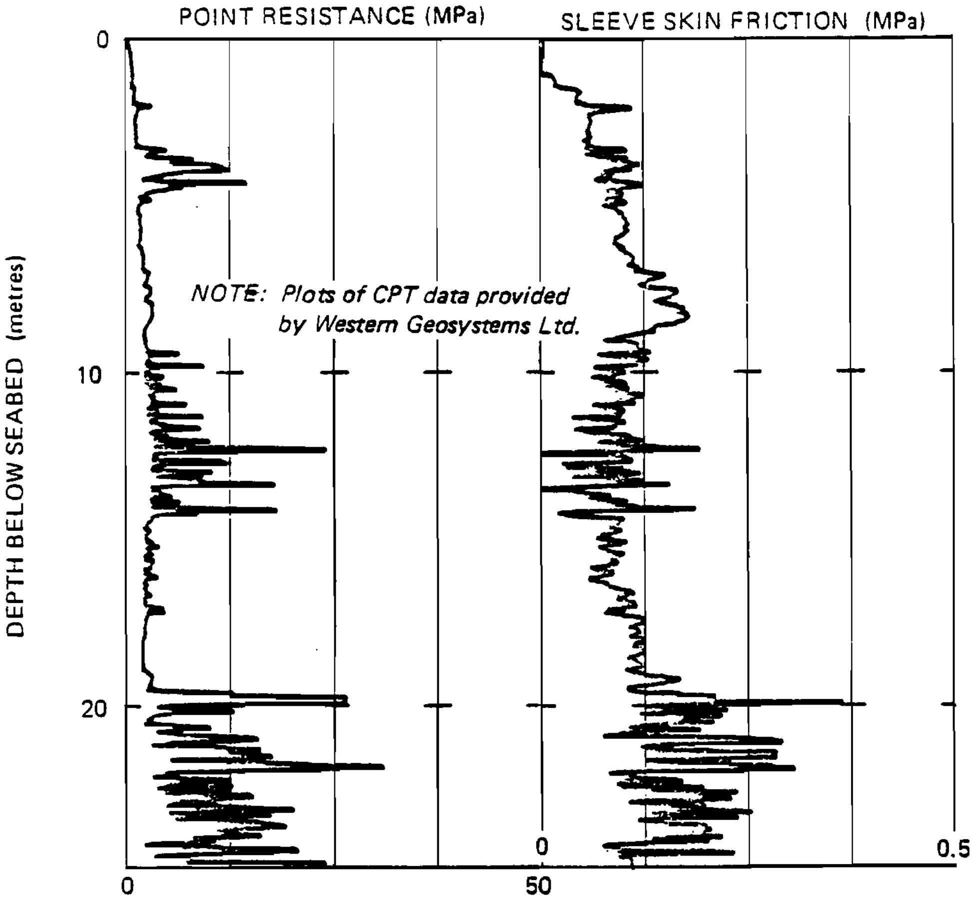


FIGURE A.2 CONE PENETRATION TEST PROFILE
TEST KR82C05 - KRINGALIK

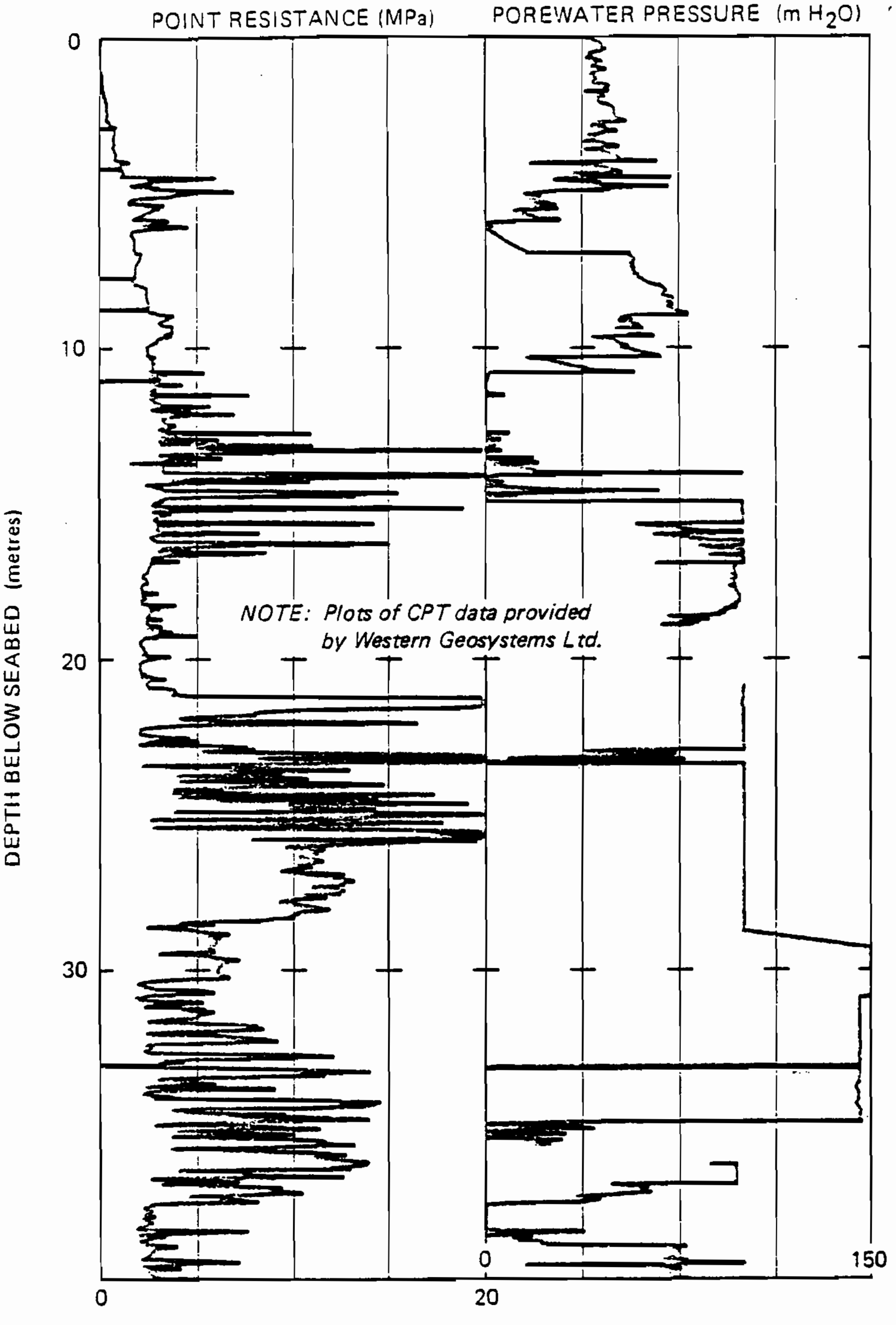


FIGURE A.3 CONE PENETRATION TEST PROFILE
TEST KR82C06 - KRINGALIK

# APPENDIX B

## Diagnostic Profiles

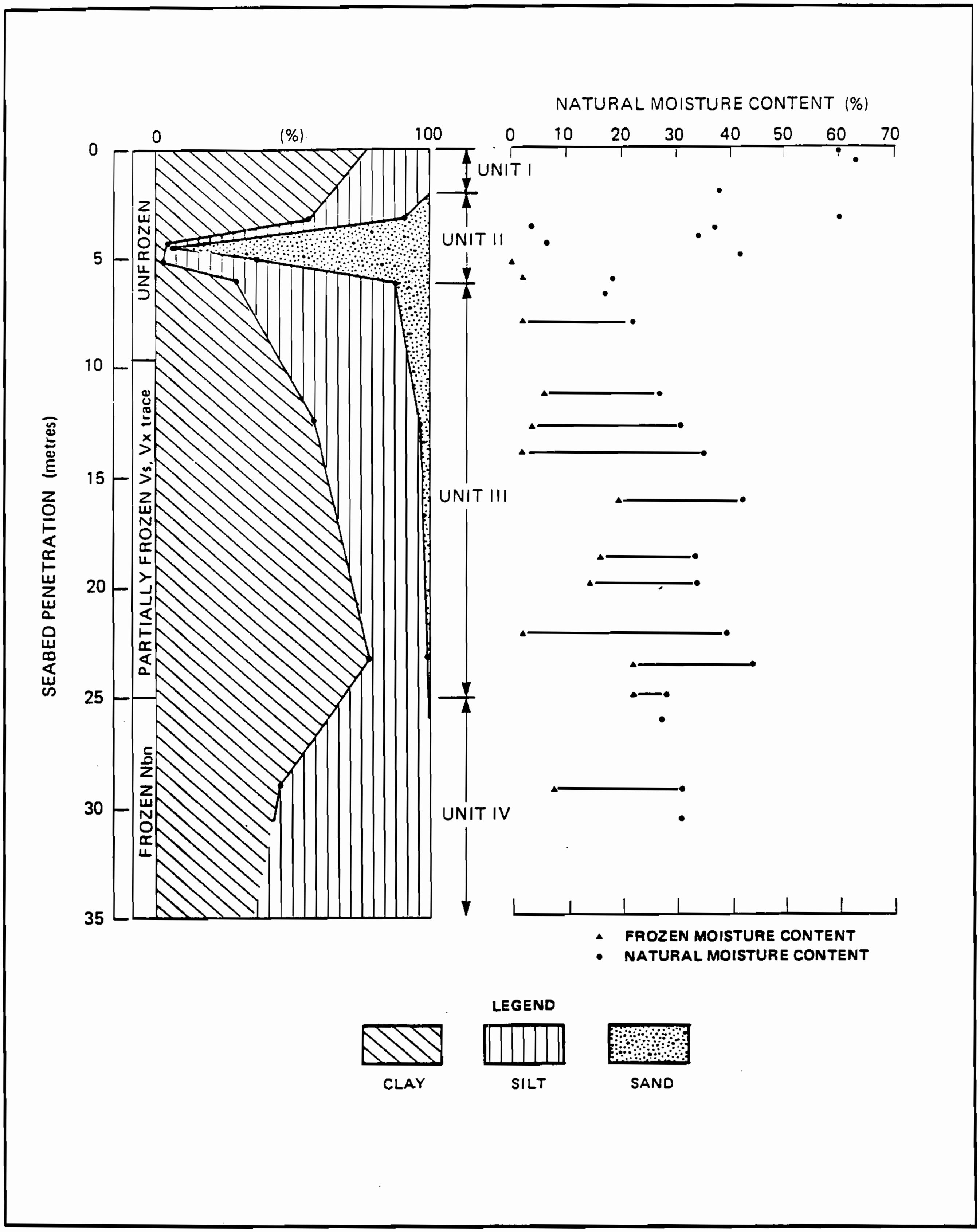


FIGURE B.1 NATURAL MOISTURE CONTENT PROFILE, KRINGALIK AREA

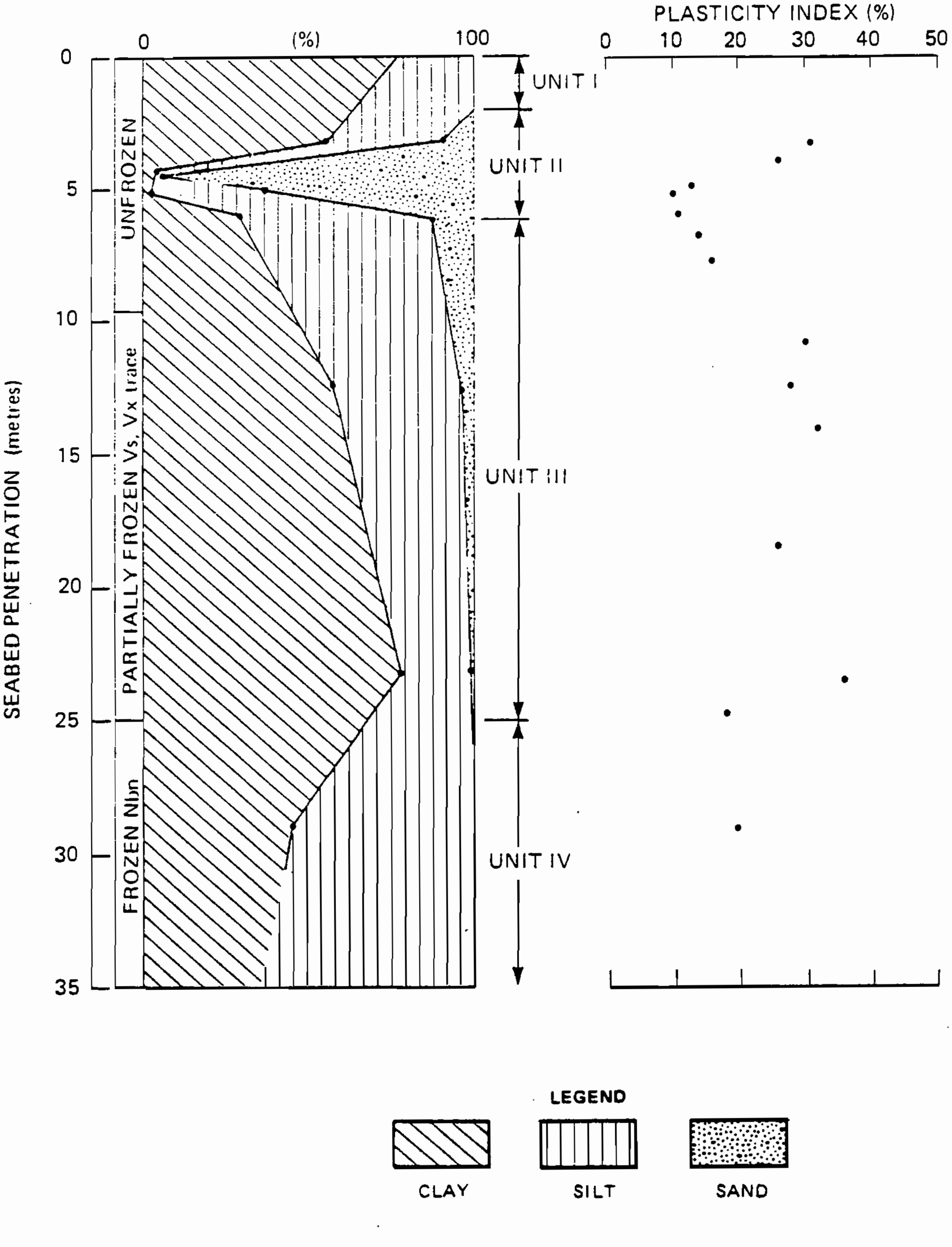


FIGURE B.2 PLASTICITY INDEX PROFILE, KRINGALIK AREA

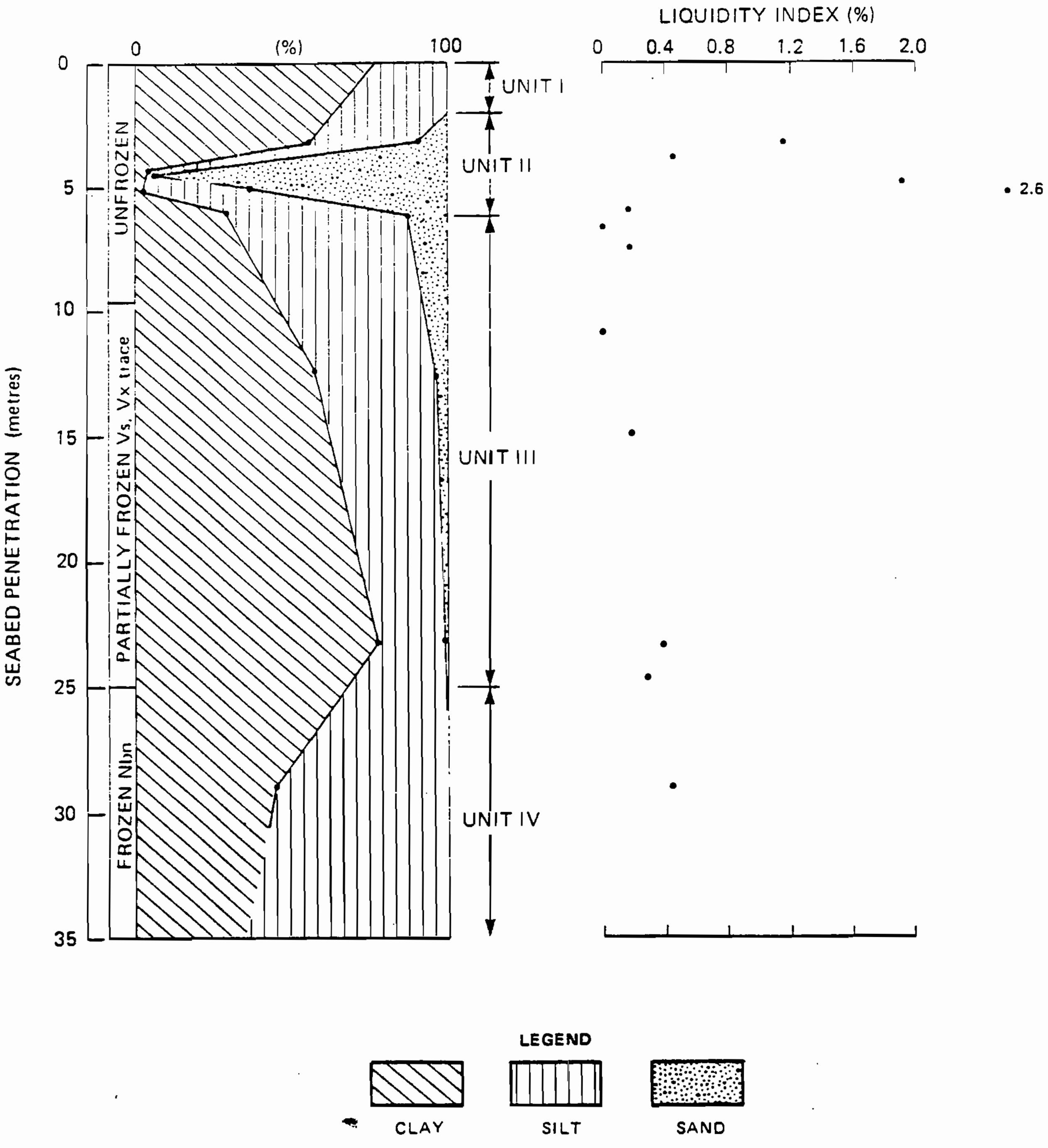


FIGURE B.3 LIQUIDITY INDEX PROFILE, KRINGALIK AREA

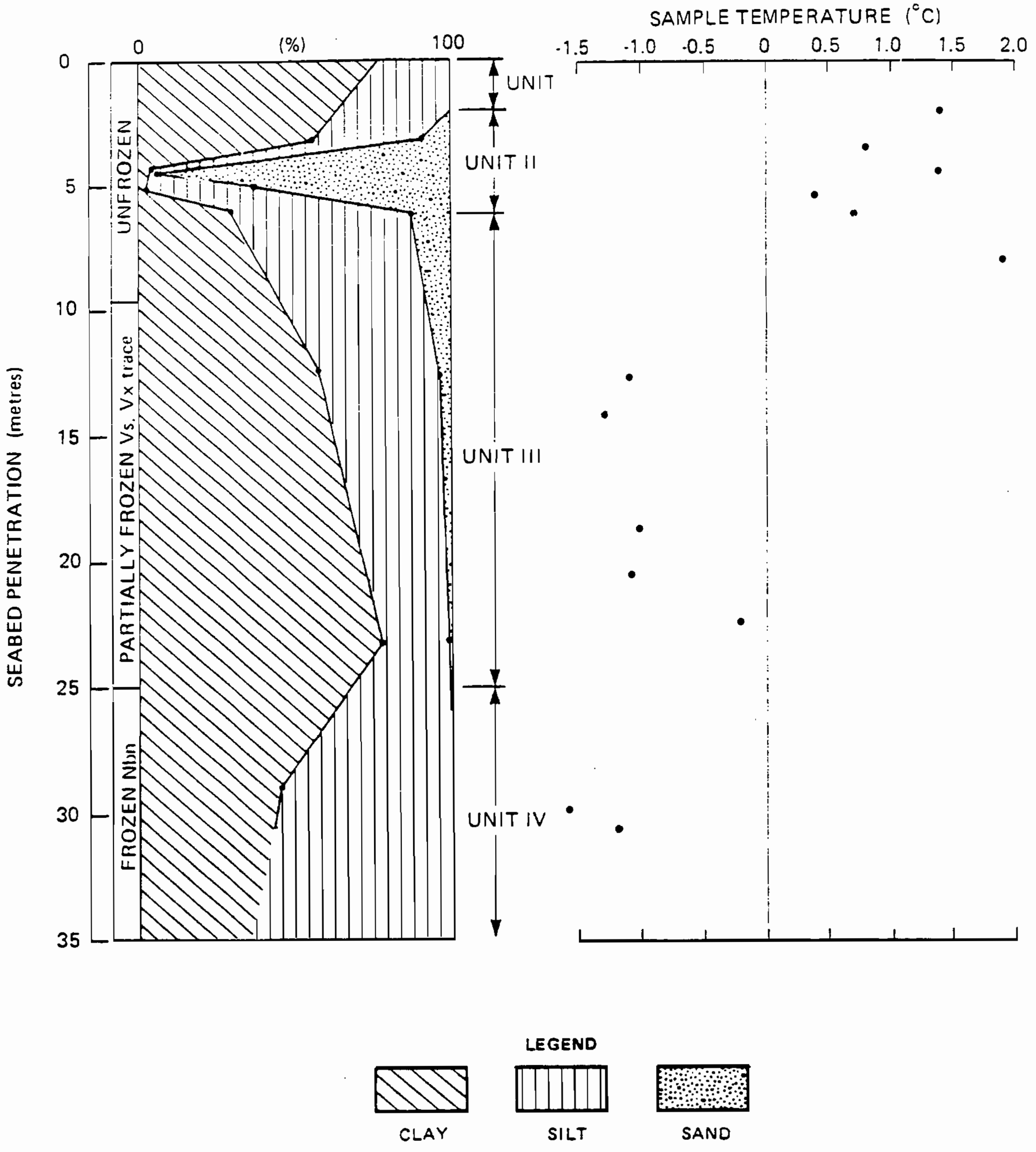


FIGURE B.4 SAMPLE TEMPERATURE PROFILE, KRINGALIK AREA

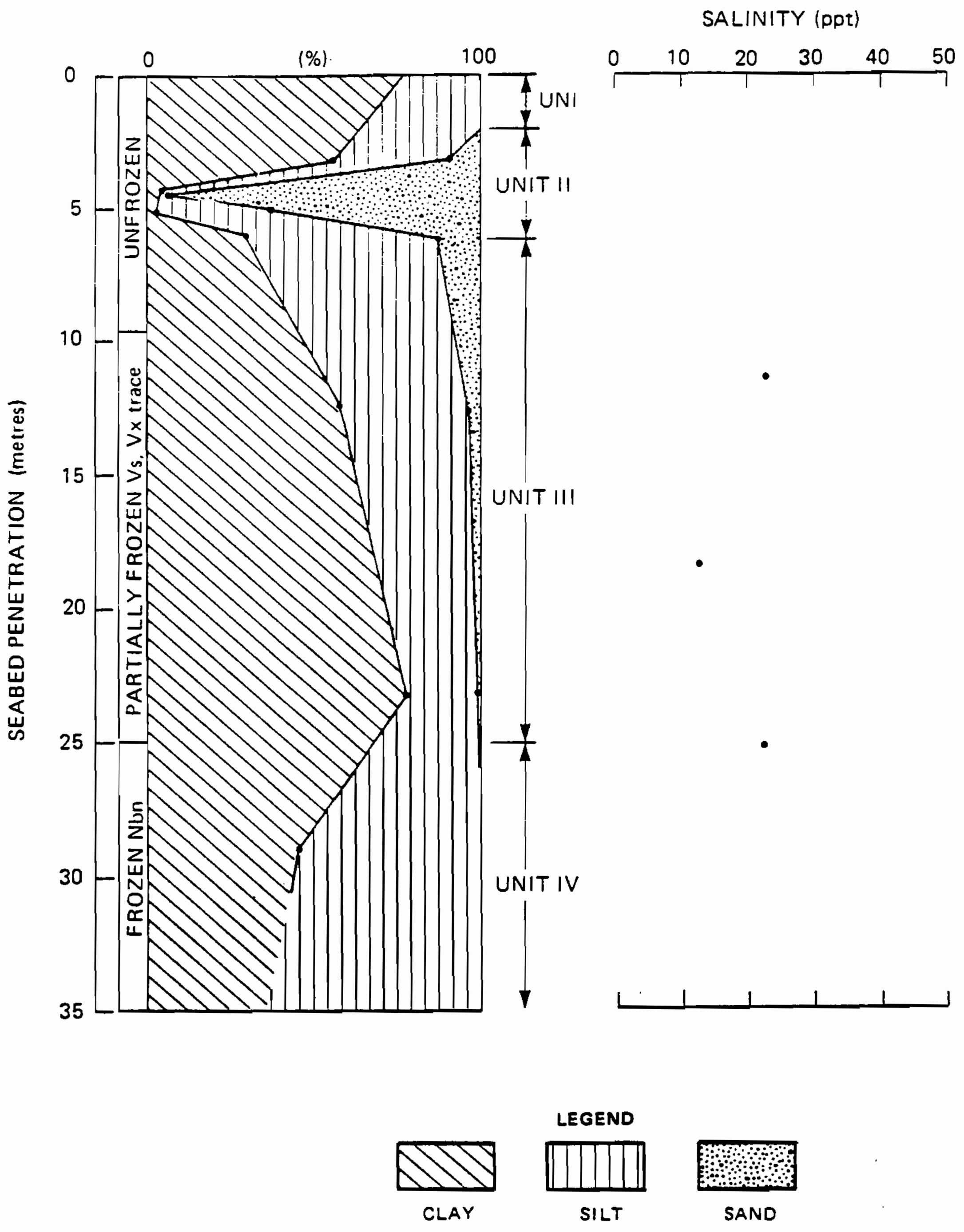
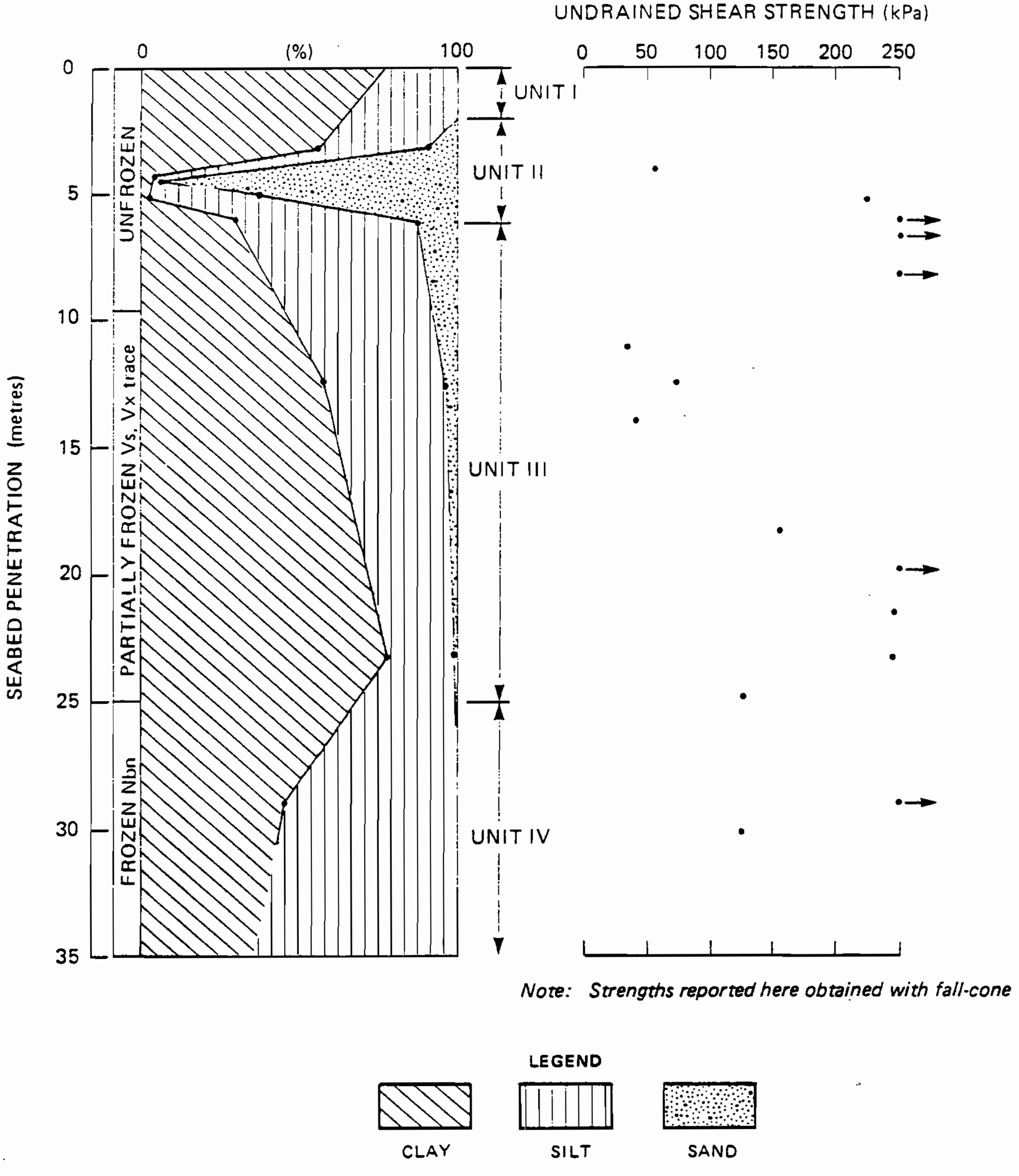


FIGURE B.5 SALINITY PROFILE, KRINGALIK AREA



*Note: Strengths reported here obtained with fall-cone*

FIGURE B.6 UNDRAINED SHEAR STRENGTH PROFILE, KRINGALIK AREA

# APPENDIX C

# Classification and Index Test Results

# SUMMARY OF TEST RESULTS

FR32S01

| Sample Number | Sample Type | Depth (metres) *Sample Photographed | Unified Soil Classification | Ground Ice Description (%) | Temp. (°C) | Moisture Content (%) | Frozen Moisture Content (%) | Bulk Density (Mg/m³) | ATTERBERG LIMITS Liquid Limit (%) | ATTERBERG LIMITS 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | T | SB - 0.43 | CL | | | | | | 56 | 30 | | | | | | | | | | | | | |
| P1A | NS | 0.43 | | | | | | | | | | | | | | | | | | | | | |
| P2 | T | 1.52 - 2.12 | CL | | 1.4 | | | | | | | | | | | | | | | | | | |
| P2A | NS | 2.12 | | | | | | | | | | | | | | | | | | | | | |
| 1A | B | * 3.05 - 3.35 | | | 0.8 | 60 | | | 53 | 24 | 57 | 34 | 10 | | | | | | | | | | |
| 1B | NS | * 3.77 - 3.82 | | | | 37 | | | | | | | | | | | | | | | | | |
| 2A | B | 3.96 - 4.23 | | | 1.4 | 34 | | | 48 | 22 | | | | | | Fc | 56 | | stiff | | | | |
| 2B | B | * 4.23 - 4.54 | | | | | | | | | | 5 | 95 | | 200 | | | | | | | | |
| 3A | B | 4.88 - 5.05 | | | | 42 | | | 30 | 17 | | | | | | | | | | | | | |
| 3B | B | * 5.05 - 5.18 | | | | | | | | | 3 | 35 | 62 | | | | | | | | | | |
| 3C | B | 5.18 - 5.30 | CL | | 0.4 | | 0 | | 26 | 16 | | | | | | Fc | 221 | | hard | | | | |
| 4A | B | 5.79 - 6.30 | CL | | 0.7 | 18 | 1.0 | | 27 | 16 | 30 | 58 | 12 | | | Fc | 250⁺ | | | | | | |
| 5A | B | 6.70 - 6.77 | CL | | | 17 | | | 32 | 18 | | | | | | Fc | 250⁺ | | | | | | |
| 6A | B | 7.62 - 8.20 | CL | | 1.9 | 22 | 1.0 | | 36 | 19 | | | | | | Fc | 250⁺ | | | | | | |
| 7A | T | 8.53 - 8.93 | CL | | | | | | | | | | | | | | | | | | | | |
| 8A | B | * 10.67 - 11.45 | CL | Vs-Vr 5% | | | 3.0 | | 56 | 26 | | | | | | Fc | 32 | | firm | | | | |
| 8B | GS | 11.22 - 11.31 | | | | 27 | | | | | | | | | | | | | | | | | 23 S |
| 8C | B | 11.32 - 11.40 | | | | | | | | | | | | | | | | | | | | | |
| 8D | B | 11.40 - 11.45 | | | | | | | | | | | | | | | | | | | | | |
| 9A | B | 12.19 - 12.97 | CL | Vx10-15% | -1.1 | | 2.0 | | 54 | 26 | 58 | 40 | 2 | | | Fc | 72 | | stiff | | | | |
| 9B | NS | 12.53 - 12.76 | | | | 31 | | | | | | | | | | | | | | | | | |

**LEGEND AND NOTES**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| B | Bag Sample | PF | Permafrost Sample | MV | Minivane | UU | Unconsolidated Undrained Triaxial | O | Organic Content |
| G | Gas Sample | PW | Porewater Sample | FC | Fall Cone | UUp | UU Triaxial with Pore Pressure Measurements | S | Salinity |
| L | Liner Sample | T | Sample Stored in Tube | TV | Torvane | CU | Consolidated Undrained Triaxial | TS | Thaw Strain |
| P | Piston Sample | W | Waxed Sample | PV | Pilcon Vane | CUp | CU Triaxial with Pore Pressure Measurements | | |
| NR | No Recovery | RC | Radiocarbon Sample | RV | Remote Vane | CD | Consolidated Drained Triaxial | | |
| NS | No Sample Remaining | | | | | | | | |

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Reviewed By: ______________________ P.Eng.

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# SUMMARY OF TEST RESULTS

ER82S01

| Sample Number | Sample Type | Depth (metres) Sample Photographed | Unified Soil Classification | Ground Ice Description (%) | Temp. (°C) | Moisture Content (%) | Frozen Moisture Content (%) | Bulk Density (Mgm³) | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10A | B | * 13.72 - 14.50 | CL | Vs 10% | -1.3 | | 1.0 | | 59 | 27 | | | | | | Fc | 39 | | firm | | | | |
| 10B | NS | 14.06 - 14.28 | | | | 35 | | | | | | | | | | | | | | | | | |
| 11A | T | 15.24 - 15.37 | CL | | | | | | | | | | | | | | | | | | | | |
| 12A | NS | 16.30 - 16.35 | CL | | | 42 | 10.0 | | | | | | | | | | | | | | | | |
| 12B | T | 16.15 - 16.30 | | | | | | | | | | | | | | | | | | | | | |
| 13A | NS | 18.29 - 18.32 | CL | | | 33 | | | | | | | | | | FC | 159 | | V.stiff | | | | |
| 13B | S | 18.32 - 18.35 | CL | | | | | | | | | | | | | | | | | | | | 13 S |
| 13C | G | 18.35 - 18.39 | | | | | | | | | | | | | | | | | | | | | |
| 13D | B | * 18.45 - 19.04 | | Vs 5% | -1.0 | | 8.0 | | 53 | 27 | | | | | | | | | | | | | |
| 14A | NS | 19.81 - 19.83 | CL | | | 34 | | | | | | | | | | Fc | 250⁺ | | | | | | |
| 14B | B | 19.83 - 20.46 | | | -1.1 | | 7.0 | | | | | | | | | | | | | | | | |
| 15A | NS | 22.20 - 22.24 | CL | | -0.2 | 39 | 1.0 | | | | | | | | | | | | | | | | |
| 15B | B | 21.34 - 22.20 | | | | | | | | | | | | | | Fc | 245 | | hard | | | | |
| 16A | NS | 23.68 - 23.71 | CL | | -0.2 | 44 | 11.0 | | | | | | | | | | | | | | | | |
| 16B | B | 22.86 - 23.69 | | | | | | | 65 | 29 | 79 | 21 | | | | Fc | 245 | | hard | | | | |
| 17A | NS | 25.05 - 25.10 | CL | | | 28 | | | | | | | | | | | | | | | | | |
| 17B | B | 24.38 - 25.05 | | | | | | | 41 | 23 | | | | | | Fc | 122 | | V.stiff | | | | |
| 17C | S | 25.10 - 25.13 | | | | | | | | | | | | | | | | | | | | | 32 S |
| 17D | G | 25.13 - 25.18 | | | | | 11.0 | | | | | | | | | | | | | | | | |
| 18A | NS | 25.91 - 26.06 | SM | Nbn | | 27 | | | | | | | | | | | | | | | | | |
| 20A | NS | 29.29 - 29.32 | ML | Vx | -1.6 | 31 | 4.0 | | | | | | | | | | | | | | | | |

LEGEND AND NOTES

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| B | Bag Sample | PF | Permafrost Sample | MV | - Minivane | UU | - Unconsolidated Undrained Triaxial | O | - Organic Content |
| G | Gas Sample | PW | Porewater Sample | FC | - Fall Cone | UUp | - UU Triaxial with Pore Pressure Measurements | S | Salinity |
| L | Liner Sample | T | - Sample Stored in Tube | TV | - Torvane | CU | - Consolidated Undrained Triaxial | TS | - Thaw Strain |
| P | Piston Sample | W | - Waxed Sample | PV | - Pilcon Vane | CUp | - CU Triaxial with Pore Pressure Measurements | | |
| NR | No Recovery | RC | - Radiocarbon Sample | RV | - Remote Vane | CD | - Consolidated Drained Triaxial | | |
| NS | No Sample Remaining | | | | | | | | |

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# SUMMARY OF TEST RESULTS

| ER82S01 |  |  |  |  |  |  |  |  | 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 |
| 20B | B | 28.96 - 29.32 |  |  |  |  |  |  | 42 | 22 | 45 | 55 |  |  |  | Fc | $250^{+}$ |  |  |  |  |  |  |
| 21A | NS | 30.65 - 30.68 | ML | Nbn | -1.2 | 31 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 21B | B | 30.28 - 30.65 |  |  |  |  |  |  |  |  |  |  |  |  |  | Fc | 123 |  | V stiff |  |  |  |  |

**LEGEND AND NOTES**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| B | Bag Sample | PF | Permafrost Sample | MV | · Minivane | UU | · Unconsolidated Undrained Triaxial | O | Organic Content |
| G | Gas Sample | PW | Porewater Sample | FC | · Fall Cone | UUp | · UU Triaxial with Pore Pressure Measurements | S | · Salinity |
| L | Liner Sample | T | · Sample Stored in Tube | TV | · Torvane | CU | · Consolidated Undrained Triaxial | TS | Thaw Strain |
| P | Piston Sample | W | Waxed Sample | PV | · Pilcon Vane | CUp | · CU Triaxial with Pore Pressure Measurements | | |
| NR | No Recovery | RC | Radiocarbon Sample | RV | · Remote Vane | CD | · Consolidated Drained Triaxial | | |
| NS | No Sample Remaining | | | | | | | | |

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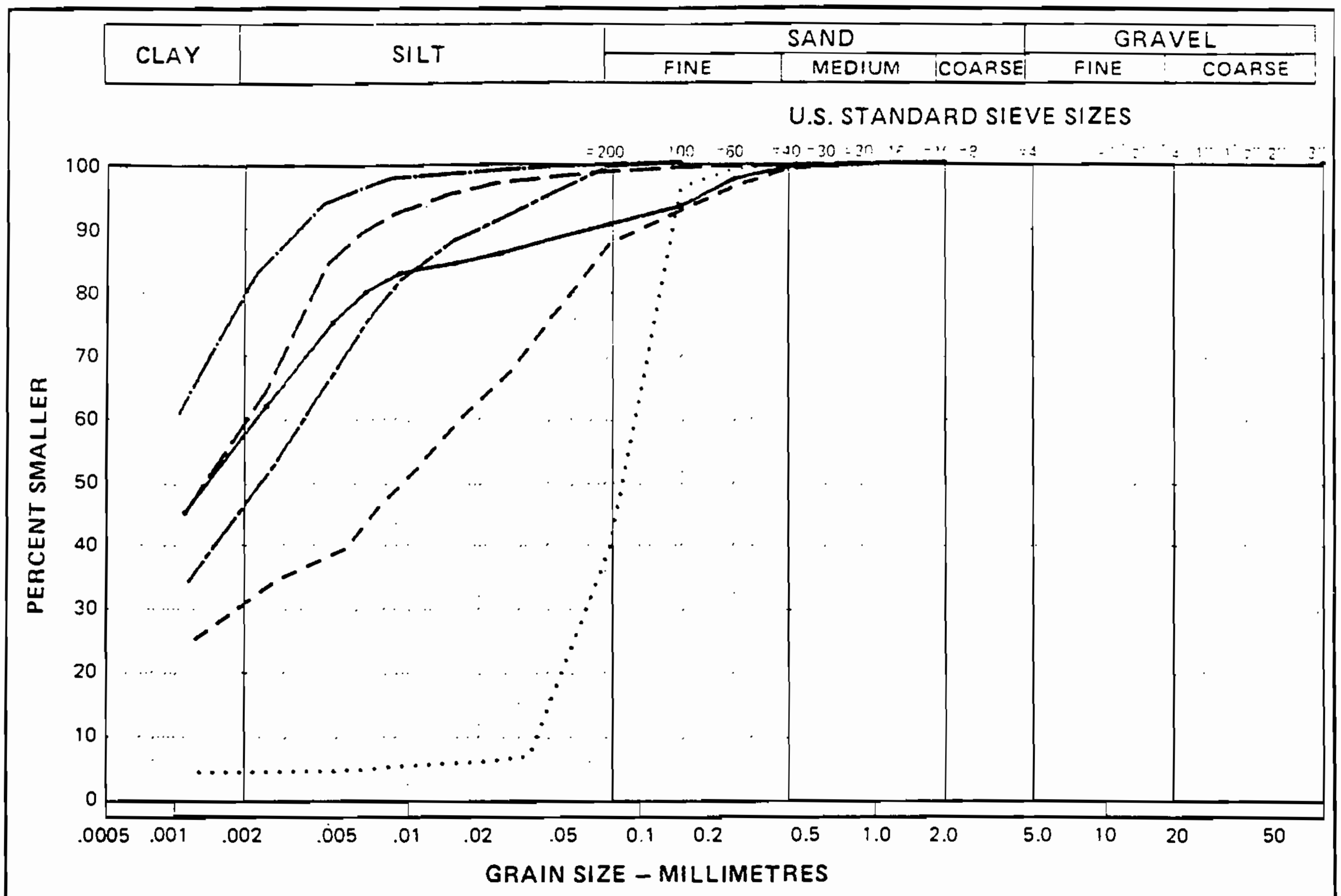
Reviewed By: ____________________ P.Eng.

## PARTICLE - SIZE ANALYSIS OF SOILS



| SYMBOL | BOREHOLE NUMBER | DEPTH (m) | DESCRIPTION CLAY (%) | SILT (%) | SAND (%) | GRAVEL (%) | Cu | Cc | U.S.C. |
|---|---|---|---|---|---|---|---|---|---|
| ——— | KR82S01 | 3.05 - 3.82 | 56.5 | 33.9 | 9.6 | 0.0 | - | - | |
| · · · · · | KR82S01 | 5.05 - 5.18 | 3.0 | 35.2 | 61.8 | 0.0 | 2.6 | 1.0 | SM |
| — — — | KR82S01 | 5.79 - 6.30 | 29.6 | 57.7 | 12.7 | 0.0 | - | - | |
| —— —— | KR82S01 | 12.19 - 12.97 | 58.3 | 40.4 | 1.3 | 0.0 | - | - | |
| ——·— | KR82S01 | 22.86 - 23.68 | 78.7 | 21.2 | .1 | 0.0 | - | - | |
| ——— — — | KR82S01 | 28.96 - 29.32 | 45.1 | 54.5 | .4 | 0.0 | - | - | |

JOB NO. 101 -3658

DATE 82-09-29

# APPENDIX D

## SHEAR STRENGTH TEST RESULTS

Further testing of soils sampled at the Kringalik location is anticipated in the future.

# APPENDIX E

## Consolidation Test Results

# APPENDIX E

## CONSOLIDATION TEST RESULTS

Further testing of soils sampled at the Kringalik location is anticipated in the future.

# APPENDIX F

## Subconsultants Results

# REPORT ON
# HYDROCARBON GAS ANALYSES
# BOREHOLE KR82S01 - Kringalik

JOB 101-3658.3

FOR

EBA ENGINEERING CONSULTANTS LTD.
J.P. RUFFELL

PREPARED BY

Dr. J.F. BARKER
DEPARTMENT OF EARTH SCIENCES
UNIVERSITY OF WATERLOO

DECEMBER 2, 1982

## METHODS

At the drill site, fresh core material is placed in cans with water so as to eliminate any head space. In the laboratory, 100 $cm^3$ of helium is added and 100 $cm^3$ of water withdrawn via gas-tight septa. The sediment/water/helium mixture is vigorously shaken so that hydrocarbon gases will be taken into the helium gas phase. A few microlitres of the gas phase is analyzed by gas chromatography for methane, ethane, ethylene, propane, and propylene. A commercial, analyzed gas mixture is used as standards. The concentration of each component is reported in parts per million (ppm) on a volume basis (v/v). That is, $10^4$ ppm, v/v indicates that there is 1 $cm^3$ of that gas per 100 $cm^3$ of wet sediment. It is assumed that 100 $cm^3$ (100 ml) of wet sediment has been canned at the drill site. In addition, the sediment was dried and weighed so that the amount of gas per dry weight of sediment can be reported if the client wishes.

## RESULTS

Analyses of the hydrocarbon gases present in these core sample are as follows:

| SAMPLE | DEPTH (m) | GAS CONTENT (ppm, v/v) Methane | Ethylene | Ethane |
|---|---|---|---|---|
| 8B | 11.3 | $2.2 \times 10^4$ | — | 2 |
| 13B | 18.4 | sample leakage - no results | | |
| 17D | 25.1 | $4.3 \times 10^4$ | — | 7 |

Dashes indicate the component was not detected. Propane and propylene also were not detected. Failure of the can for sample 13B during analysis precluded detection of hydrocarbon gases.

The very low concentration of dominantly-petrogenic gases (ethane and propane) gases suggest that these hydrocarbon gases are biogenic in origin. No clearly biogenic gases (ethylene and propylene) were detected, however. This is not unusual in environments where methane is being produced by bacteria. Methane concentrations appear to increase slightly with depth as expected if more reducing conditions are found at depth in these sediments.

The solubility of methane in porewaters as a function of temperature, pressure and salinity is poorly documented. Methane solubility increases as temperature decreases, as pressure increases and as salinity decreases. For example, sediment with 50% fresh water content at 25°C and at 200 psi could retain about $2 \times 10^4$ ppm methane in solution. The reported values are in this range and so there is possibility that significant methane could exist as bubbles in the gas phase and could contribute to pore pressure. Continued generation of methane could enhance this problem.

# APPENDIX G

# Laboratory Test Procedures

# LABORATORY TEST PROCEDURES

## Procedures Specified

1. Classification and Index Tests
2. Triaxial Shear Tests
3. Direct Shear Tests
4. Laboratory Miniature Vane
5. Swedish Fall Cone Shear Strength Determination
6. Consolidation Tests
7. Porewater Salinity Tests
8. Organic Content Determination
9. Radiography

# LABORATORY TEST PROCEDURES

## 1. CLASSIFICATION AND INDEX TESTS

These tests are quite 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 |
| Specific Gravity | D 854 |
| Relative Density | D 2049 |
| Unified Soil Classification | D 2487 |

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

## 2. SHEAR STRENGTH TESTS

Procedure #1 - Unconfined Compression

Procedure #2 - Unconsolidated Undrained Triaxial
With and without pore pressure measurement

Test specimen is mounted in triaxial cell and jacketed. Cell pressure equivalent to estimated in situ total horizontal stress ($K_o = 0.7$) is applied without sample drainage. A pore pressure response test is carried out prior to shear. If $B < 0.95$, sample is loaded to failure at rate of 1%/min with no pore pressure measurement. If $B > 0.95$ specimen loaded to failure at rate of 0.02%/min with pore pressures monitored continuously. Frozen samples are permitted to thaw (undrained condition) prior to measurement of B value.

For quick UU tests, data is presented in the form of stress-strain curves. Where pore pressure is monitored, the following curves are obtained:

1. Stress-strain
2. Effective stress ratio-strain
3. Excess pore pressure-strain
4. P/Q stress path

## CONSOLIDATED-UNDRAINED TRIAXIAL TESTS

Procedure 1 - Sample is mounted in triaxial cell and jacketed. A pore pressure response test is carried out prior to shearing. If further saturation is required, back pressure can be applied to the sample. Frozen samples are placed in a pre-chilled triaxial cell, then permitted to thaw before commencing consolidation. Cell pressure equivalent to estimated total horizontal stress is applied with drainage allowed. Once consolidation is complete, drainage is shut off. Samples are sheared by increasing axial stress at controlled rate of strain based on the consolidation characteristics of the material determined during the consolidation phase of the test. Stress-strain curve and other diagnostic plots are produced.

## CONSOLIDATED-DRAINED TRIAXIAL TESTS

Procedure 1 - Sample is mounted in triaxial cell and jacketed, then thawed under a nominal pressure of 35 kPa. A pore pressure response test is carried out prior to shearing. If further saturation is required, back pressure can be applied to the sample. Sample is consolidated to cell pressure equivalent to estimated mean horizontal in situ effective stress. With drainage open, sample is sheared by increasing the axial stress at a controlled rate of strain. The rate of strain is selected on the basis of consolidation properties of the soil determined during the consolidation phase of the test. Stress-strain curve and other diagnostic plots are produced.

Procedure 2 - Lack of undisturbed samples of sand from certain strata necessitate reconstituting disturbed samples for strength testing. Relative density test is conducted on the sand and reconstituted samples are then prepared to approximately 70% relative density. A pore pressure response test is carried out prior to shearing. If saturation is required, back pressure is applied to the sample. Sample is consolidated to cell pressure equivalent to the estimated in situ mean horizontal effective stress. With the drainage open, the sample is sheared by increasing the axial stress at a controlled rate of strain as detailed in Procedure 1. Stress-strain curve and other diagnostic plots are produced.

NOTES:

1. Standard UU triaxial procedure ASTM D2850.
2. Standard CU and CD triaxial procedures taken from Bishop & Henkel (1969).
3. Samples reconstituted according to procedures outlined in Bjerrum, Kringstad, and Kummeneje (1961).

## 3. DIRECT SHEAR TESTS

Procedure 1 - Standard direct shear procedure. Frozen samples are permitted to thaw and consolidate under applied normal pressure before commencing shear. Resheared strength is measured on plane cut after peak strength has been determined. Generally, a minimum of 3 tests are performed on each material type to define effective stress parameters c' and 0'. Shear stress - deformation curve and other diagnostic plots produced.

Procedure 2 - If no undisturbed sample is available, an appropriate sample may be reconstituted for testing following the same general procedure indicated above.

NOTES:

1. Standard direct shear procedure ASTM D 3080.
2. Samples reconstituted according to procedures outlined in Bjerrum, Kringstad, and Kummeneje (1961).

## 4. LABORATORY MINIATURE VANE

Procedure 1 - Sample is either retained in sampling tube or extruded into split ring. Vane is lowered into sample ensuring total submergence of the vane. Vane is rotated at 10 degrees/min. Test is run until steady post-peak value is reached. Stress-strain curves, peak and post-peak shear strengths are produced.

## 5. FALL-CONE SHEAR STRENGTH DETERMINATION

Procedure 1 - Small portion of sample is extruded into testing cup. Cone is selected with reference to expected shear strength of soil. Cone is lowered to contact the surface of the sample and is then released. Depth of penetration of cone is measured. Shear strength is interpreted from cone strength correlation charts.

## 6. STANDARD OEDOMETER/CONSOLIDATION TESTS

Procedure 1 - Sample is set up in oedometer with dry stones. Standard incremental loading is applied done to a specified vertical effective stress that exceeds the in situ effective overburden pressure. The oedometer is then flooded with a saline solution similar to that of the soil, unloaded and permitted to rebound. After rebound, the specimen is reloaded in increments of 50% increase until a specified vertical effective stress, is reached. Thereafter, the standard doubling of pressures is resumed to test completion. All load increments are left on for a time interval determined by the root time method. e-log-p' curve, $c_v$, k, $m_v$, and Pc' data produced.

Procedure 2 - Sample is set up frozen in oedometer, then moved from cold room to standard apparatus. Stress is applied to seat load cap and sample is then thawed under nominal pressure. Procedure continues as for Procedure 1. e-log-p' curve, $c_v$, k, $m_v$, and Pc' data produced.

NOTE: 1. Modifications made to standard procedure (ASTM D 2435) are taken from Andresen et al. (1979) and Broms (1980), as recommended for overconsolidated soils. Procedure is appropriate in view of large reduction in total stress that typically occurs upon sampling.

In addition to the specific procedures described above, all samples programmed for testing may have other basic tests performed as follows:

1. Moisture content
2. Bulk density
3. Core photography (where practical)
4. Detailed description of sedimentological features, and
5. Identification and preservation of discrete organic matter when present.

## 7. POREWATER SALINITY TESTS

Procedure 1 - Sample is trimmed to remove disturbed material. Porewater is extruded from thawed sample and chloride titration is performed to establish equivalent salinity (NaCl).

NOTES: 1. A silver nitrate titration is performed to determine the chloride ion content (ASTM D 512 Method B).

2. Chloride ion content was converted to an equivalent salinity using the following empirical relationship.

Salinity (o/oo) = 0.03 + (1.805 x Chlorinity (o/oo))

## 8. ORGANIC CONTENT DETERMINATION

Procedure 1 - Small portion of sample is weighed then oven dried. Dried sample is mixed with hydrogen peroxide solution (HO) and boiled. After reaction ceases sample is oven dried and reweighed. Loss in weight is inferred as organic content.

## 9. RADIOGRAPHY

Procedure 1 - Samples are transported to be radiographed on subcontractors premises. Samples are returned with processed film negatives.

Procedure 2 - Samples are radiographed at EBA. Samples are removed from storage area and returned immediately. Film is processed on site and results reviewed.

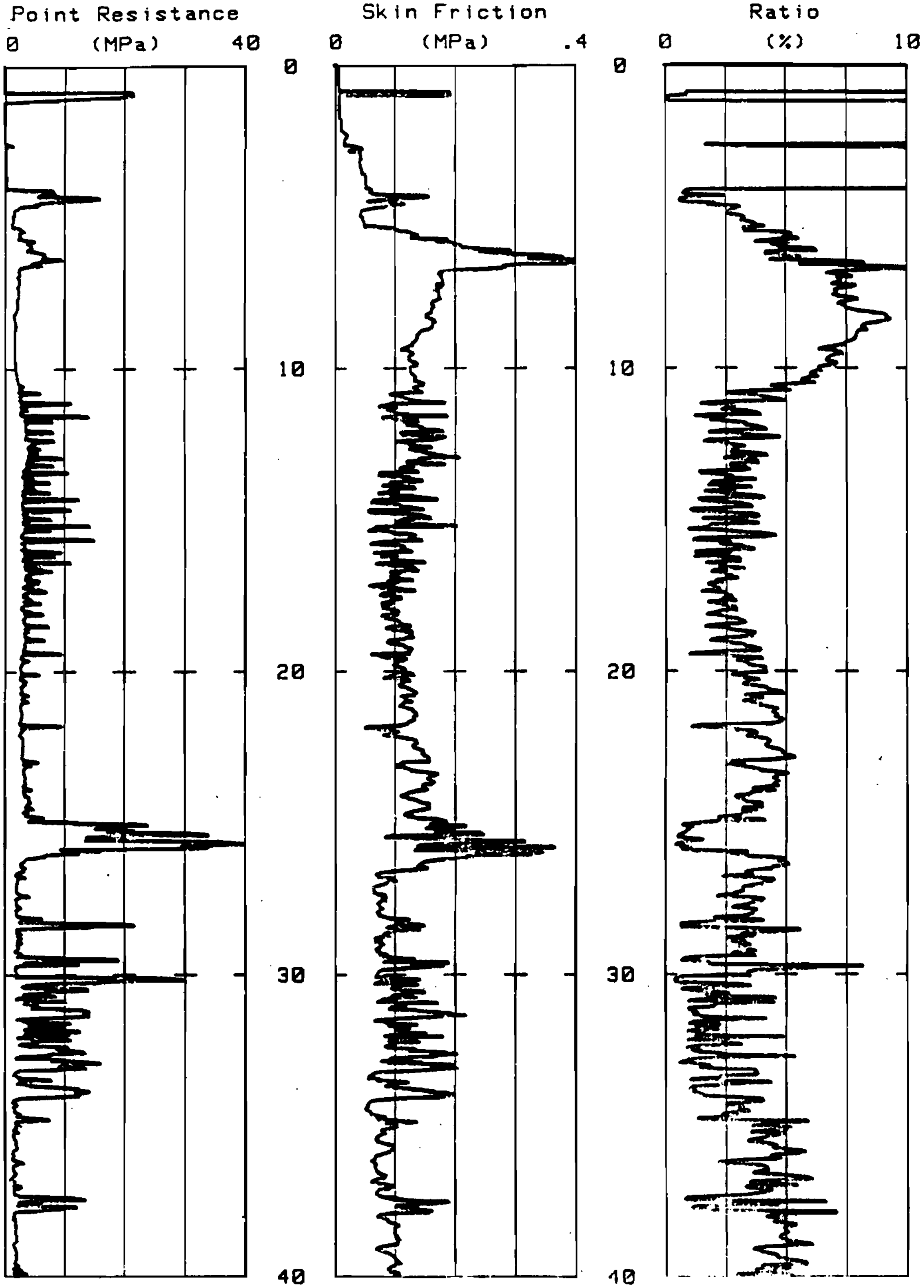
NOTE: 1. For report presentation, radiography subcontractor can prepare high quality B/W prints from film negatives.

# APPENDIX H

# CONE PENETROMETER TESTS RESULTS

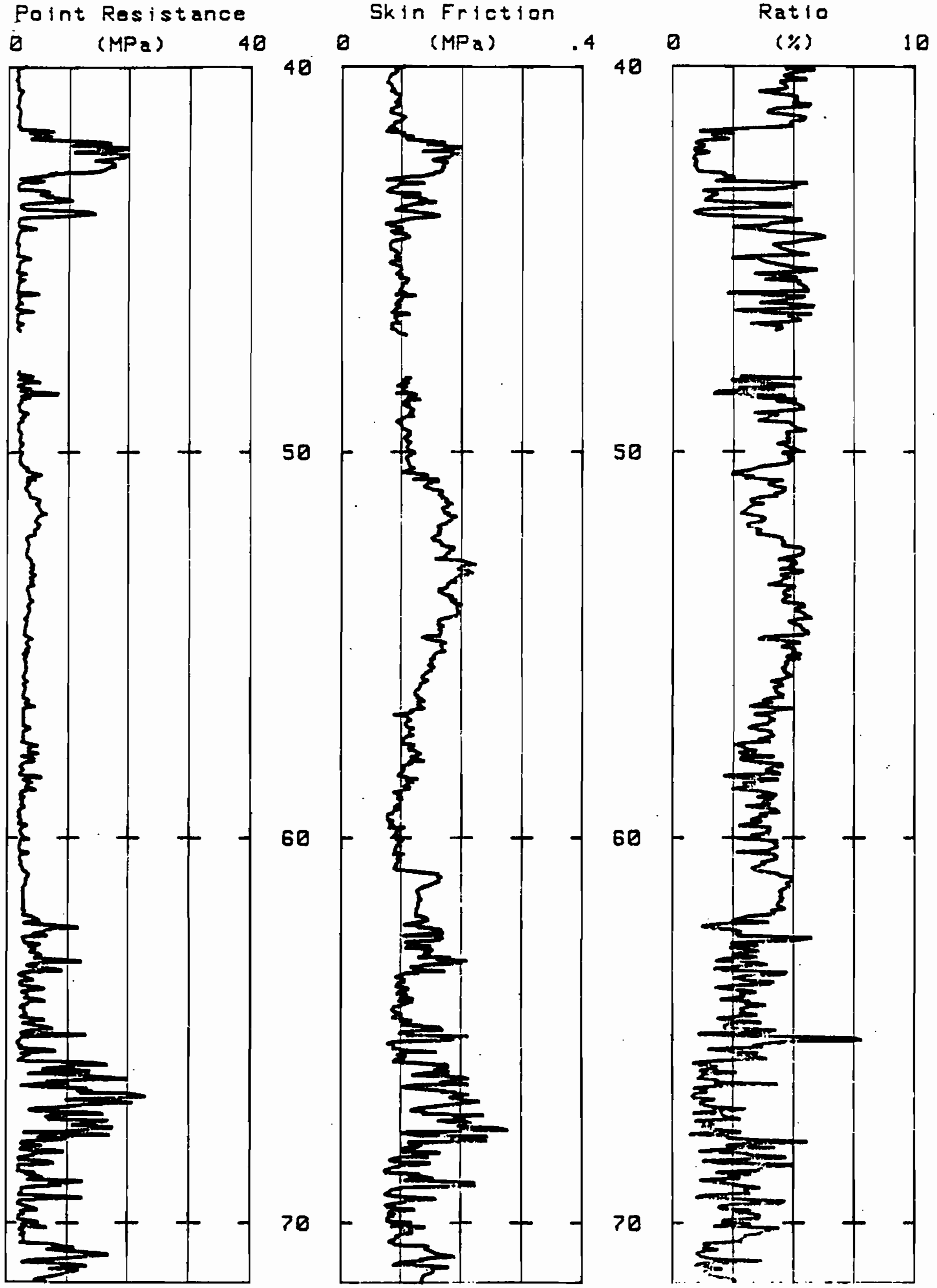
Location: Kringalik
Test No. 01
Code: KR82C01

Date: 82 08 29
Operator: Geosystems
Soil Penetration (m): 71.54
Water depth (m):



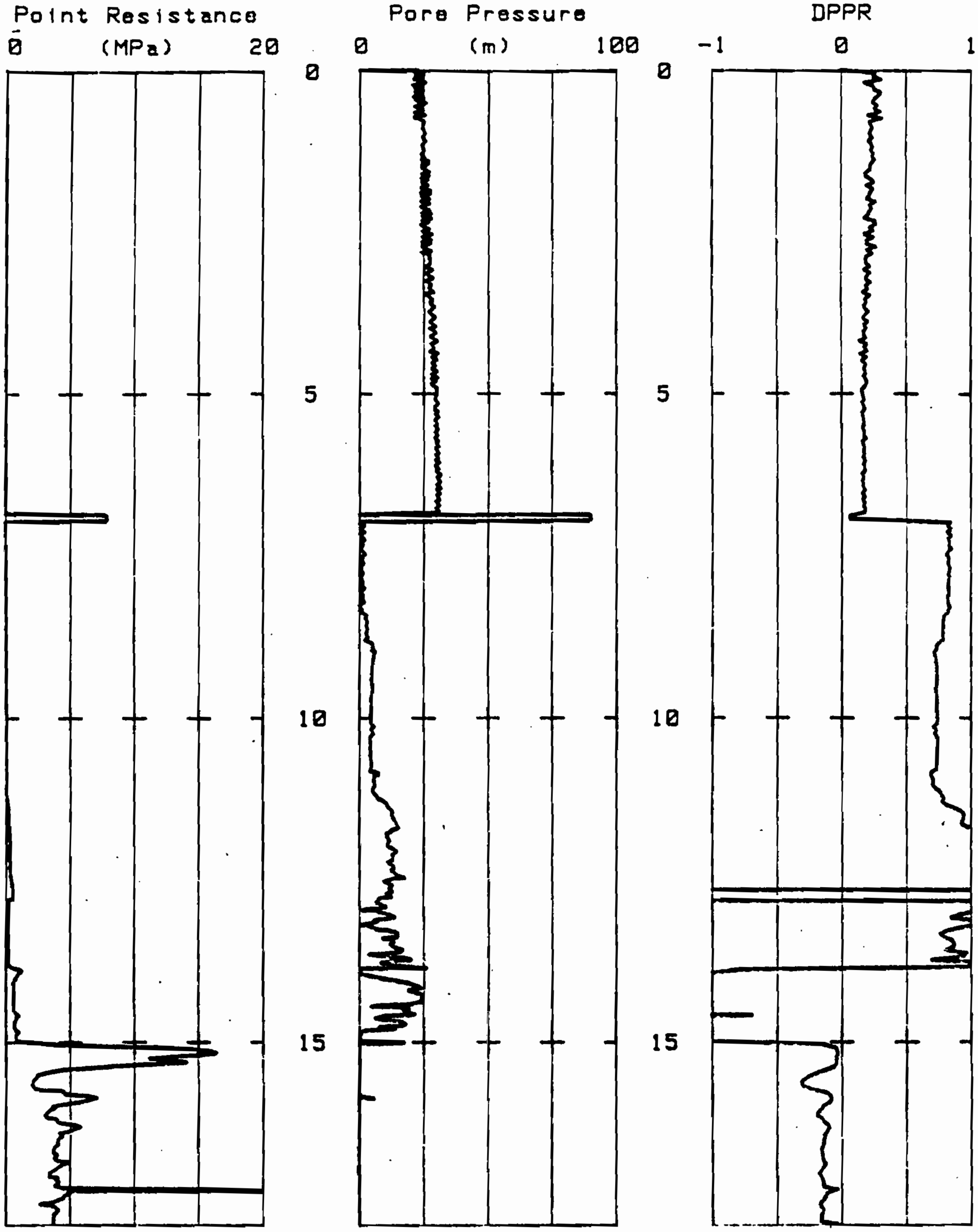
Location: Kringalik
Test No. 01
Code: KR82C01

Date: 82 08 29
Operator: Geosystems
Soil Penetration (m): 71.54
Water depth (m):

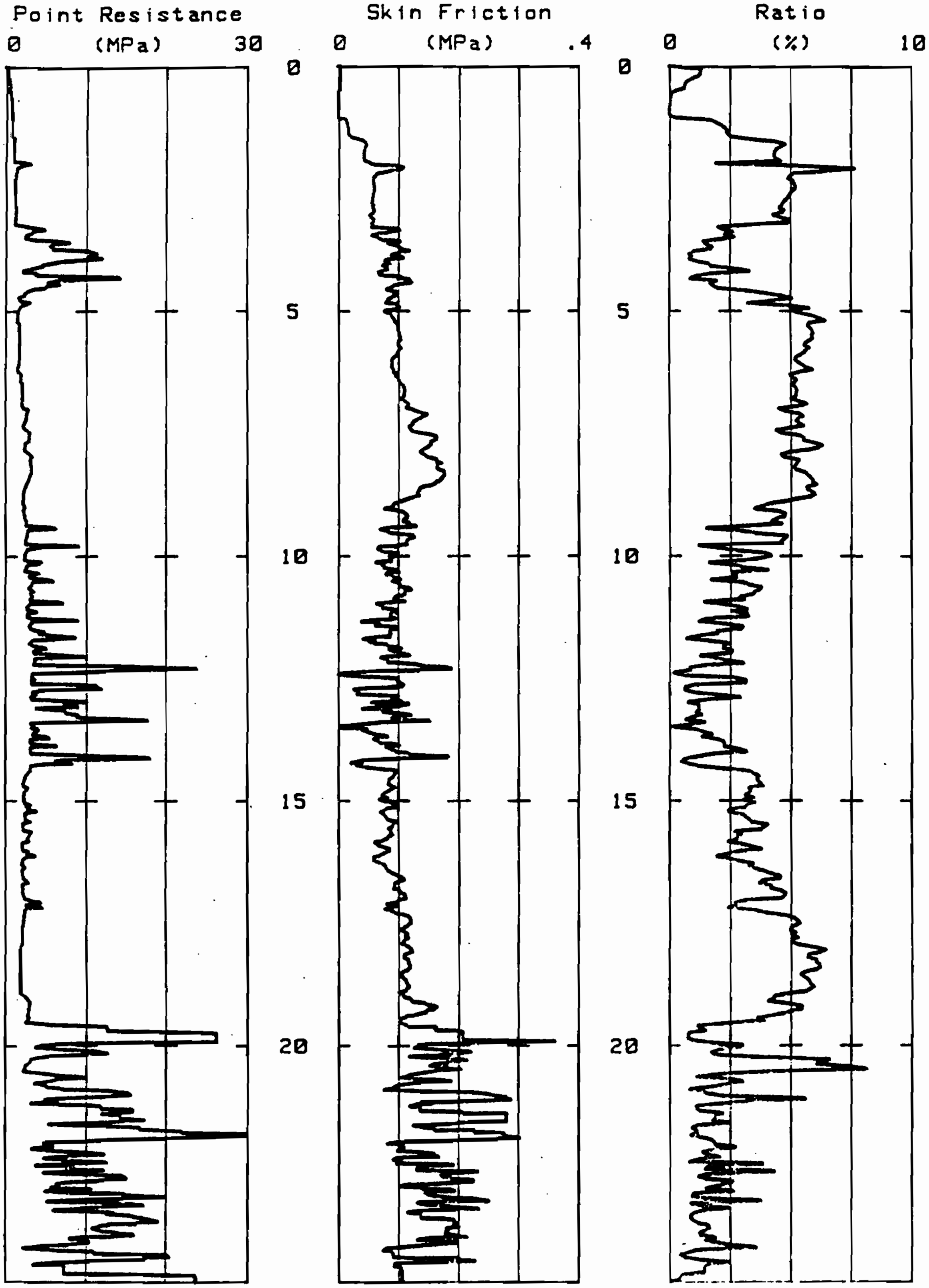


Location: Kringalik
Test No. 03
Code: KR82C03

Date: 82 08 30
Operator: Geosystems
Soil Penetration (m): 17.84
Water depth (m): 32.



Location: Kringalik
Test No. 05
Code: KR82C05
Date: 82 09 01
Operator: Geosystems
Soil Penetration (m): 24.84
Water depth (m):



Location: Kringalik
Test No. 06
Code: KR82C06

Date: 82 09 02
Operator: Geosystems
Soil Penetration (m): 42.68
Water depth (m): 34.0