GEOLOGICAL AND GEOTECHNICAL PROPERTIES OF SEDIMENTS OFFSHORE RICHARDS ISLAND, BEAUFORT SEA

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INTRODUCTION

The Beaufort Sea is located in the southern part of the Arctic Ocean extending along the Alaskan,Yukon and Northwest Territories coast bounded by latitudes 70 and 76 N and longitudes 127 and 144 W. The Beaufort Continental Shelf extends from the shoreline to the 70 m bathymetric contour, approximately 100 km offshore. Deposition onto the shelf originates from the Mackenzie River which produced the Mackenzie River Delta. A Beaufort Sea borehole drilling and geophysical field program was undertaken in the spring of 1984 by the Geological Survey of Canada. One of AGC's objective of the study, was to acquire nearshore data for evaluating the geological history using the geotechnical and sedimentological properties of the seabottom sediments. The objective of the Terrain Sciences division was to evaluate the acoustic properties of the subsea permafrost while Resource Geophysics and Geochemistry conducted refraction and temperature experiments.

The scientists and technical staff who carried out the field and lab studies came from several divisions of the Geological Survey of Canada (GSC) and the National Research Council (NRC). The study was led by GSC Terrain Sciences division personnel, P.J. Kurfurst and M.F. Nixon. From the Resource Geophysics and Geochemistry Division of GSC, J.A. Hunter, S.Pullen,H.A. MacAuley,and R.A. Burns participated. The Atlantic Geoscience Centre Division participants were K. Moran, P. Hill and F.D. Jodrey. T.H.W. Baker of the Building Research Division of NRC and J.L. Morack and W. Harrison of the University of Alaska - Department of Physics and Geophysical Institute also participated in the program.

From the data acquisitioned by the above participants, the sediment parameters of the site were determined. These parameters were used to extend the geological interpretation of the Beaufort Shelf to the nearshore areas and to provide regional geotechnical data for potential site evaluation of an offshore pipeline. The physical properties derived from laboratory tests included water content, liquid and plastic limits, bulk density, undrained shear strength and consolidation.

Additionally, geothermal and geophysical data were collected. At the site several tests were performed in the boreholes and under the landfast ice. The following is a list and description of each of the physical tests performed:

(1) Core Temperature Measurements

Thermal measurements were made on the cores using the Atkins temperature probe and read-out. As soon as the sample reached the surface, the probe was inserted in the tube sampler - Shelby tube, and readings were taken.

(2) Sub Seabottom Temperature Measurements

Temperature cables were installed in most of the boreholes. The cables contained 12 YSI thermistors spaced at 2 m intervals. Daily readings were made until thermal equilibrium occurred.

(3) Water Temperature Measurements

Temperature cables containing 12 YSI thermistors were used to measure water temperatures at 0.5 m depth intervals over a 24 hour period.

(4) Uphole Seismics Measurements

Two types of uphole detectors were used to measure seismic velocities. For boreholes 41+00 to 44+00 a Mark Product P-38 hydrophone was supported in the water filled borehole. The OYO-3-component wall lock geophone was used for the remaining boreholes. Following the sampling program, the geophone was clamped to the PVC casing which was placed in all boreholes. The seismic source used for all boreholes was a seismocap. The source was detonated adjacent to the borehole at a 2 m water depth.

(5) Seabottom Seismic Refraction Measurements

A 12 channel hydrophone (Mark Products P-44) array on the seabottom was mobilized to measure seabottom seismic refraction at each borehole. Each seismocap was detonated at each end of the array to give a reversed profile.

(6) Borehole Heating and Thermal Conductivity

The thermal conductivity of the sediments of boreholes 4+50 and 36+00 were measured. After the boreholes were electrically heated, the temperature response from the sediments were monitored until temperature and thermal conductivity of the sediments stabilized.

(7) Acoustic Velocity Tests

To get a variety of materials analyzed by the acoustic velocity test, frozen and unfrozen samples from several boreholes were selected. For the compressional and shear wave velocity measurements, the OYO Sonic Viewer 5217A was used. The viewer measured the compressional and shear wave independently by using two pairs of transmitters and receivers. The tests were repeated in the cold room at the GSC laboratory in Ottawa.

This report deals with the geotechnical data obtained from the field and laboratory. The data is plotted using predefined geologic boundaries and in this way comparisons and correlations can be made between the geologic and geotechnical data. Therefore, the intent of this report is to present data that will assist researchers and engineers in defining the seabottom sediment characteristics of the nearshore region of Richards Island in the southern Beaufort Sea.

PHYSIOGRAPHY

The study area lies northwest of Richards Island, between Hooper and Pullen Islands, in the southern Beaufort Sea. The area under investigation is situated within latitudes 69 to 71 N and longitudes 135 to 137 W (Fig.1). The water depth of the

PHYSIOGRAPHIC REGIONS OF THE BEAUFORT SEA

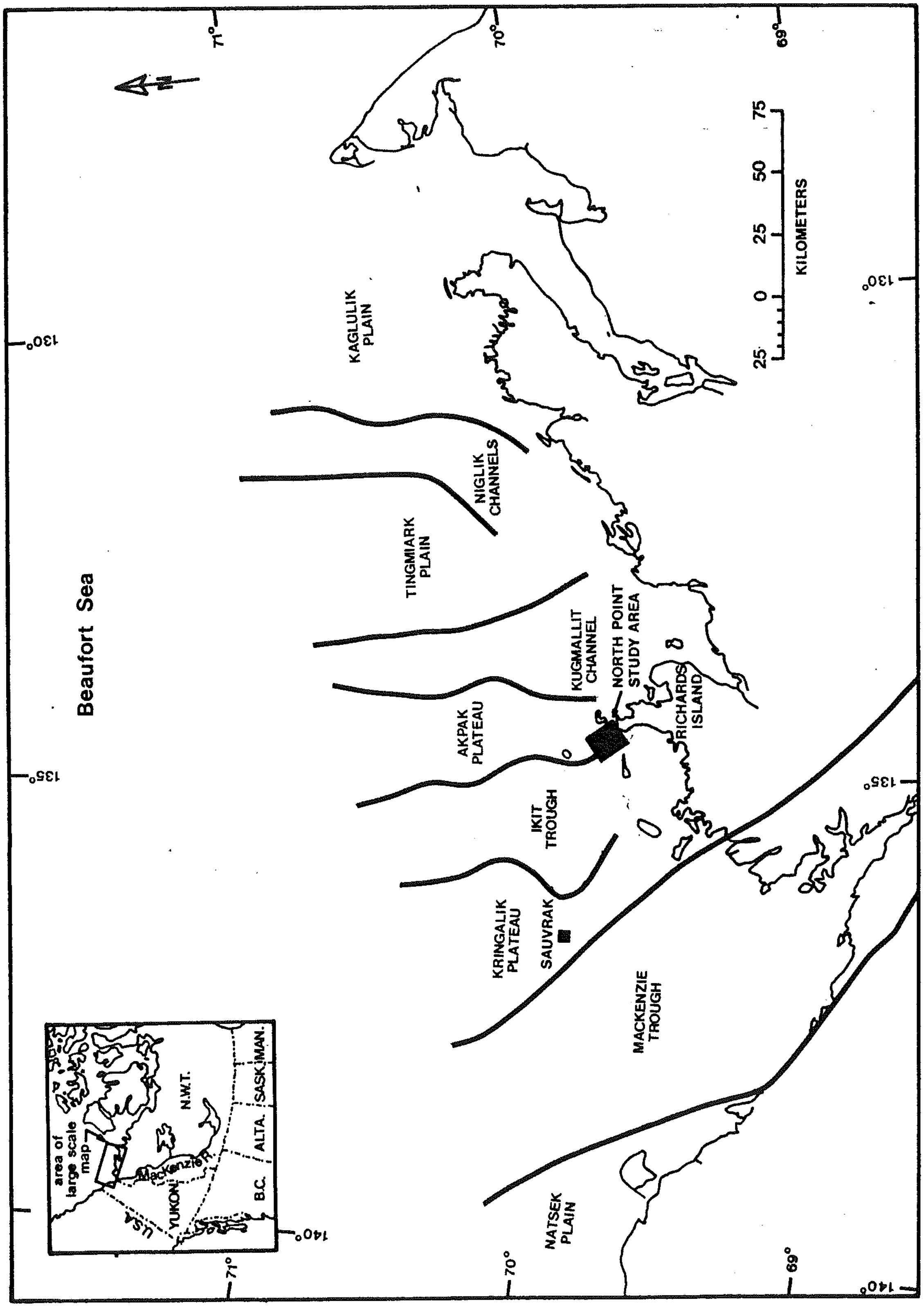

FIGURE 1

region studied ranged from 1 to 11 m. The physiographic province (O'Connor, 1982b) which boreholes 0+00 to 23+279 and boreholes 41+00 to 44+00 traverse is the Ikit Trough, and boreholes 32+00 to 38+00 traverse across both the Ikit Trough and the Akpak Plateau. Fig.2 shows the borehole transects.

GEOLOGIC SETTING

The Beaufort Sea surficial geology (upper 200 m) is of the mid-Wisconsian to Holocene Period. The region is divided into physiographic provinces (O'Connor, 1982b) comprised of such physiographic features as plateaus, troughs, plains and channels. The depositional environment for these sediments in the provinces include marine, deltaic, glacial and littoral environments. Previous reports by M.J. O'Connor indicate the presence of permafrost in the Ikit Trough and Akpak Plateau. However, no evidence of ice scour was found during the spring program. As the name suggests the Ikit Trough is a wide geological depression comprised of silty clay and clayey silt. The Akpak Plateau is an elevated region which may have been a previous extension of Richards Island. To characterize the surficial geology of the Beaufort Sea, the geological model proposed by M.J. O'Connor (1980) is used. The model subdivides the geology into 3 units:

UNIT A - Ranges from 0 to 15 m below seabottom and is composed of recent marine silts and clays deposited since the last marine transgression. The shear strength is low and the soil is normally consolidated.

UNIT B - Ranges from 15 to 150 m below seabottom. This unit contains sediments which underwent sorting during the last marine transgression. Composition of this unit includes sand, silt and clay of deltaic, lagoonal and littoral origin. The shear strength of this unit is medium to high. Since the sediments have been reworked, they may be overconsolidated and normally consolidated.

UNIT C - Ranges also between 15 and 150 m and is separated from Unit B by an erosional unconformity. The older unit is composed of coarse grained sediments of glacial and deltaic origin. Due to the depth and age of this unit it has higher shear strengths and is overconsolidated to normally consolidated.

LABORATORY STUDIES

The geotechnical properties of the sediments were determined from the following laboratory tests:

(1) Atterberg Limits

The limits test included the liquid and plastic limit. The standard laboratory procedure outlined by ASTM was followed. The plastic limit was defined as the moisture content above which a sediment behaves as a plastic. The liquid limit was defined as the moisture content above which a sediment behaves as a viscous fluid. The plasticity index was determined from the liquid and

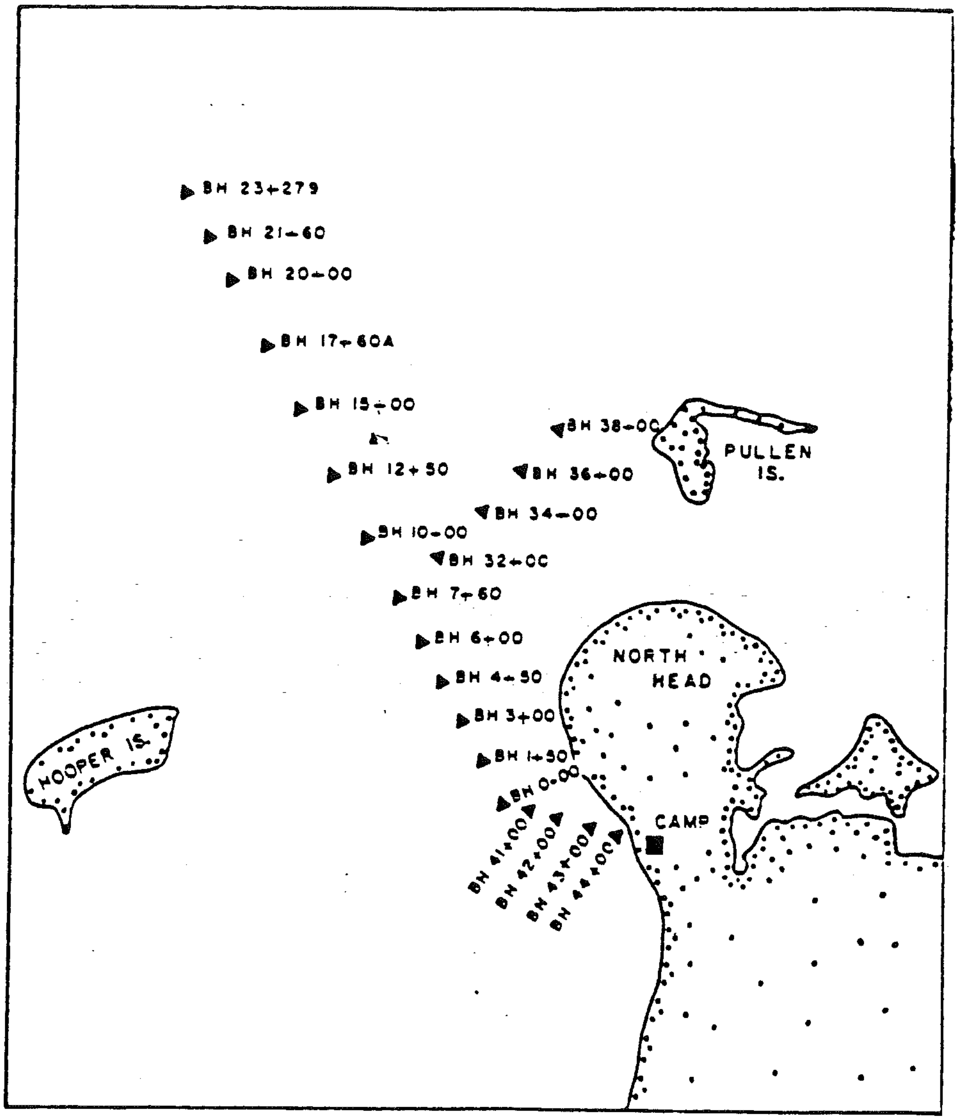

Figure 2 - Map of sample sites for the GSC 1984 Spring Drilling Program (mod. Hill et al, IN PRESS).

plastic limit. The expression for plasticity index is the following:

PI = LL - PL   PL = Plastic Limit
                PI = Plasticity Index
                LL = Liquid Limit

The chart resulting from the PI and LL is the plasticity chart. The chart is divided into 2 regions by the A-Line. The equation for the A-Line is shown below:

PI = (LL - 20) * 0.73   (Casagrande, 1948)

The A-Line is one boundary which defines a sediment as having organic/inorganic silt or clay behavior. As shown in Fig.3 the plasticity chart is further divided into 4 regions.

(2) Water Content

Water content is the ratio of mass of water to the mass of solids in the sediment. The mathematical expression for marine sediments assuming 35 ppt salt water is:

water content = 1.03 * (wt. of wet soil)/(1.35(wt.dry soil) -0.035(wt. wet soil)

(3) Bulk Density

Bulk density is the ratio of the total mass to the total volume of the soil. The expression is:

Density = M/V   M = mass
                 V = volume

The bulk density was measured using an extruder of a constant volume of 7.60 cm.

(4) Shear Strength

Shear strength characterizes the soil's internal resistance to displacement, slip, deformation and volume change. The shear strength was determined using the miniature shear vane apparatus at a rotation of 50 /min (Monney,1968) using a vane of ratio 1:1. The shear strength data can be used as an indicator of varying material types with silty layers having higher shear strength values than clay layers. This results from loss of pore water as the vane in the undrained shear vane test passes through a silt layer, thus strengthening as the sequence is tested. However, when the vane passes through clay, the clay is unable to drain, resulting in more representative (lower) undrained shear strength values.

Geological and Geotechnical Properties of Offshore Richards Island Sediments

Geological Properties

The geotechnical and geologic data acquired from the North Point program was used to establish geological facies which are

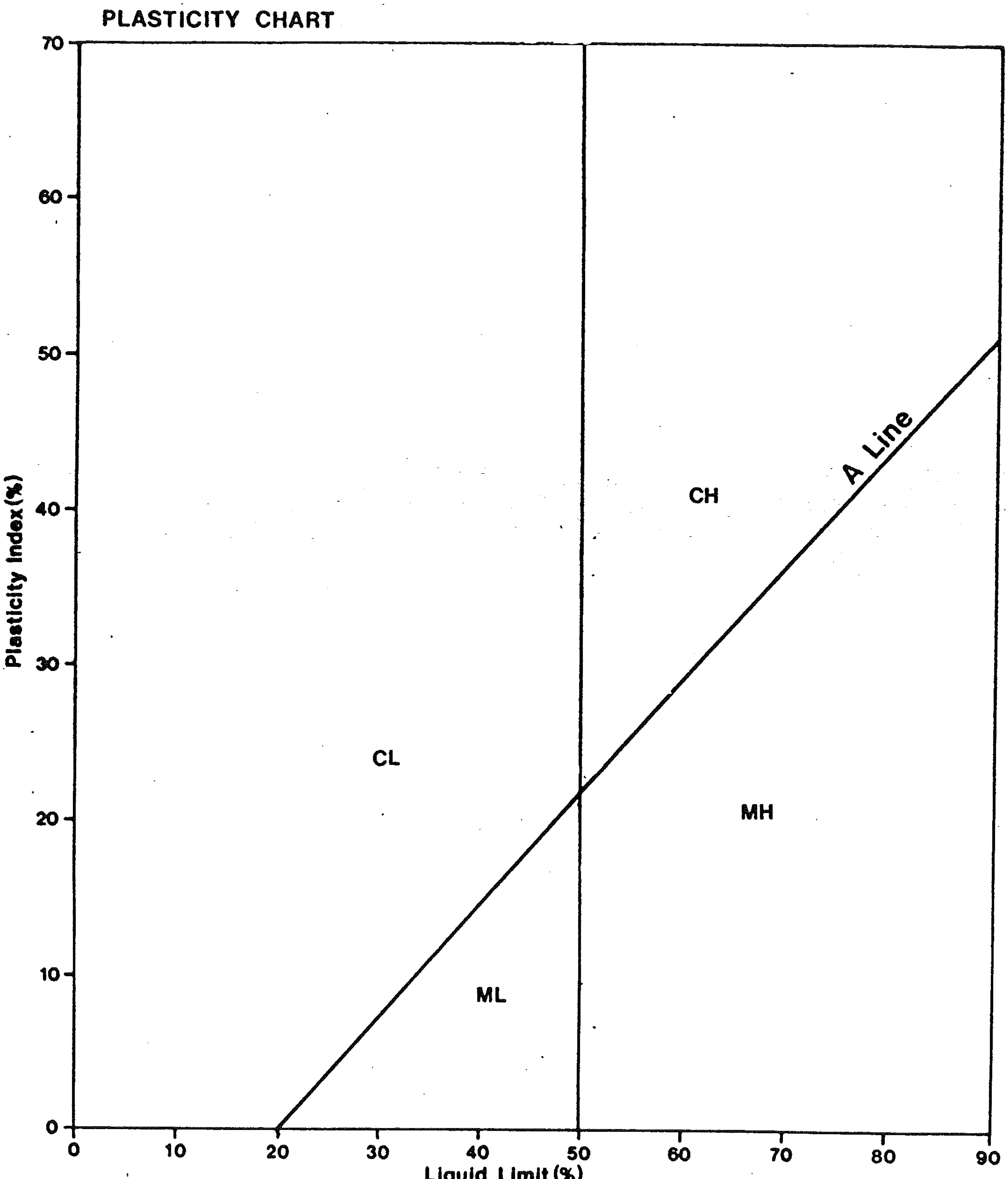
PLASTICITY CHART
70
60
50
40
30
20
10
0
Plasticity Index (%)
CH
A Line
CL
MH
ML
0
10
20
30
40
50
60
70
80
90
Liquid Limit (%)

FIGURE 3

outlined by geologic sections A-C (App.A,Fig.1),D-E (App.A,Fig.2) and A-B(App.A,Fig.3). The following is a brief description of each geologic facies:

FACIES 1A - Bioturbated clay with minor silt

FACIES 1B - Bioturbated silt with minor clay

FACIES 2 - Laminated silt and clay

FACIES 3 - Massive to graded silt

FACIES 4 - Thin graded sands and sand lenses

FACIES SA1 - Medium to coarse sand with mollusc shells

FACIES SA2 - Fine to medium barren sand

App.A,Fig.1, a cross-section of transect 0+00 to 21+60 illustrates the distribution of the geologic facies. From boreholes 0+00 to 6+00 the sediments were predominantly laminated silt and clay of Facies 2. The remaining boreholes contain the massive to graded silt of Facies 3. Beneath facies 3 for boreholes 7+60 to 15+00 lies the bioturbated silt with minor clay of facies 1B. From borehole 15+00 to 21+60 the coarse grained sediments of facies SA1 and SA2 existed below facies 3. From the cross-section it is evident that the nearshore sediment was predominantly clayey silt, whereas further offshore the sediment was predominantly silt, underlain by coarse grained sediments. The origin of the sediments are deltaic to marginal marine. The radio carbon dating in Table 1 shows the sediments to be deposited within the last 10000 years.

TABLE 1

BOREHOLE #	DEPTH(m)	SAMPLE #	AGE
15+00	13.37	BETA-9501	3530+80 B.P.
34+00	18.45	BETA-9504	5580+80 B.P.
34+00	18.62-18.85	BETA-9507	6210+100 B.P.
38+00	6.65-6.75	BETA-9508	9470+110 B.P.

The geologic facies cross-section for transect 32+00 to 38+00 is shown in App.A,Fig.2 . The following describes the cross-section:

(1) Within approximately the first 10 m, sediment from facies 3 extends from 7+60 to between 34+00 and 36+00.

(2) Facies 2 extends to borehole 38+00.

(3) Beneath 10 m, sediments from facies 1B,2,3,4,5,Sa2 exist in an intermingled fashion.

The geologic facies cross-section for transect 0+00 to 44+00 is shown in App.A,Fig.3. The following describes the cross-section:

(1) Within the first 10 m, sediment from facies 2,3 and 4 exists.

(2) Extending from borehole 41+00 to 43+00 below 10 m,

sediment from facies 1B is found.

Comparisons Between Geologic and Geotechnical Properties

The previous section described geologic facies for the three transects. This section describes each facies according to its geotechnical properties. The geotechnical properties (shear strength, grain size, bulk density, water content, plastic limit and liquid limit) for each facies are given in Appendix B - Table 1. The borehole geotechnical data was grouped according to the defined geological facies. It should be noted that establishment of geologic technical data is unadvised due to the variable geotechnical properties which depend upon time of deposition, loading conditions and pore pressure conditions.

(A) Atterberg Limits

The plasticity chart for each facies is given in App.C,Figs.1,2,3,4,5.

The following is a list of observations of the Atterberg Limits data and comparisons between the geologic and geotechnical data:

(1) The Atterberg Limits for facies 1A was distributed along both sides of the A-Line indicating a clayey silt to silty clay sediment of medium plasticity. The indication of silt/clay composition corresponded with the geologic description of facies 1A.

(2) The Atterberg Limits for facies 1B plotted predominantly above the A-Line and in the lower liquid limit region (liquid limit < 50%). From the plasticity chart, facies 1B can be described as a clayey silt which is in agreement with its geologic description of a bioturbated silt with minor clay.

(3) The Atterberg Limits for facies 2 plotted in the low liquid limit region , but were scattered above and below the A-Line. The scattered distribution suggested a laminated nature of low plasticity. The geologic description of laminated silt and clay for facies 2 correlated with the Limits results.

(4) The Atterberg Limits for facies 3 also plotted in the low liquid region and generally below the A-Line. This trend was indicative of predominant silt sediments with minor clay which correlated with the geologic description for facies 3.

(5) The Atterberg Limits for facies 4 plotted predominantly above and parallel to the A-Line. The majority of data points were concentrated in the CL region thereby describing the sediment as a sandy clay of low plasticity. The Limits data correlated with the geologic description of sand.

In conclusion, the Atterberg Limits correlated well with the geologic facies description. To compare the correlations discussed above, the geologic facies cross-section was modified to include the Unified Soils Classification for each borehole in App.A, Figs.1,2,3.

(B) Liquidity Index versus Water Content

The liquidity index versus water content graphs are shown in App.D,Figs.1,2,3,4,5. Below is a list of observations and comparisons between geotechnical and geologic data:

(1) The liquidity index/water content data for facies 1A was inconclusive due to the lack of data points. Therefore, no observations could be made.

(2) The liquidity index/water content data for facies 1B showed the trend that as water content increased, liquidity index increased. A minimum scatter of data existed, perhaps resulting from the dominant silt sediment described in the geologic model.

(3) The graphs for facies 2 exhibited a wider scatter of data points than in facies 1B. The scattered distribution may be characteristic of the lamination structure present in facies 2.

(4) The graphs for facies 3 gave a wide scatter similar to facies 2. However, the liquidity index values were slightly lower than in facies 1B and 2. The lower liquidity index may be attributed to the high silt content described by the geologic model. Therefore, the geologic description of massive to graded silt agreed with the liquidity index/water content observations.

(5) Conclusions from the liquidity index/water content data of facies 4 could not be made due to a lack of data points.

(C) Grain Size

The grain size distribution curves are shown in App.E,Figs.1,2,3,4,5. Table 3 lists the clay/silt content for each sample tested in each facies. A list of observations and geologic/geotechnical comparisons is given below:

(1) The grain size distribution of facies 1A indicated the silt content to be slightly higher than the clay content. The determination of silt/clay composition agreed with the bioturbated silt with minor clay geologic description.

(2) The grain size distribution of facies 1B showed a difference between the silt and clay content. For example, one sample had a silt content of 85.1% and a clay content of 14.9%. The grain size suggested facies 1B to be predominantly silt with minor clay. Therefore, the bioturbated silt with minor clay geologic description correlated with the grain size results.

(3) The grain size distribution of facies 2 gave similar distributions to facies 1B. The data suggested a predominant silt content with minor clay content. Due to the silt/clay composition depicted by the grain size data, the geologic description of laminated silt and clay corresponded with the grain size data.

(4) The grain size distribution of facies 3 specified the soil to be predominantly silt with minor clay. The high silt content corresponded with the massive to graded silt geologic description.

(5) The grain size distribution of facies 4 yielded the highest sand content compared with the other facies. The high sand content correlated with the geologic description of thin graded sand and sand lenses.

In conclusion, the grain size distribution curves supported the

TABLE:3 - GRAIN SIZE PERCENT VALUES

FACIES: 1A

Borehole	Depth(cm)	%silt	% clay	% sand
23+279	135-150	56.1	42.9	1.0
23+279	0-15	69.2	30.8	-

FACIES: 1B

Borehole	Depth(cm)	%silt	%clay	%sand
34+00	760-775	69.3	30.7	-
15+00	855-870	72.1	23.2	4.7
12+20	1725-1740	85.1	14.9	-
7+60	1050-1060	84.7	15.3	-
41+00	1475-1490	86.0	14.0	-
42+00	1370-1385	71.9	26.5	1.6
41+00	1170-1185	85.1	14.9	-
43+00	1925-1940	70.8	41.0	2.7

FACIES: 2

Borehole	Depth(cm)	%silt	%clay	%sand
0+00	1556-1571	82.1	17.9	-
1+50	1280-1295	80.8	19.2	-
3+00	35-50	79.9	19.1	1.0
36+00	336-351	70.2	22.8	7.0
38+00	70-85	72.3	13.8	13.9

FACIES: 3

Borehole	Depth(cm)	%silt	%clay	%sand
34+00	625-640	73.5	26.5	-
7+60	25-40	85.2	14.8	-
7+60	300-315	93.1	6.9	-
15+00	15-20	72.5	27.5	-
15+00	550-565	66.0	34.0	-
17+60	835-850	79.5	18.5	2.0
20+00	150-165	59.1	40.9	-
20+00	1220-1235	70.4	29.6	-
21+60	170-185	60.2	39.8	-
21+60	620-635	84.2	14.8	1.0
23+279	305-320	58.2	41.8	-
32+00	225-240	75.2	22.8	2.0
34+00	110-125	82.2	17.8	-
42+00	32-52	90.0	10.0	-

FACIES: 4

Borehole	Depth(cm)	%silt	%clay	%sand

32+00	1745-1760	62.2	31.8	6.0
23+279	1525-1540	62.2	26.8	11.0
15+00	1590-1605	68.4	31.6	-
21+60	1377-1392	57.0	33.4	9.6
21+60	1868-1882	42.1	54.5	3.4
23+279	1677-1692	54.5	43.5	2.0

geologic description of each facies.

(D) Organic Content

The organic contents were determined for a group of boreholes. The organic contents were labelled on the Atterberg Limits Chart in order to determine the effect organic content has on the plasticity index and liquid limit (App.F). The following is a list of observations from the Limits and organic content data:

(1) Organic contents ranging from 0.69 to 1.89 were located on the ML (inorganic silts, silty or clayey fine sands with slight plasticity) region of the plasticity chart.

(2) The organic content values of 1.00-1.89 had index values less than 5% and liquid limit values below 50%. Evidently, the high organic content reduced the index values.

(E) Shear Strength versus Depth

The undrained shear strength data versus depth is shown in App.G,Figs.1,2,3,4,5. The following is a list of observations of the shear data and comparisons with the geologic descriptions:

(1) For facies 1A, the shear strength increased with depth upto approximately 3 m. Below 3 m the shear strength decreased. The highest shear strength value of 49 kPa at 3m suggested the presence of silt at that depth. The lower shear strength values indicated a high clay low silt content. Therefore, the shear strength data showed a silt/clay composition which agreed with the geologic description of bioturbated clay with minor silt.

(2) The shear strength data for facies 1B yielded a scattered distribution. The scatter of data points was representative of a silt/clay sediment. In comparison the geologic facies description agreed with the silt/clay sediment shown in the shear data.

(3) The shear strength data for facies 2 had shear values ranging from 2 kPa to 25 kPa over the 20 m depth. The scatter of data within the range of 2-25 kPa indicated silt/clay laminations . The results correlated with the laminated silt/clay geologic description.

(4) The shear strength data for facies 3 showed a scattered distribution of data points. The scatter was over a wide range of shear data values namely from 2-49 kPa. The wide range of data suggested a high silt content intermingled with clay. The geologic description for facies 3 was massive to graded silt. Consequently, the geologic description and the interpretation from the shear data were in agreement.

(5) The shear strength data for facies 4 was inconclusive due to a lack of data points. Therefore, no interpretations on the shear data could be made.

In general, the shear data correlated well with the geologic data.

(F) Shear Strength versus Water Content

The graphs of shear strength versus water content showed the trend that as shear strength decreased, water content increased. Since silt will show greater shear strength values than clay, the graphs were used to define the sediment. The following is a list of observations from the graphs (App.H,Figs.1,2,3,4,5) and comparisons with the geologic descriptions:

(1) The shear strength versus water content data for facies 1A was inconclusive due to a lack of data points. Consequently, no interpretations of the data could be made.

(2) The shear strength versus water content data for facies 1B was concentrated within shear strength values of 7 kPa to 34.80 kPa and water content values of 20.76% to 37.20%. The narrow range of shear strength and water content values may have suggested the dominance of one type of sediment. The geologic description of bioturbated silt with minor clay agreed with the graph interpretations of one sediment being dominant.

(3) The shear strength versus water content data for facies 2 was concentrated within shear strength values of 4 - 29 kPa and water content values of 25.14 to 46.34. The localized scatter of data indicated the presence of a predominant sediment type intermingled with a minor sediment structure. The geotechnical observations correlated with the geologic description of laminated silt/clay.

(4) The shear strength versus water content data for facies 3 showed a scatter of data as compared with facies 1B and 2. The shear strength values were higher than in the aforementioned facies. The scatter of data may have suggested a predominant silt structure with a lower clay content than in facies 1B, and 2. In comparison, the geologic description of massive to graded silt concurred with the shear strength and water content interpretation.

(5) The shear strength and water content data for facies 4 was inconclusive due to a lack of data points. Consequently, no interpretation of the data could be made.

Overall, the shear strength versus water content data correlated with the geologic facies model.

(G) Density versus Water Content

In order to study variations in density, water content was plotted against density for the various facies(App. I,Figs.1,2,3,4,5). Below is a list of observations of the density and water content graphs and comparisons with the geologic descriptions:

(1) The density versus water content data for facies 1A was inconclusive due to a lack of data points. Therefore, no interpretations could be made.

(2) The density versus water content data for facies 1B had density values from 1.69 to 1.84 Mg/m and water content values ranging from 21.26 to 37.20 %. The wide range of water content over a narrow range of density may be caused by

laminations which may have existed due to variations in sediment type. The geologic description of bioturbated silt with minor clay suggested variations in sediment which correlated with the interpretation of the density versus water content data.

(3) The density versus water content data for facies 2 had a wider scatter of data points than facies 1B. The water content ranged from 27.15 to 46.34 % and the density ranged from 1.56 to 1.913 Mg/m. The wide range of density and water content may be attributed to variations in sediment type. The sediment variations correlated with the geologic description of laminated silt/clay.

(4) The ranges of water content and density values for facies 3 are listed below:

(a) Water Content: 13.69 - 44.36 %

(b) Bulk Density: 1.472 - 1.8813 Mg/m

The scatter of data points may be due to a high silt content causing inconsistent density values. This observation correlated with the geologic description of massive to graded silt.

(5) The density versus water content data for facies 4 was inconclusive due to a lack of data points. Therefore, no interpretations could be made.

The density versus water content data correlated with the geologic description for each facies.

(H) Consolidation Characteristics

The sediments from the spring program were normally to overconsolidated (Christian, 1985). Overall, the sediments were not organic, however bioturbation was present. The consolidation tests were performed using a back pressure consolidometer. Borehole 20+00 was tested at depth intervals of 4.85 m, 10.95 m, and 13.74 m. The data from these tests are found in App.J,Fig.1. Conclusions drawn from the tests described sediments above 10 m being overconsolidated and sediments below 10 m being normally consolidated.

<u>Summary</u>

In conclusion, the geologic facies were well represented by the geotechnical data. The following is a list summarizing the geotechnical properties of each geologic facies:

FACIES 1A - The geologic description of facies 1A was bioturbated clay with minor silt. The Atterberg Limits indicated a clayey silt to silty clay sediment. From the grain size, the silt content was slightly higher than the clay content. Therefore, the sediment composition was similar to the geologic description in that both Atterberg Limits and grain size confirmed the presence of silt and clay. The shear strength versus depth data suggested the presence of silt at 3 m and a dominant clay structure throughout. The shear strength versus water content data was inconclusive due to a lack of data points. Similarily, no conclusions were drawn from the density versus water content and liquidity index versus water content data.

FACIES 1B - The geologic description of facies 1B was bioturbated silt with minor clay. The Atterberg Limits plotted above the A-Line and in the low liquid limit region, thereby indicating a clayey silt sediment. The conclusion from the Limits was substantiated by the grain size distribution curves. The curves indicated the silt content to be much higher than the clay content. The influence of the dominant silt sediment was also shown in the shear strength versus depth data. The shear strength values reached a maximum value of 38 kPa, thereby indicating the presence of silt. The shear strength versus water content resulted in low water content values relative to the data from the other facies. The low water content values suggested a dominant silt content. The density versus water content also exhibited dominant silt behavior by the high density values and low water content values as compared with the other facies. In comparison, all the geotechnical properties for facies 1B correlated with the geologic facies description.

FACIES 2 - The geologic description of facies 2 was laminated silt and clay. The Atterberg Limits for facies 2 were scattered above and below the A-Line perhaps suggesting equal influence from a silt and clay sediment. Results from the grain size distribution curve concluded a slightly higher silt content than clay content. The shear strength versus depth data gave a lower shear strength range than for facies 1B. The shear strength versus water content data indicated a slightly higher water content and lower shear strength as compared with facies 1B. The higher water content can be attributed to a slightly lower silt content than in facies 1B. The clay content was similar in value to the clay content of facies 1B. Since the grain size data indicated facies 1B and 2 to have similar silt/clay contents, the difference in shear data may be attributed to the lamination structure of facies 2. The density versus water content indicated a wider scatter of data points than in facies 1B. The water content of facies 2 was slightly higher than that of facies 1B indicating the clay lamination to be an influencing factor. The clay laminations also influenced the bulk density, for the density was slightly lower than for facies 1B.Therefore, the geotechnical data correlated with the geologic data. Also, the various geotechnical properties agreed with each other.

FACIES 3 - The geologic description of facies 3 was massive to graded silt. The Atterberg Limits for facies 3 showed values plotting below the A-Line and in the low liquid limit region. The Limits indicated a dominant silt sediment. The grain size described facies 3 as having a dominant silt content. The shear strength versus depth data scattered over a wide range of shear strength values. The strength values ranged from 8 kPa to 49 kPa. As compared with facies 1B,2 and 4, facies 3 exhibited the highest shear values. The high shear values resulted from the 59% to 93.1% silt content. The shear strength versus water content data also scattered over a wide range of shear strength and water content values. The wide range of values developed from the high silt content. The density versus water content exhibited a slightly higher density than facies 2 or 1B. The higher density can be caused by the high silt content.

FACIES 4 - The geologic description of facies 4 was thin graded sand and sand lenses. The Atterberg Limits plotted in a region describing the sediment as a sandy clay. The results from the grain size showed a sand content as compared with facies 1A, 1B, 2, and 3. The shear strength versus depth, shear strength versus water content, liquidity index versus water content and bulk density versus water content were inconclusive due to lack of data points.

Implications for Pipeline Design and Construction

The geologic and geotechnical data identify the area under investigation as being composed of normally to overconsolidated clay, silt and sand. For construction purposes, the presence of clay is favorable, however silt and sand are not desired, since secondary settlement is crucial in silts and sands. Since there is considerable sediment influx from the MacKenzie Delta in this area, the behavior of the soil under surface load is unpredictable. In addition, due to the magnitude and seasonal nature of pack ice, the ice flow pattern must also be considered. Offshore surveys have shown that construction is feasible and has already been proven. Several conditions favorable for construction include a stable soil environment, absence of permafrost in the upper 20 m, and the increased content of clay. Perhaps with future inshore surveys, the feasibility for inshore construction will more acutely be defined.

Further Studies

In order to gain a complete picture of the geotechnical and geological properties of the Beaufort Sea (nearshore and offshore), further study is required. Several field tests in addition to those performed during the North Point program should be performed in future investigations. These field tests should include the following:

(1) high resolution reflection seismic
(2) static cone penetrometer test

The high resolution reflection seismic gives a continuous cross-section of a transect which could be compared with the geotechnical data. The static cone performs the following tests:

(1) cone bearing
(2) pore water pressure
(3) cone friction

These measurements can be interpreted for stratigraphy, shear strength and density. The advantages of using an electric cone penetrometer are:

(1) performance of the test requires less time than performance of borehole drills.

(2) gives continuous profile for pore pressure, friction and tip resistance.

(3) gives continuous record of type of soil structure.

(4) reduces the number of borehole samples required.

Although the electric cone penetrometer is less time consuming, it cannot completely replace the borehole sampling. If both methods are employed together, more conclusive data can be attained for a particular region(Jeffries and Funegard, 1983).

Other aspects that should be investigated are:

(1) The effects of ice scour on the consolidation and strength of the soil.

(2) Measurements of salinity should be made to determine if a relationship exists between salinity and plasticity.

(3) Effects of freeze-thaw cycles on the strength, plasticity and consolidation of the sediment.

Recommendations

From analyzing the data of the spring 1984 program, several incomplete sediment properties were identified. In order to eliminate the grey areas of data, several recommendations have been made for future testing. The recommendations are listed below:

(1) Consolidation Tests - Performed on one borehole, namely borehole 20+00. Consolidation tests should be done on all boreholes using the back pressure consolidometer.

Therefore, if the above mentioned laboratory test are combined with the recommended field tests, a concise picture of the geologic and geotechnical properties in the North Point area can be attained.

Conclusion

The following conclusions about the shallow continental shelf soil properties from the southern Beaufort Sea can be made:

(1) The sediment composition is clay, sand and silt. Nearshore composition is predominantly silt whereas offshore composition is predominantly clay.

(2) Permafrost was not found at depths above 20m. Below 20 m at borehole 17+60 A ice-bonded sediments were present.

(3) Wood pieces and organic soils were retrieved from boreholes along transect 32+00 to 38+00. The presence of sand, wood and organics in the sediment of transect 32+00 to 38+00 indicate a different soil composition from transect 0+00 to 23+279.

The geotechnical properties acquired from laboratory analysis agreed with the defined geologic facies and therefore support the validity of the geologic model. The geotechnical data characterized the sediment to be normally to slightly overconsolidated, with no appreciable loss in strength upon remoulding. This characteristic of retaining strength is very important for offshore and nearshore construction. Therefore, with further nearshore investigations of the geological, geothermal, geophysical and geotechnical characteristics, will the sediment history and properties be better understood for construction and exploration.

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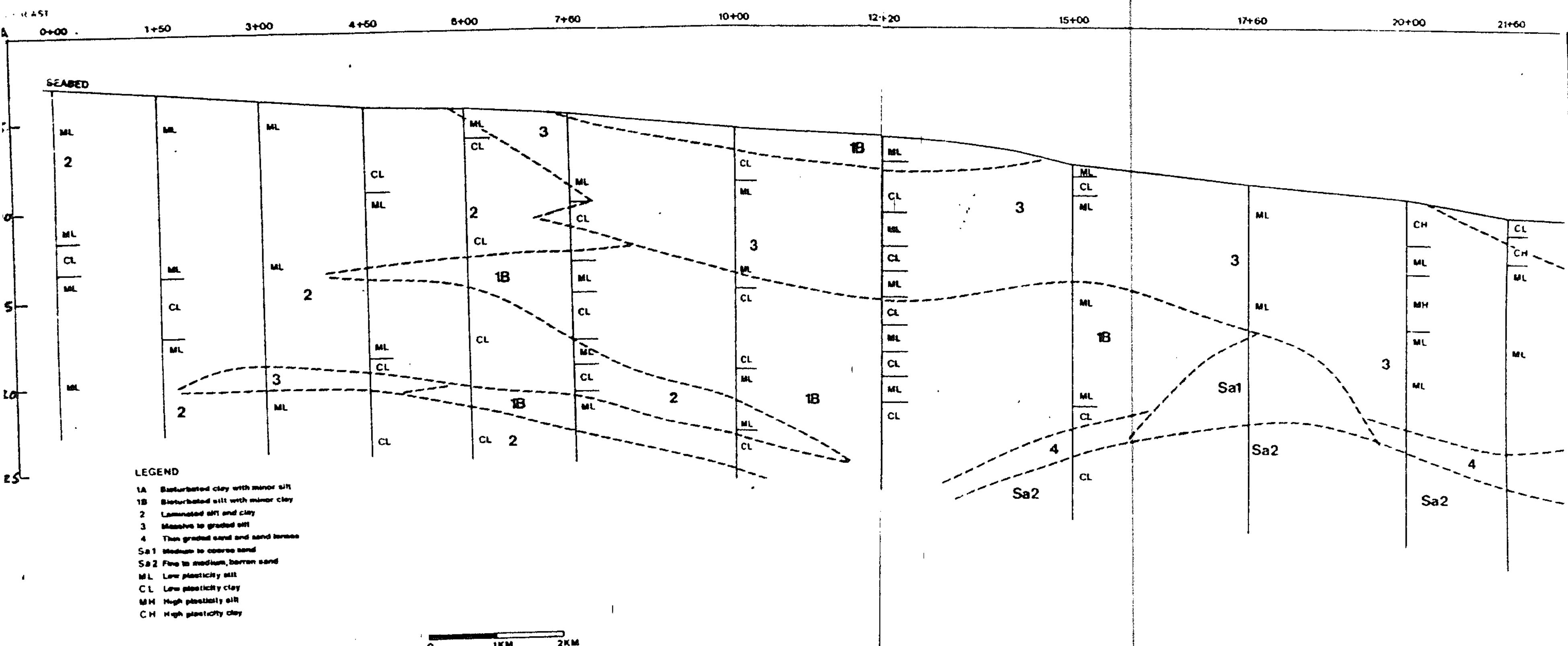
APPENDICES

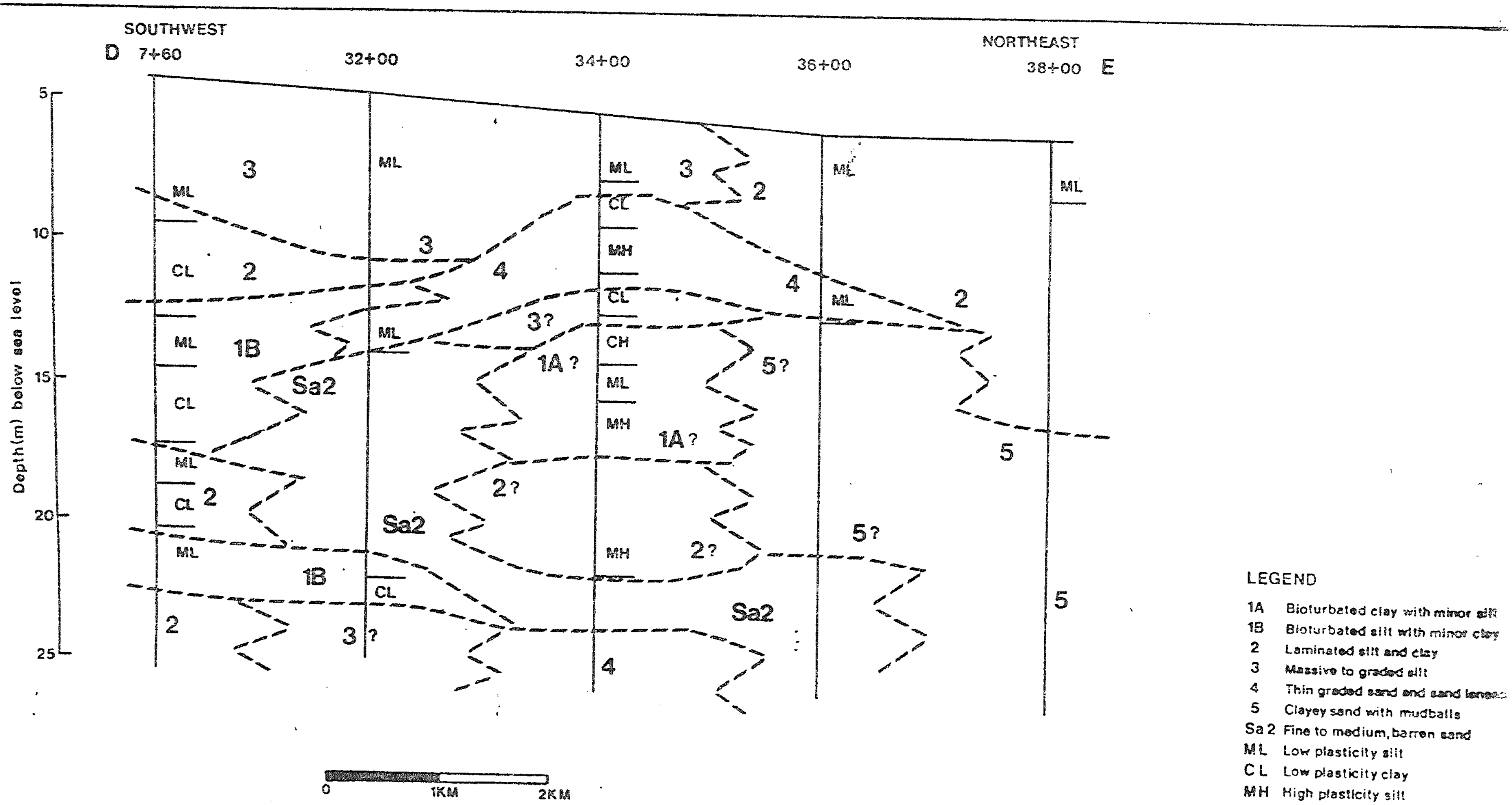
APPENDIX A

BOREHOLE CROSS - SECTIONS



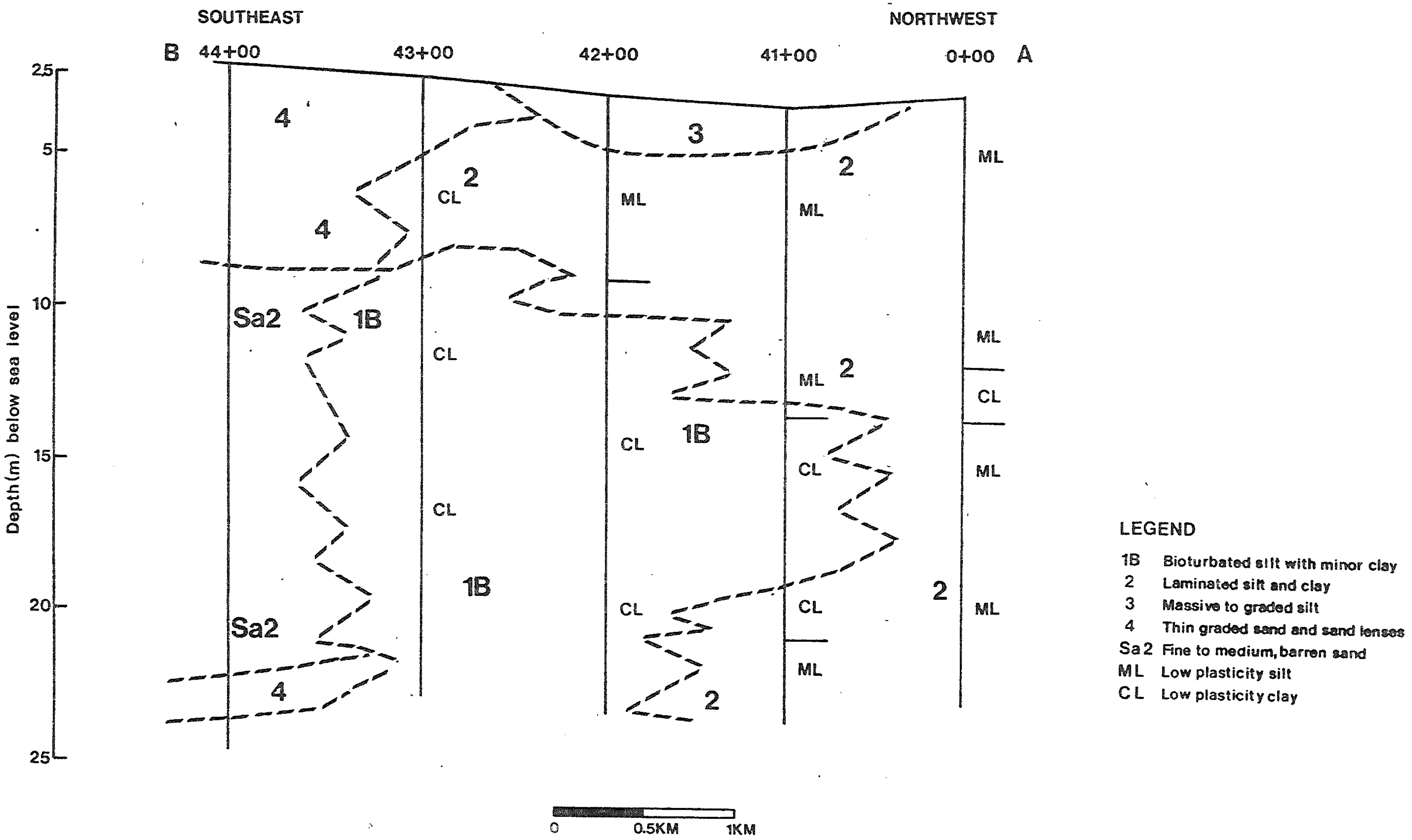
GEOLOGIC SECTION A-C, NORTH POINT

FIGURE 1



GEOLOGIC SECTION D-E, NORTH POINT

FIGURE 2



GEOLOGIC SECTION A-B, NORTH POINT

FIGURE 3

APPENDIX B

DATA TABLES

SUMMARY OF TEST RESULTS

P1

FACIES 1A

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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	CONSOLIDATION CHARACTERISTICS: P_c	CONSOLIDATION CHARACTERISTICS: C_c	TEST RESULTS TABULATED SEPARATELY
21+60		0.35				16.16			45.7	26.4							11.7						
23+279		0.12				55.67		1.60	41.3	21.6							5.5						
23+279		1.40				47.5		1.28	52.3	24.1	42.9	56.1	1.0				22.9						
23+279		3.10				38.8			50.2	28.8													

LEGEND AND NOTES :

SUMMARY OF TEST RESULTS

FACIES 1B

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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	Consolidation Characteristics: P_c	Consolidation Characteristics: C_c	Test Results Tabulated Separately
4+50		9.75				34.0			34.0	27.0													
6+00		9.75				33.1		1.67	36.0	24.0							14.6						
6+00		15.90				32.1		1.80	36.0	18.0							13.8						
7+60		9.20				24.1		1.67	35.6	25.3							14.1						
7+60		10.55				26.4		1.72	27.8	10.0	15.3	84.7					17.1						
7+60		12.05				24.3		1.71	37.7	23.8							10.8						
7+60		16.75				24.9		1.71	36.7	34.1							22.35						
10+00		1.15				28.6			38.0	20.0							7.0						
10+00		2.45							40.0	21.0													
10+00		9.95				25.9		1.69	36.0	23.0							10.8						
10+00		11.45				21.3		1.74	36.0	23.0							13.8						
10+00		13.00				24.7		1.69	37.0	22.0							79.0						
10+00		14.55				25.1		1.69	37.0	26.0							34.8						
10+00		17.80							37.3	24.5													
10+00		19.25				29.2		1.84	39.0	23.0													
12+20		0.23				37.2		1.78	35.7	24.9							21.0						
12+20		0.75				33.6		1.78	37.5	26.9							34.0						
12+20		2.10				28.8			35.2	19.6													
12+20		10.05							32.3	19.5													
12+20		11.40							35.0	25.6													
12+20		12.85				31.1		1.80	29.8	18.3							13.8						

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

FACIES 1B

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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 (%)	Silt (%)	Sand (%)	Gravel (%)	D_{50} (μm)	Shear Strength: Test	Shear Strength (kPa)	Failure Strain (%)	Consistency	Consolidation Characteristics: P_o	P_c	C_c	Test Results Tabulated Separately
12+20		14.42				31.0			31.0	20.9													
12+20		16.00				33.1			32.4	18.2													
12+20		17.40				31.9		1.83	25.8	19.6	14.9	85.1					27.9						
12+20		19.18				31.7		1.84	33.6	22.1							35.1						
15+00		6.95							34.5	25.5													
15+00		8.60							39.3	26.8	23.2	72.1	4.7										
15+00		10.25							45.2	27.3													
15+00		11.70							43.6	27.1													
15+00		13.10							38.0	26.2													
15+00		14.41							39.3	23.3													
32+00		6.95							38.3	27.0													
32+00		17.55				22.2		1.75	42.2	25.4							13.2						
34+00		7.70				32.5			50.0	26.9	30.7	69.3											
34+00		9.64							46.6	30.2													
34+00		10.85				40.2			50.8	34.0													
41+00		11.75				36.2		1.77	31.1	22.6	14.9	85.1					9.7						
41+00		13.25				31.5		1.80	31.8	22.7							8.3						
41+00		14.80				37.2		1.72	31.5	20.1	14.0	86.0					16.8						
42+00		12.35				32.7			33.2	2[illegible].2													
42+00		13.80				34.7			41.2	22.8	26.5	71.9	1.6										
43+00		5.60				19.7			37.6	24.4													

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

FACIES 1B

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified Unified Soil Classification	Ground Ice Description (%)	Temp. (°C)	Moisture Content (%)	Frozen Moisture Content (%)	Bulk Density (Mg m^{-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	Consolidation Characteristics: P_c	Consolidation Characteristics: C_c	Test Results Tabulated Separately
43+00		8.70				20.8		1.62	38.8	23.8							28.2						
43+00		19.30				23.5			44.0	25.1	41.0	70.8	2.7										

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

P1

FACIES 2

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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 (%)	Silt (%)	Sand (%)	Gravel (%)	D_{50} (μm)	Shear Strength: Test	Shear Strength (kPa)	Failure Strain (%)	Consistency	Consolidation Characteristics: P_o	P_c	C_c	Test Results Tabulated Separately
0+00		3.50				38.9			38.5	26.4													
〃		5.00				36.4			36.5	25.0							6.5						
〃		6.60							31.0	23.2													
〃		8.10				32.8		1.78	29.7	23.0							11.0						
〃		9.60				33.0			33.0	20.7							11.7						
〃		11.25				39.2			33.2	24.9													
〃		12.50				37.6			33.8	24.0													
〃		14.15				45.8			31.9	24.8													
〃		15.56				34.2			33.8	26.2	17.9	82.1											
〃		17.25				39.7			35.8	25.6													
〃		19.06				41.2		1.68	39.5	26.8							16.8						
1+50		0.15				42.9		1.69	42.0	26.0							8.6						
〃		1.55				55.1		1.60	37.8	28.3							2.8						
〃		2.05				44.3		1.70	41.9	25.8							16.0						
〃		3.05							31.9	23.1													
〃		5.00				25.6			36.5	26.8													
〃		6.30				28.8			36.7	26.6													
〃		7.95				28.3			31.7	24.9													
〃		9.85				36.7		1.63	31.8	24.8							10.1						
〃		11.35				27.2		1.75	33.0	22.9							10.0						
〃		12.85				26.9			34.0	21.9	19.2	80.8											

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

P2

FACIES 2

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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	P_c	C_c	TEST RESULTS TABULATED SEPARATELY
1+50		15.60				29.2			33.3	24.7													
"		17.35				28.6			31.2	24.6													
"		19.20				25.9			33.0	25.8													
3+00		0.45				37.1			50.5	46.4	19.1	79.9	1.0				15.5						
"		3.65				41.0			39.8	32.1													
"		6.70				36.5			33.8	25.8													
"		9.80			1.	35.3		1.77	37.2	34.5							20.6						
"		15.54							34.3	28.8													
"		20.55				35.7		1.76	41.5	31.6							29.0						
4+50		0.25				44.3			40.0	15.0							14.7						
"		3.80				41.1			41.0	24.0													
"		6.85				44.9		1.91	39.0	27.0							19.9						
"		10.05				34.0		1.65	33.0	24.0							8.3						
"		12.90				32.2			35.0	24.0													
"		19.25				34.6			42.0	23.0							20.2						
6+00		3.60				44.3			45.0	25.0							4.4						
"		6.75				40.1			39.0	23.0							24.3						
"		12.80				46.3		1.63	34.0	20.0							8.6						
"		19.10				.			42.0	23.0													
7+60		7.55				35.6		1.62	37.2	22.9							16.0						
"		13.75				34.9		1.69	37.2	27.0							13.8						

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

FACIES 2

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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	Consolidation Characteristics: P_c	Consolidation Characteristics: C_c	Test Results Tabulated Separately
7+60		15.15				29.1		1.67	36.7	18.8							21.0						
"		19.75				28.4			36.0	32.4													
34+00		14.30				36.6			56.8	35.2													
36+00		1.40				25.1		1.65	34.5	28.8							13.0						
"		3.45				32.9			31.7	26.2	22.8	70.2	7.0										
38+00		0.15				44.6			38.5	27.1							13.0						
"		0.70				30.5			38.6	29.0	13.8	72.3	13.9				13.5						
41+00		2.65				42.2		1.71	41.2	35.6							13.8						
"		4.20				38.8		1.73	40.0	29.9							12.2						
"		6.05				37.2		1.73	38.4	30.0							12.4						
"		7.15				37.2		1.75	37.5	30.4							16.3						
"		8.85				34.6		1.77	34.3	29.1							16.6						
"		16.45				37.9		1.74	36.2	21.2							19.6						
"		18.15				33.7		1.79	33.3	26.8							10.0						
"		19.60							38.1	24.4													
42+00		3.20				34.5		1.79	33.0	23.6							20.7						
"		4.60				39.3			39.0	38.6													
"		6.25				37.6		1.74	37.5	24.7							9.70						

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

FACIES 3 P1

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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	Consolidation Characteristics: P_c	Consolidation Characteristics: C_c	Test Results Tabulated Separately
3+00		15.95				32.3		1.75	33.5	27.2							25.5						
4+50		16.05				41.0		1.62	35.0	22.0							28.1						
6+00		0.20				29.7		1.87	37.0	25.0							8.3						
7+60		0.30				27.6		1.68	44.7	31.3	14.8	85.2					25.4						
"		7.55				39.0		1.62	42.3	29.8							16.0						
10+00		8.50				31.8			42.0	28.0													
12+20		3.50							38.8	20.2													
"		5.25				34.6		1.77	30.4	27.8							22.6						
"		7.05				37.1		1.80	35.0	21.1							13.8						
"		8.20				38.6			39.3	26.2													
15+00		0.10							40.0	26.0	27.5	72.8											
"		6.96							36.7	23.7	34.0	66.0											
"		2.50							39.0	26.6													
"		4.10							40.5	27.4													
"		5.62							46.0	27.3													
17+60		0.80							43.2	26.5													
"		2.33							44.6	28.9													
"		3.88							41.7	25.8													
"		7.01				38.0			33.8	25.3													
"		8.40				39.5		1.72	38.6	27.6	18.5	79.5	2.0				26.07						
20+00		3.20				32.24		1.84	40.1	25.6	40.9	59.1					74.6						

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

FACIES 3

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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	Consolidation Characteristics: P_c	Consolidation Characteristics: C_c	Test Results Tabulated Separately
20+00		6.00				43.6			51.0	31.8													
"		9.45				44.3		1.72	37.6	27.7							48.0						
"		12.30				43.9			36.5	24.0	29.6	70.4											
21+60		1.75				13.7		1.63	47.9	27.5	39.8	60.2					49.2						
"		3.22				14.6			43.5	26.8													
"		6.23				12.9			29.0	27.5	14.8	84.2	1.0										
"		7.80				31.2		1.86	39.5	28.1							54.4						
"		9.32				40.1			39.8	27.5													
"		10.90				34.7		1.80	40.4	28.5							24.3						
"		12.42				42.6		1.73	41.3	25.5							18.8						
23+20		3.10				38.8			50.2	28.8	41.8	58.2					49.0						
		4.75				36.5		1.79	43.2	26.3							61.6						
		6.45				34.4		1.77	42.1	26.0							39.1						
		11.10				34.3			41.2	25.5													
		12.30							38.9	25.8													
32+00		0.25				27.2			40.5	28.5							13.5						
		0.70				30.2			38.5	27.9													
		2.31				20.1		1.47	41.8	30.2	22.8	75.2	2.0				22.9						
		3.85				31.9		1.63	38.5	28.6							14.9						
		5.65				28.6		1.63	43.3	27.3							3.3						
34+00		0.20				35.3			35.5	27.2													

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

P3

FACIES 3									ATTERBERG LIMITS		GRAIN SIZE DISTRIBUTION					SHEAR STRENGTH				CONSOLIDATION CHARACTERISTICS			
Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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	P_c	C_c	TEST RESULTS TABULATED SEPARATELY
34+00		1.15				40.2		1.74	39.2	27.3	17.8	82.2					25.1						
"		2.15				26.7		1.88	31.4	25.7							26.8						
"		6.30				35.2			41.8	24.1	26.5	73.5					24.0						
41+00		1.00				39.1			42.8	38.8													
42+00		0.40				42.8			31.3	26.7	10.0	90.0											
		1.55				33.8		1.80	29.1	25.7							5.0						

LEGEND AND NOTES:

SUMMARY OF TEST RESULTS

FACIES 4

Sample Number	Sample Type	Depth (m) *Sample Photographed	Modified 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	Consolidation Characteristics: P_c	Consolidation Characteristics: C_c	Test Results Tabulated Separately
21+60		13.85				45.5			36.1	21.3	33.4	57.0	9.6				11.3						
"		18.70				35.6			56.4	29.7	54.5	42.1	3.4				49.2						
23+27		15.37				13.8		1.55	41.0	22.0	26.8	62.2	11.0				20.6						
		16.85				21.1			49.4	24.3	43.5	54.5	2.0				12.2						
32+00		17.55				22.2		1.75	42.2	25.4	31.8	62.2	6.0				10.2						
34+00		3.25							41.7	22.8							22.3						
"		4.65							61.4	53.9							13.2						
36+00		5.20				39.4			40.2	26.2							8.9						

LEGEND AND NOTES:

APPENDIX C

PLASTICITY CHARTS

PLASTICITY CHART OF FACIES 1A, NORTH POINT

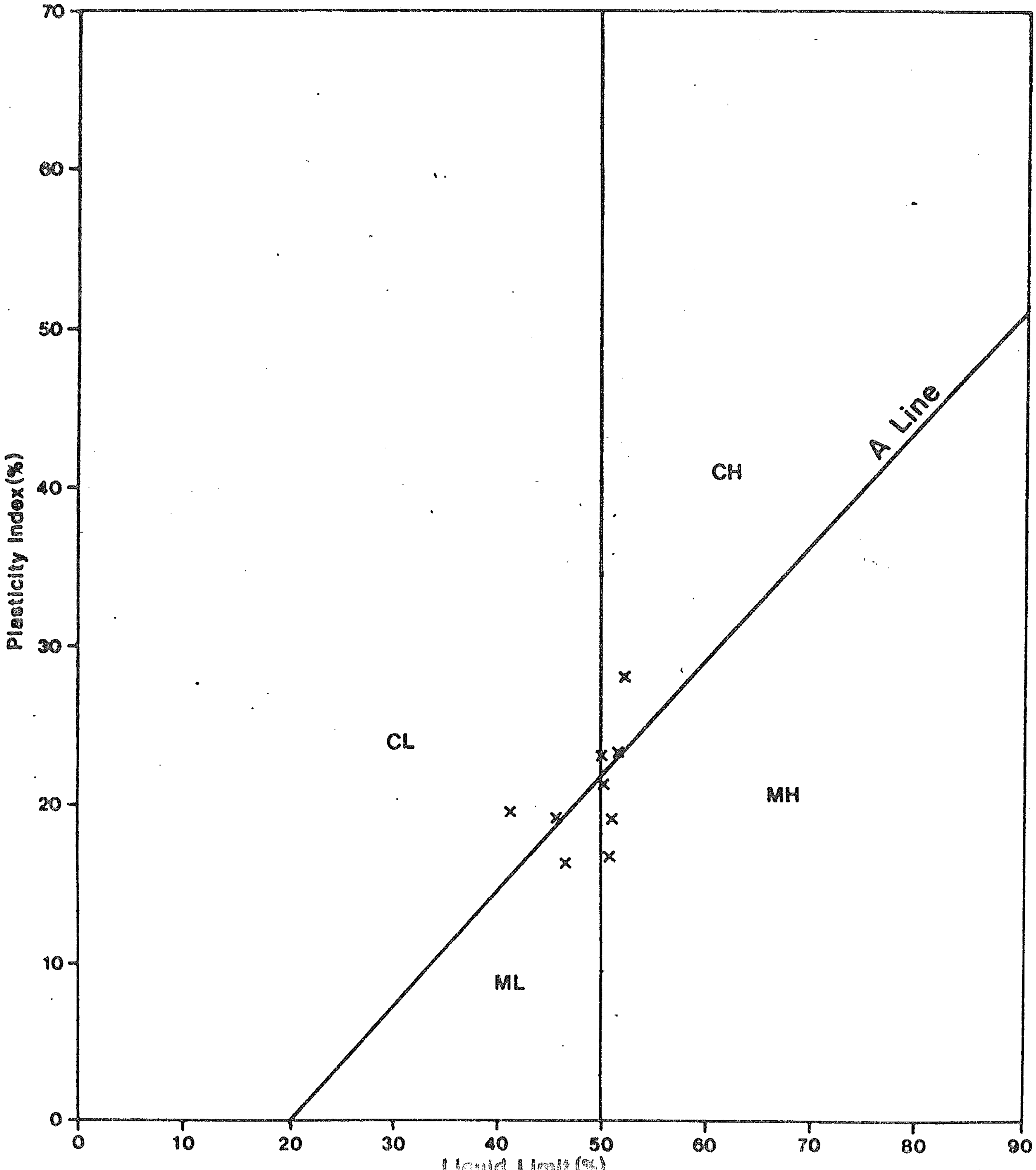


FIGURE 1

PLASTICITY CHART OF FACIES 1B, NORTH POINT

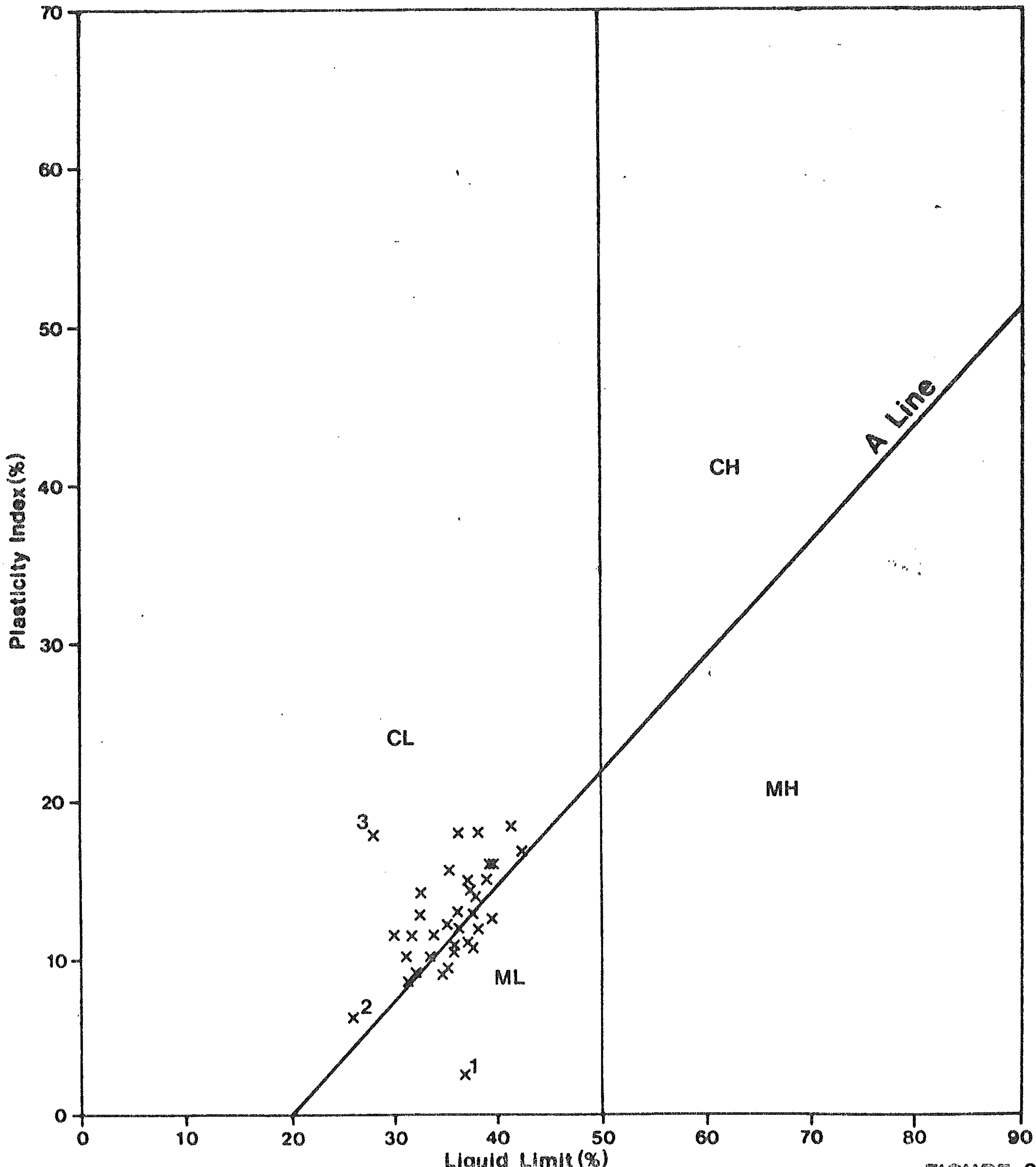


FIGURE 2

PLASTICITY CHART OF FACIES 2, NORTH POINT

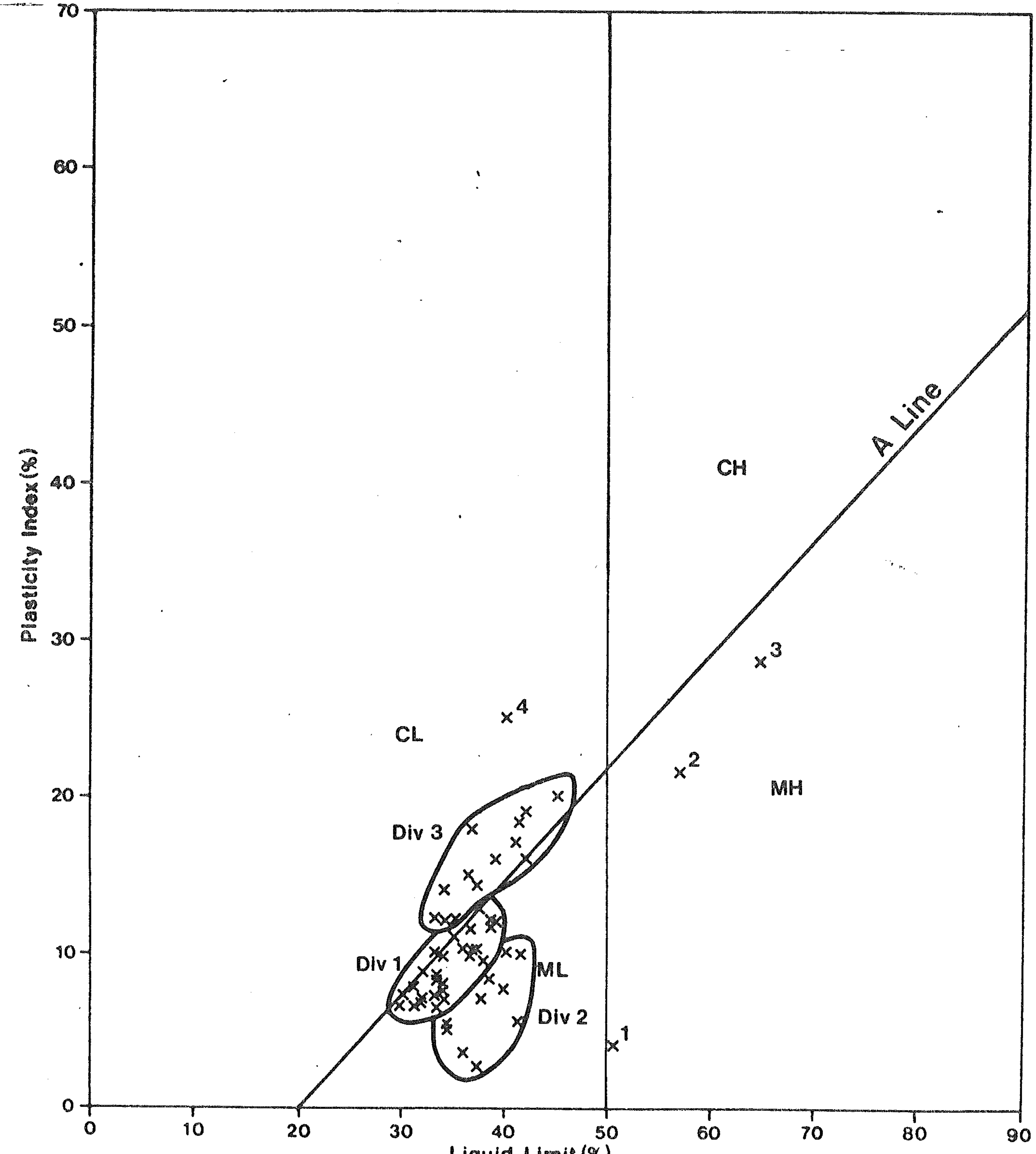


FIGURE 3

PLASTICITY CHART OF FACIES 3, NORTH POINT

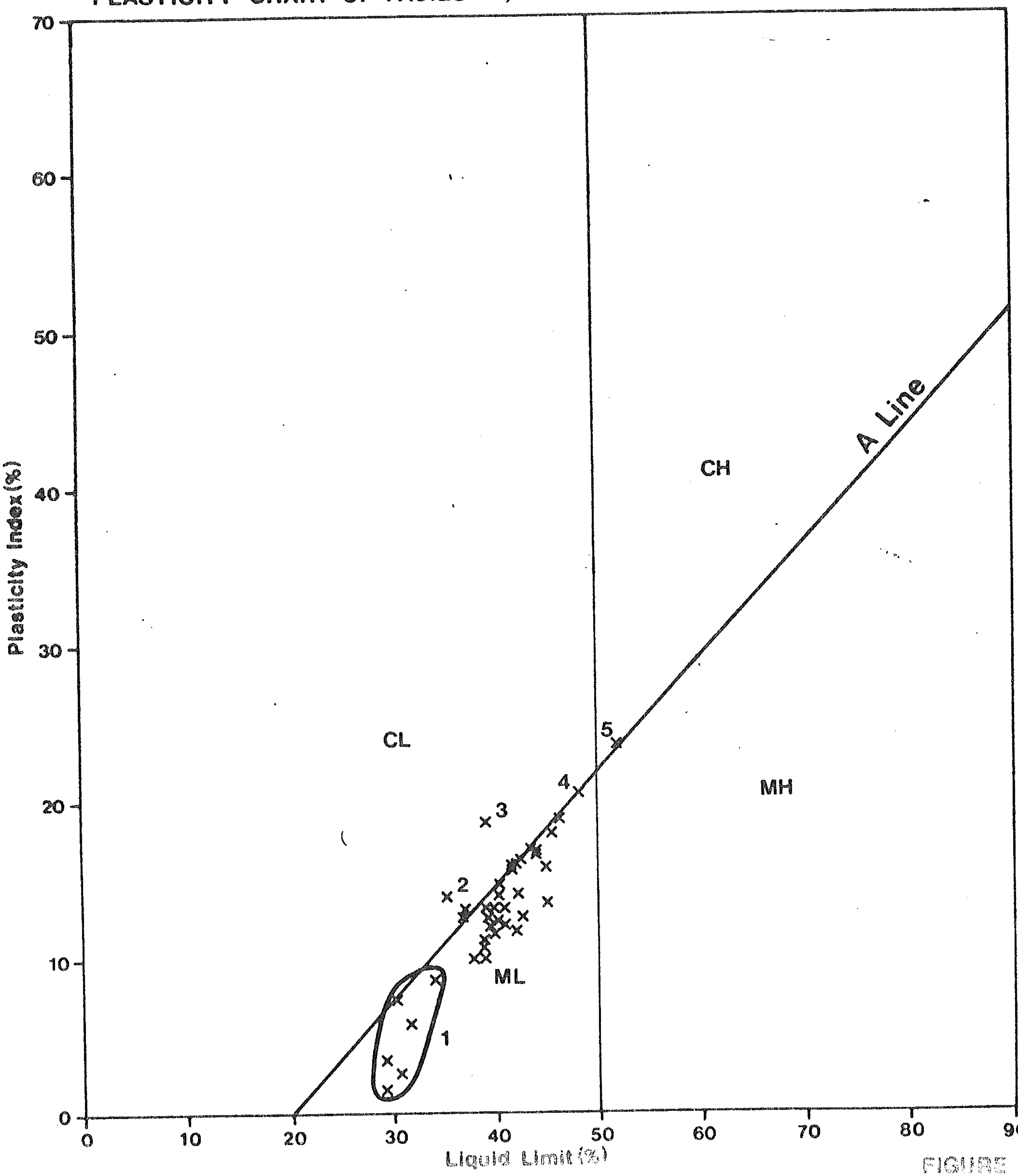
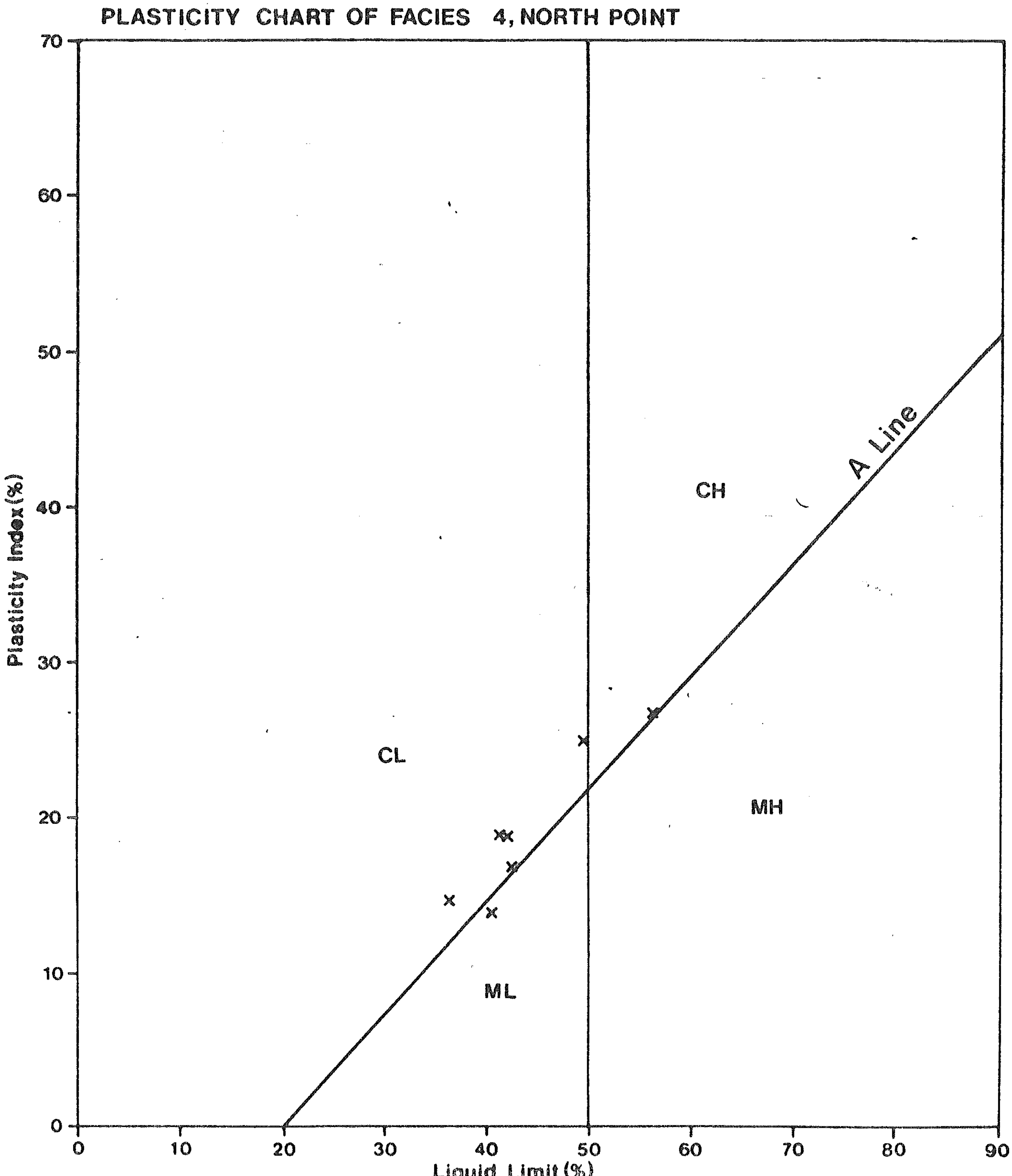


FIGURE 4



PLASTICITY CHART OF FACIES 4, NORTH POINT
Plasticity Index (%)
Liquid Limit (%)
A Line
CH
CL
MH
ML
0
10
20
30
40
50
60
70
80
90

FIGURE 5

APPENDIX D

LIQUIDITY INDEX VERSUS WATER CONTENT

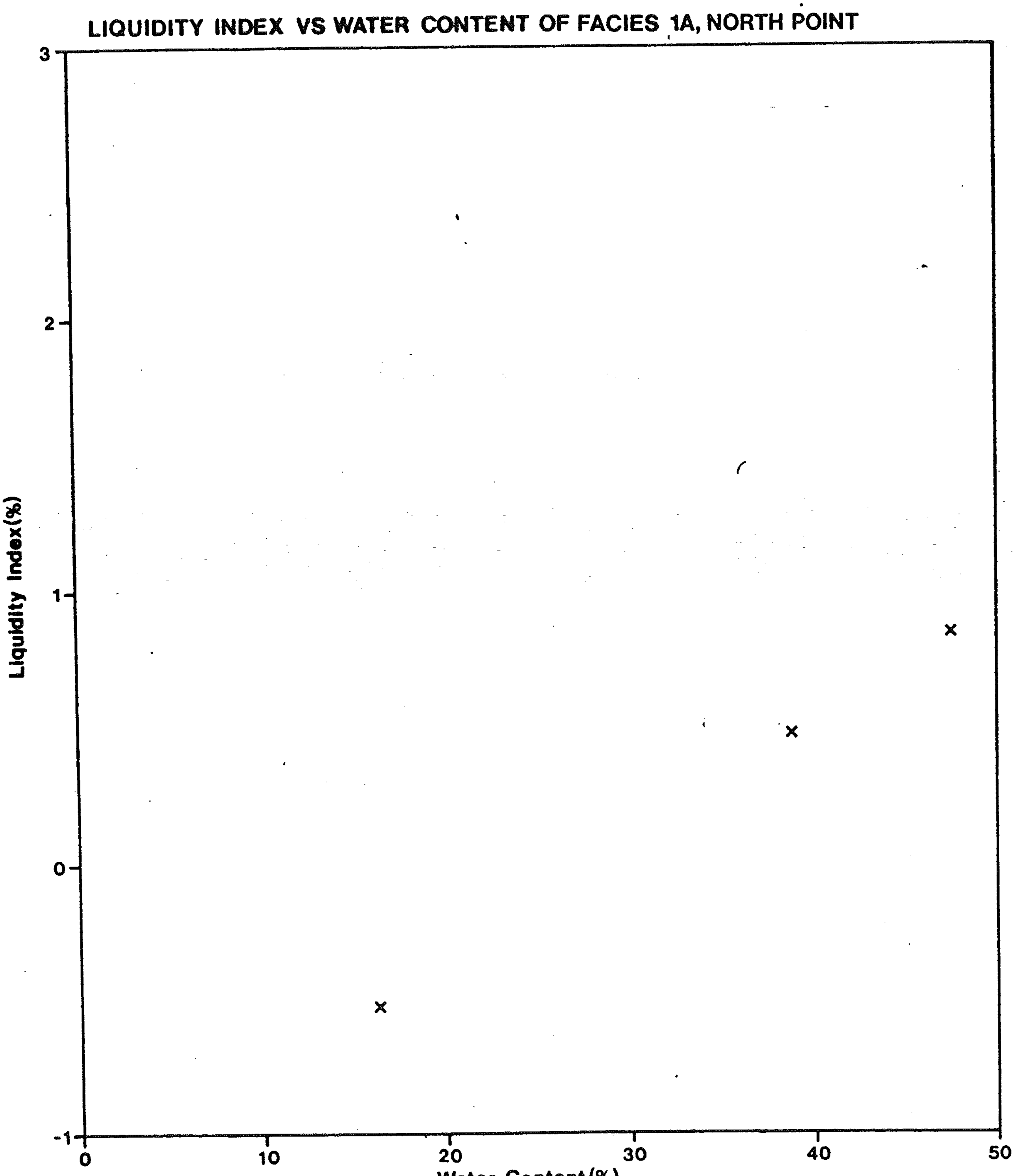

LIQUIDITY INDEX VS WATER CONTENT OF FACIES 1A, NORTH POINT
Liquidity Index(%)
3
2
1
0
-1
0
10
20
30
40
50
Water Content(%)

FIGURE 1

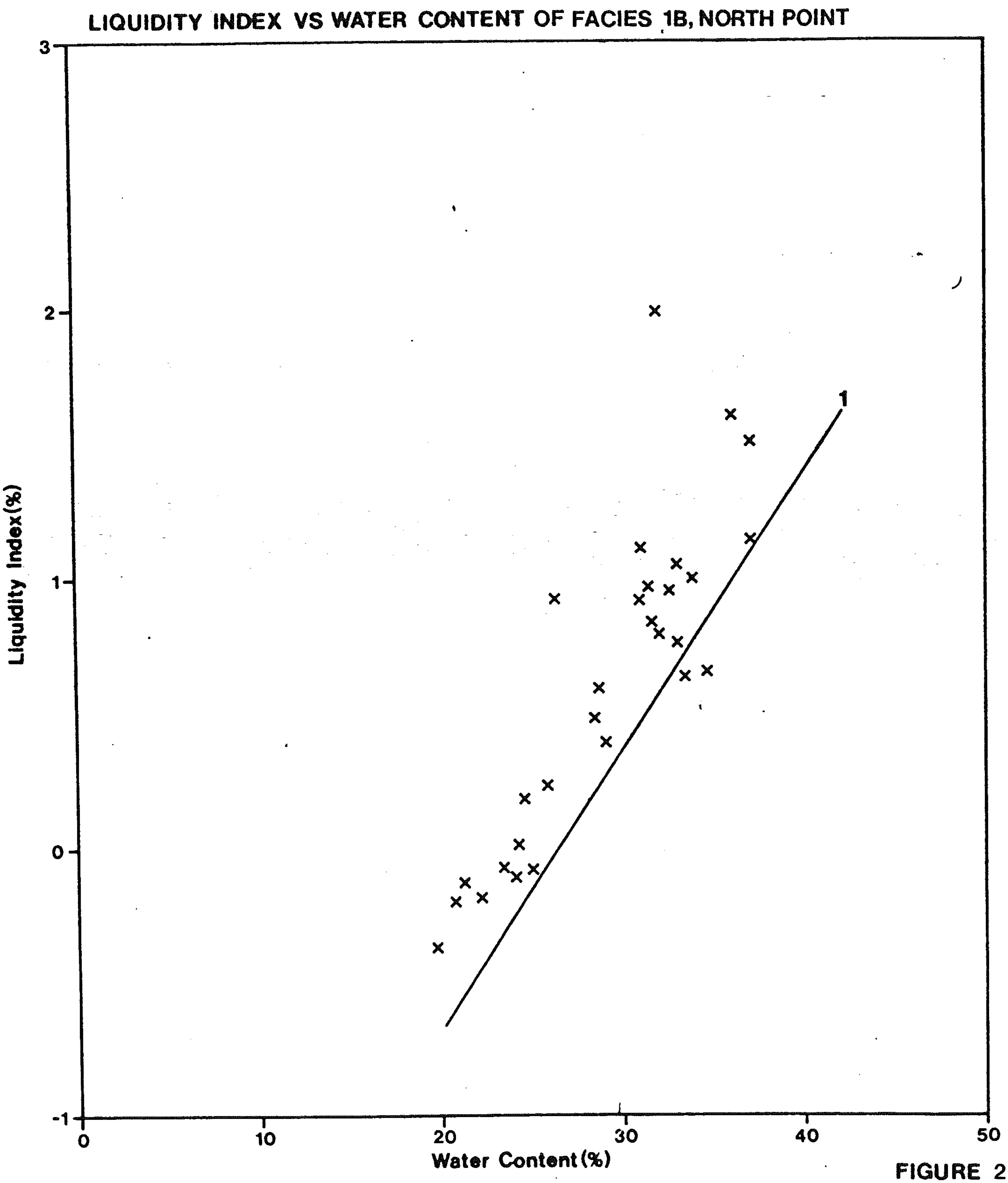

LIQUIDITY INDEX VS WATER CONTENT OF FACIES 1B, NORTH POINT
Liquidity Index (%)
Water Content (%)
3
2
1
0
-1
0
10
20
30
40
50
1

FIGURE 2

LIQUIDITY INDEX VS WATER CONTENT OF FACIES 2, NORTH POINT

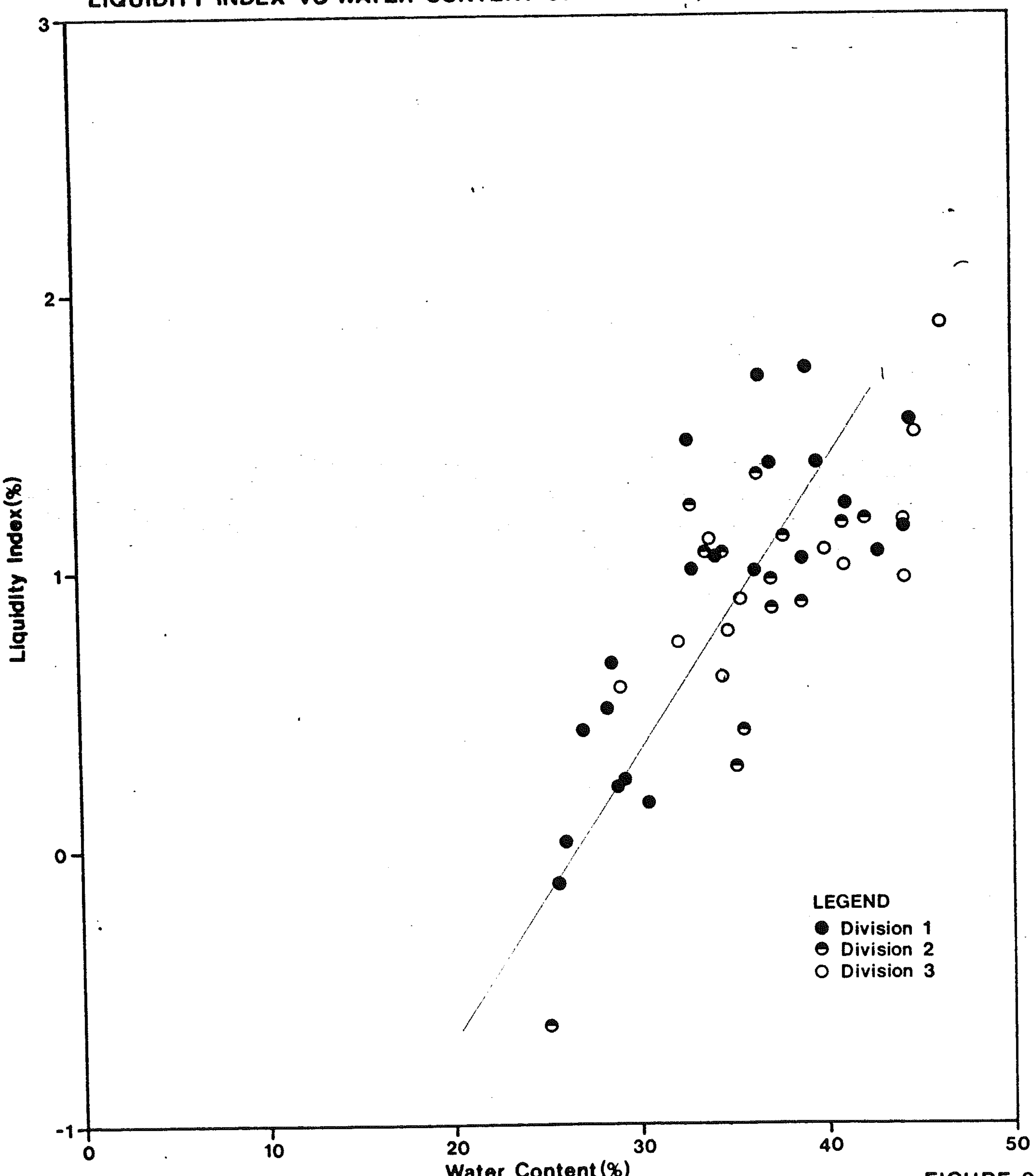


FIGURE 3

LIQUIDITY INDEX VS WATER CONTENT OF FACIES 3, NORTH POINT

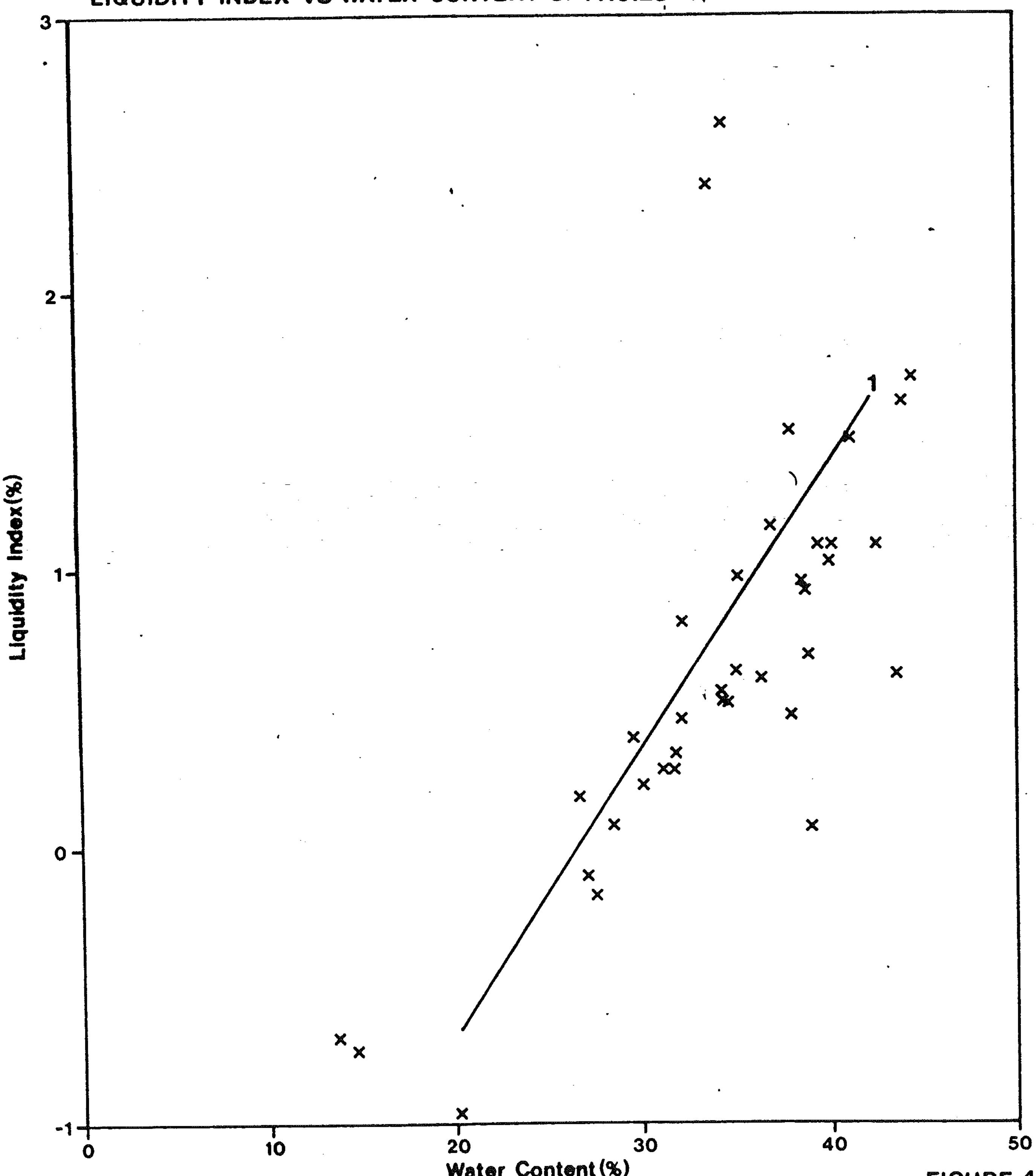


FIGURE 4

LIQUIDITY INDEX VS WATER CONTENT OF FACIES 4, NORTH POINT

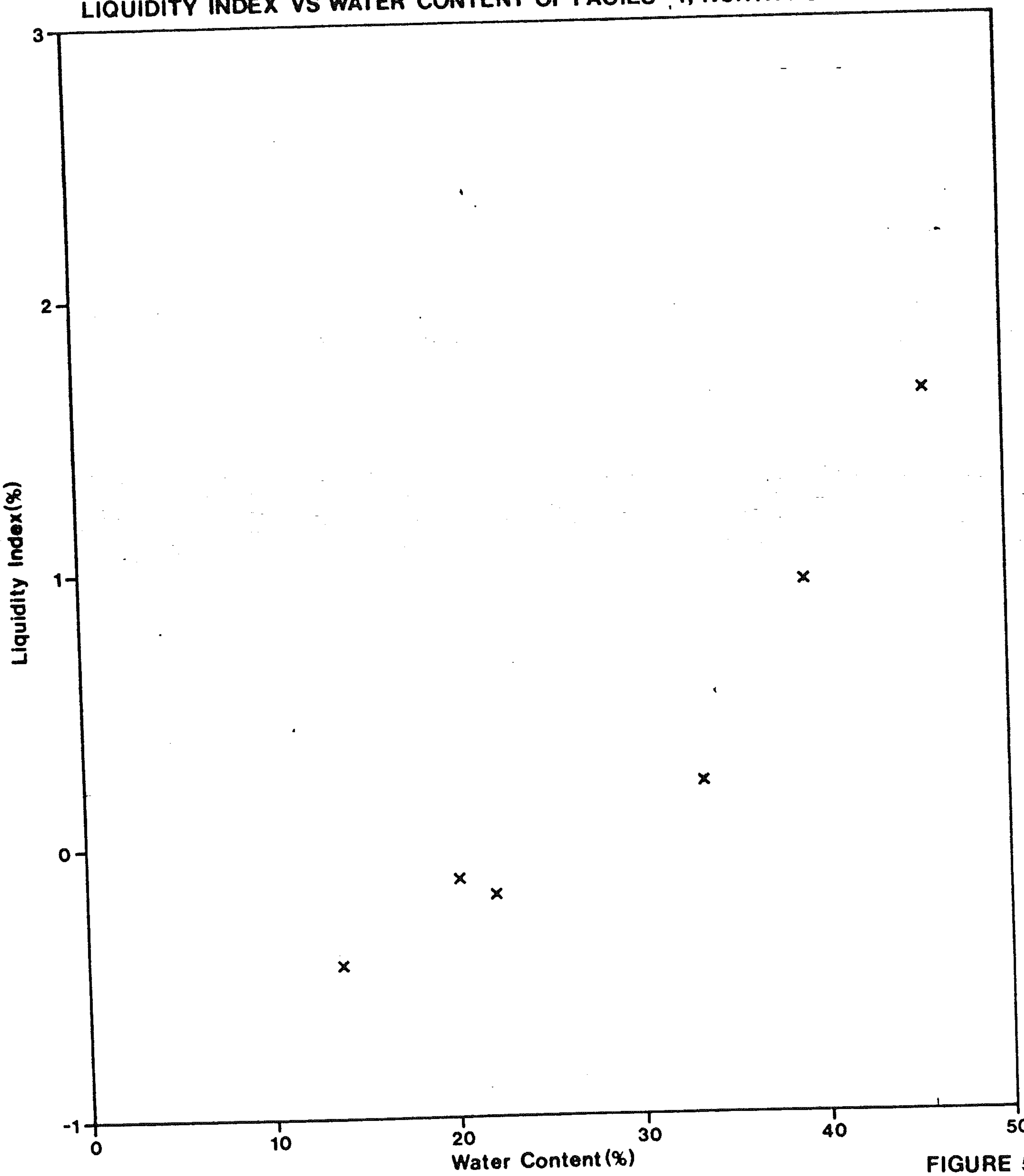
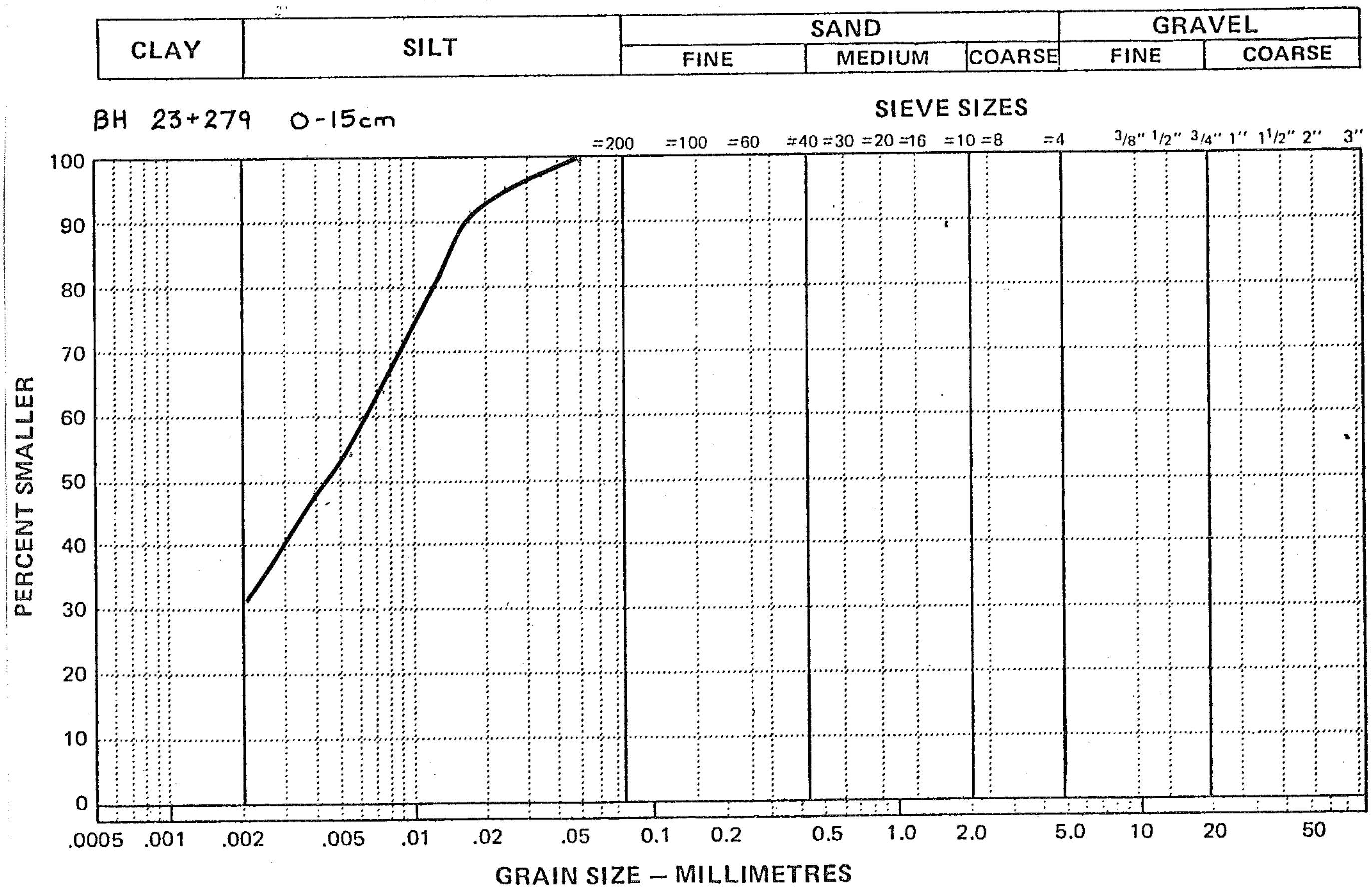


FIGURE 5

APPENDIX E

GRAIN SIZE DISTRIBUTION CURVES

FIGURE I – FACIES 1A



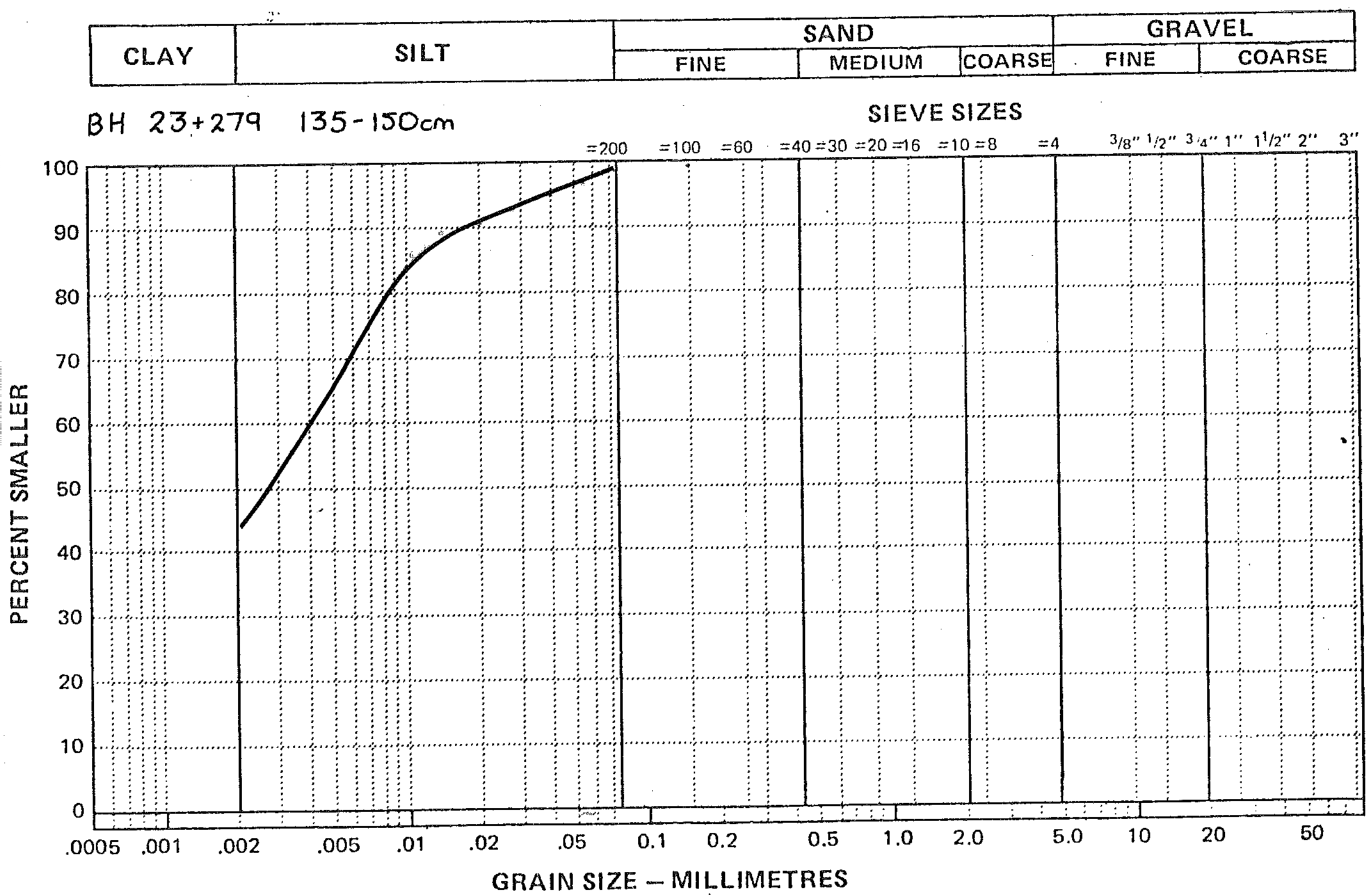
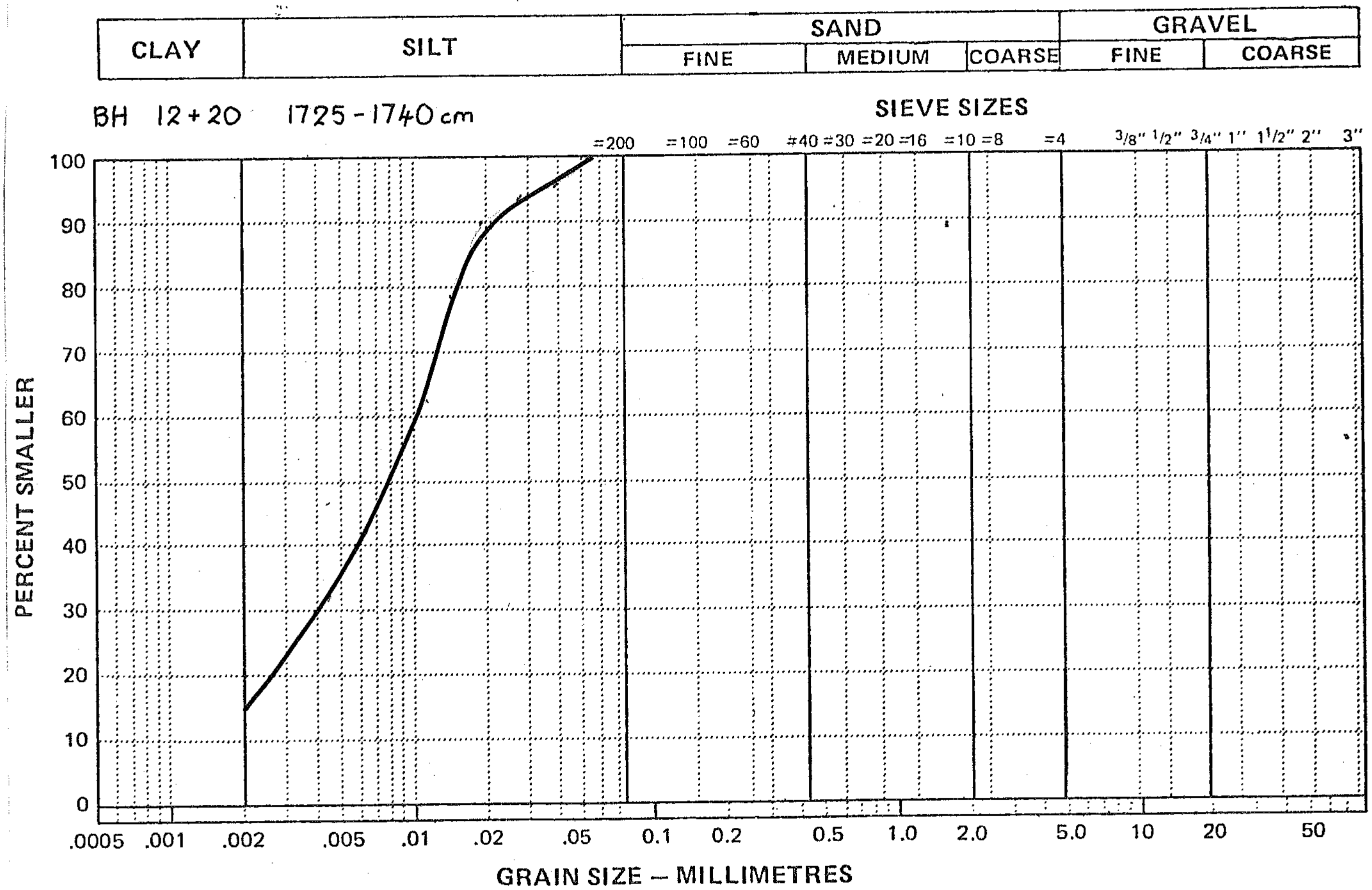
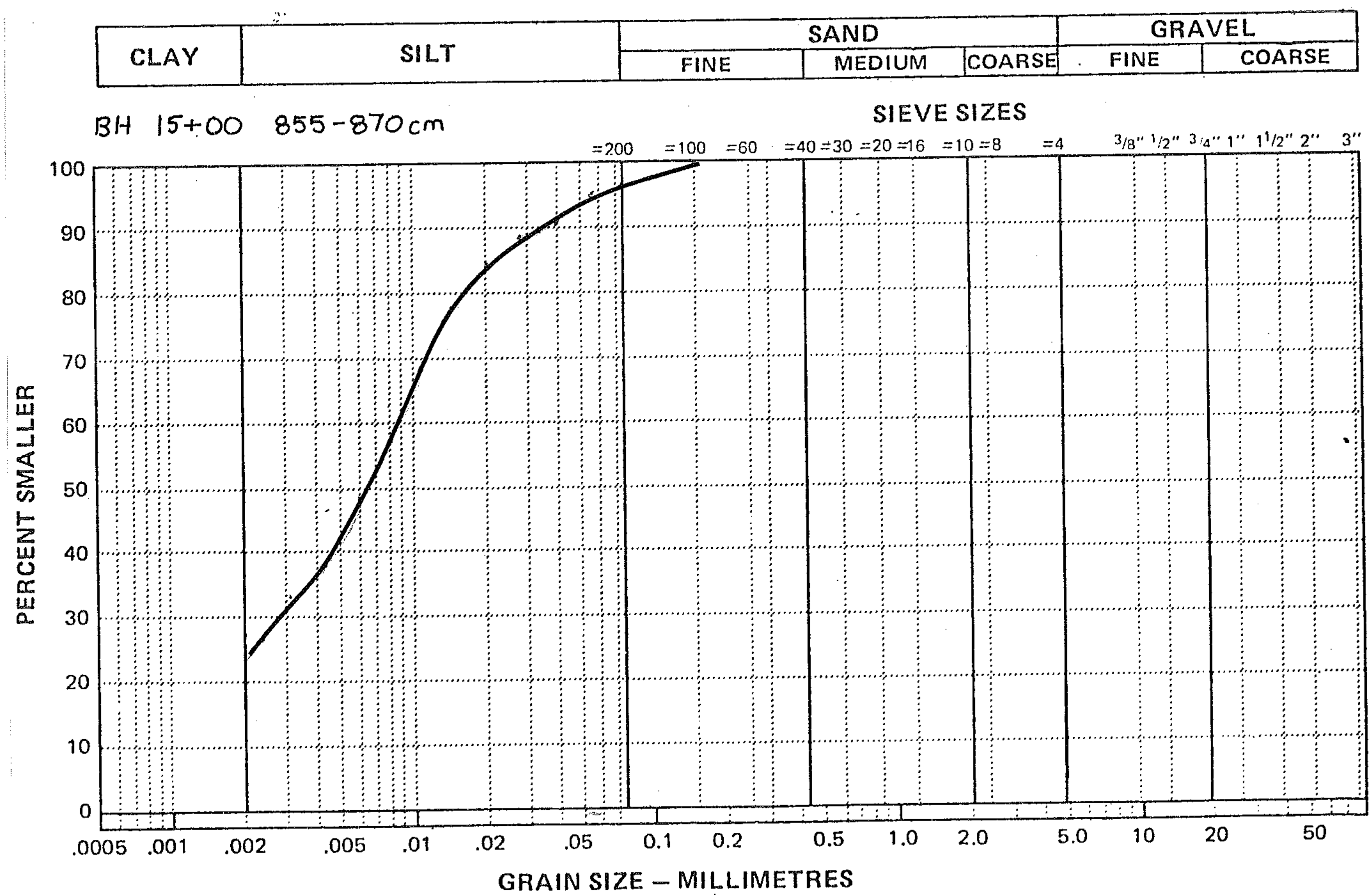
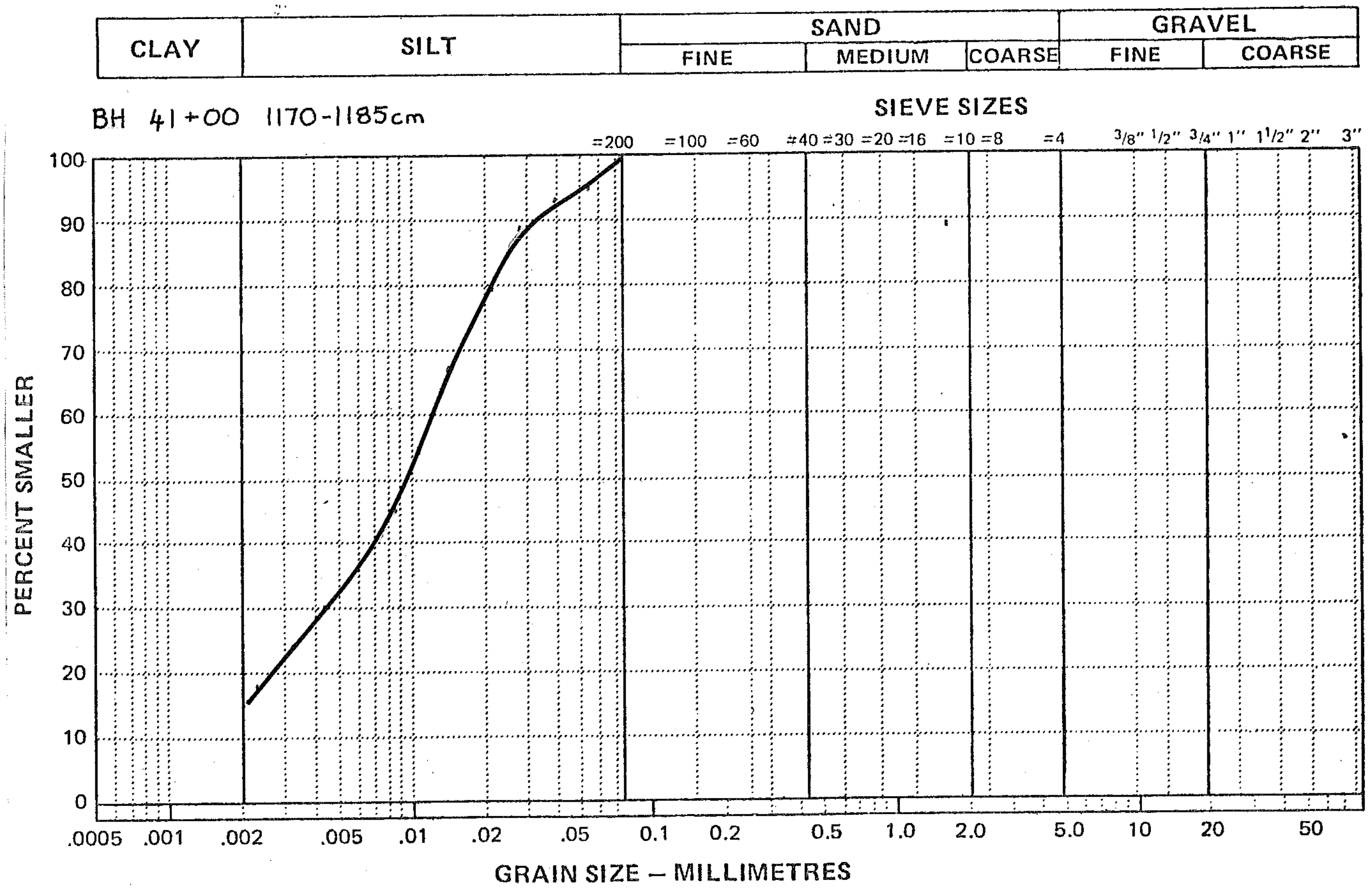
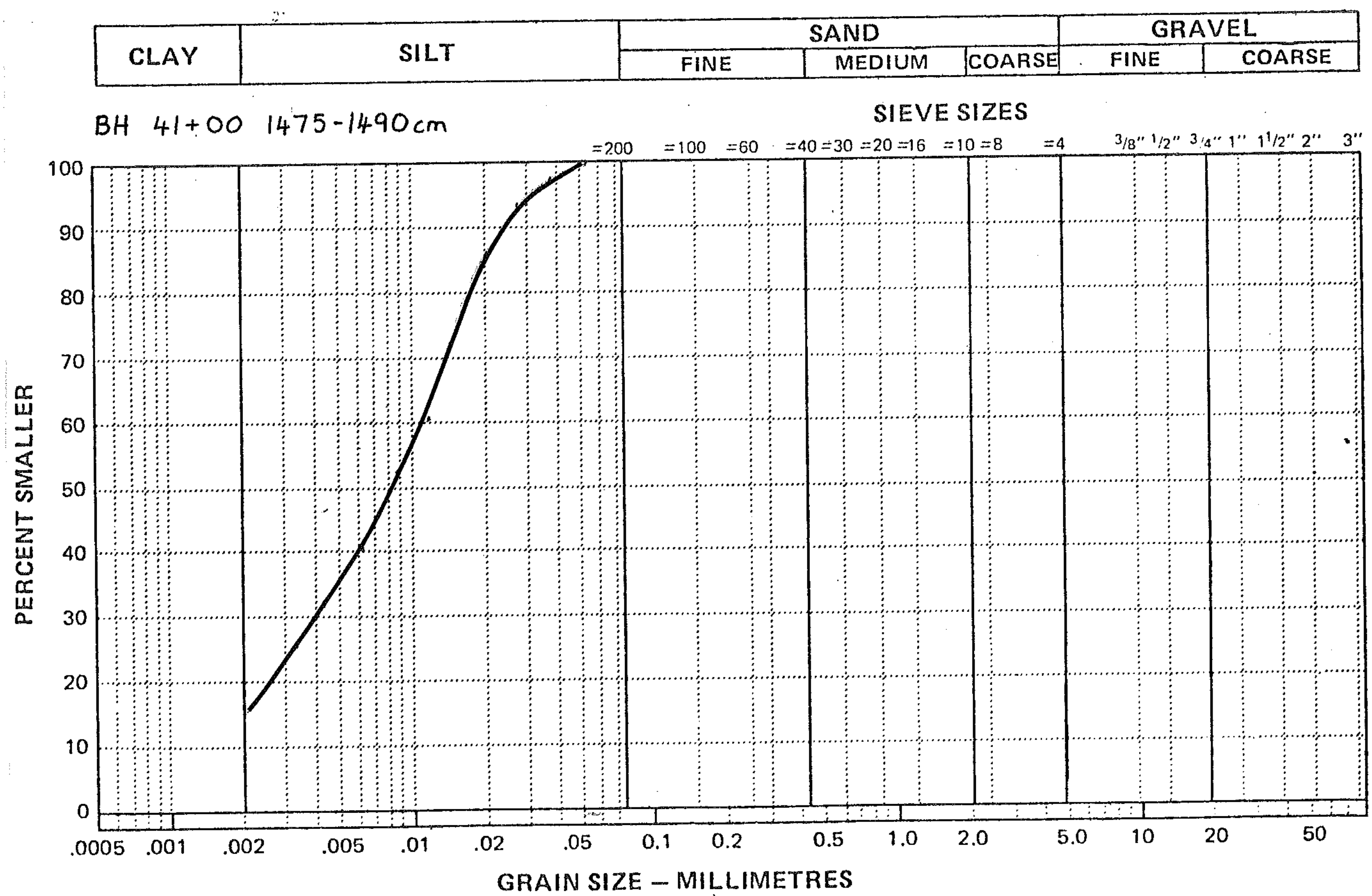


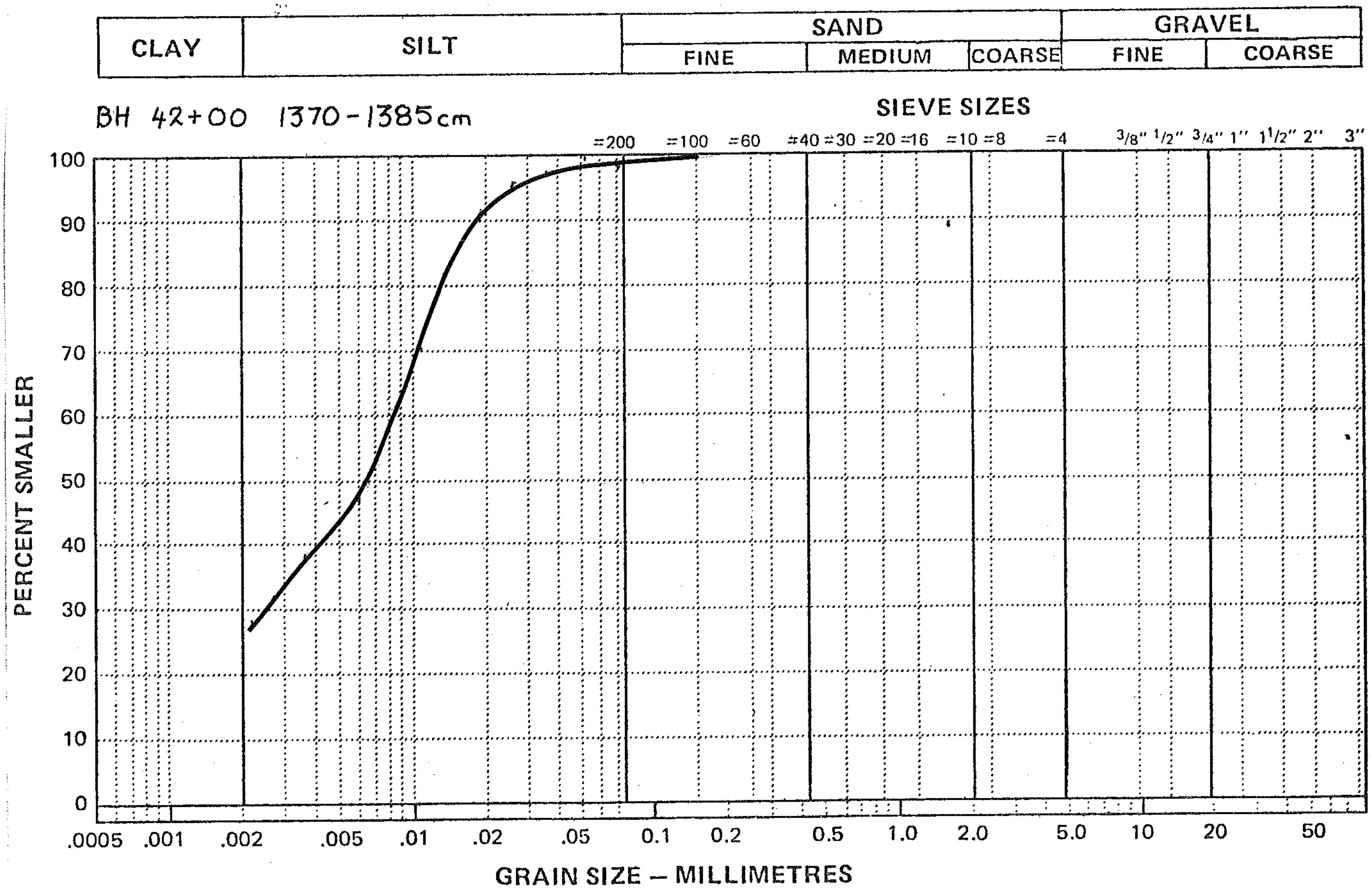
FIGURE 2 – **FACIES 1B**






CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 41+00 1170-1185cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE — MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 41+00 1475-1490cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE — MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 42+00 1370-1385cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

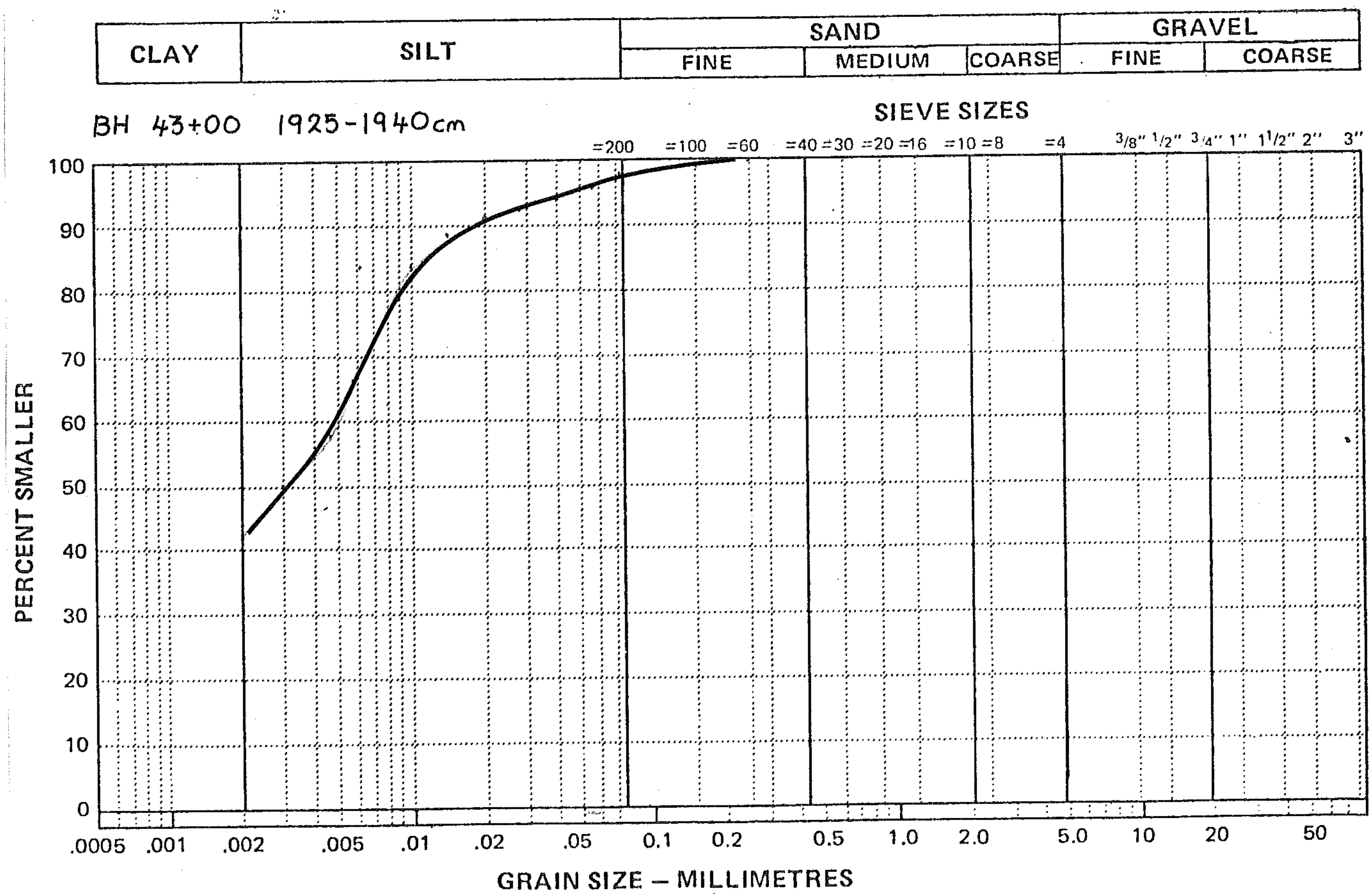
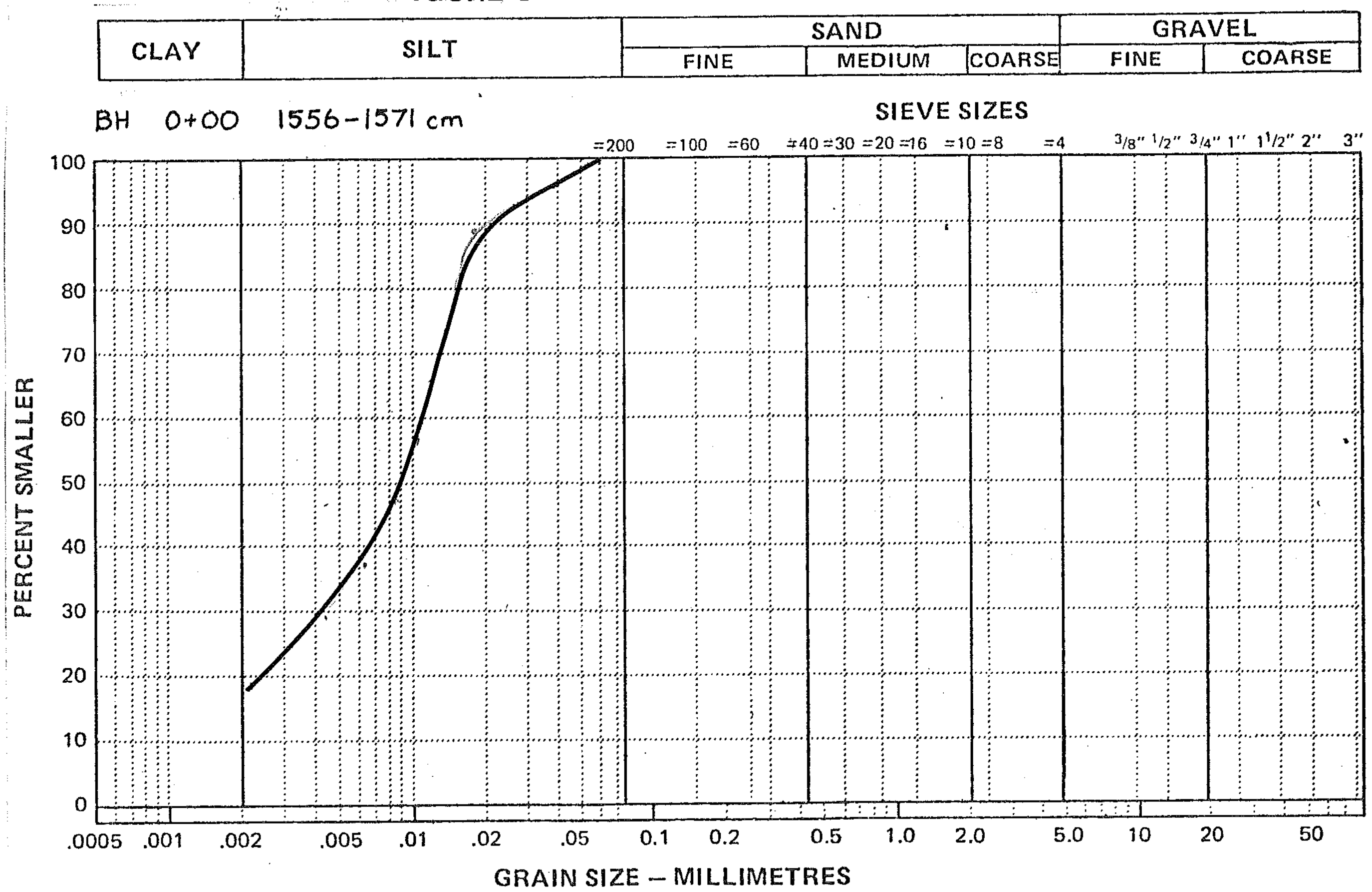
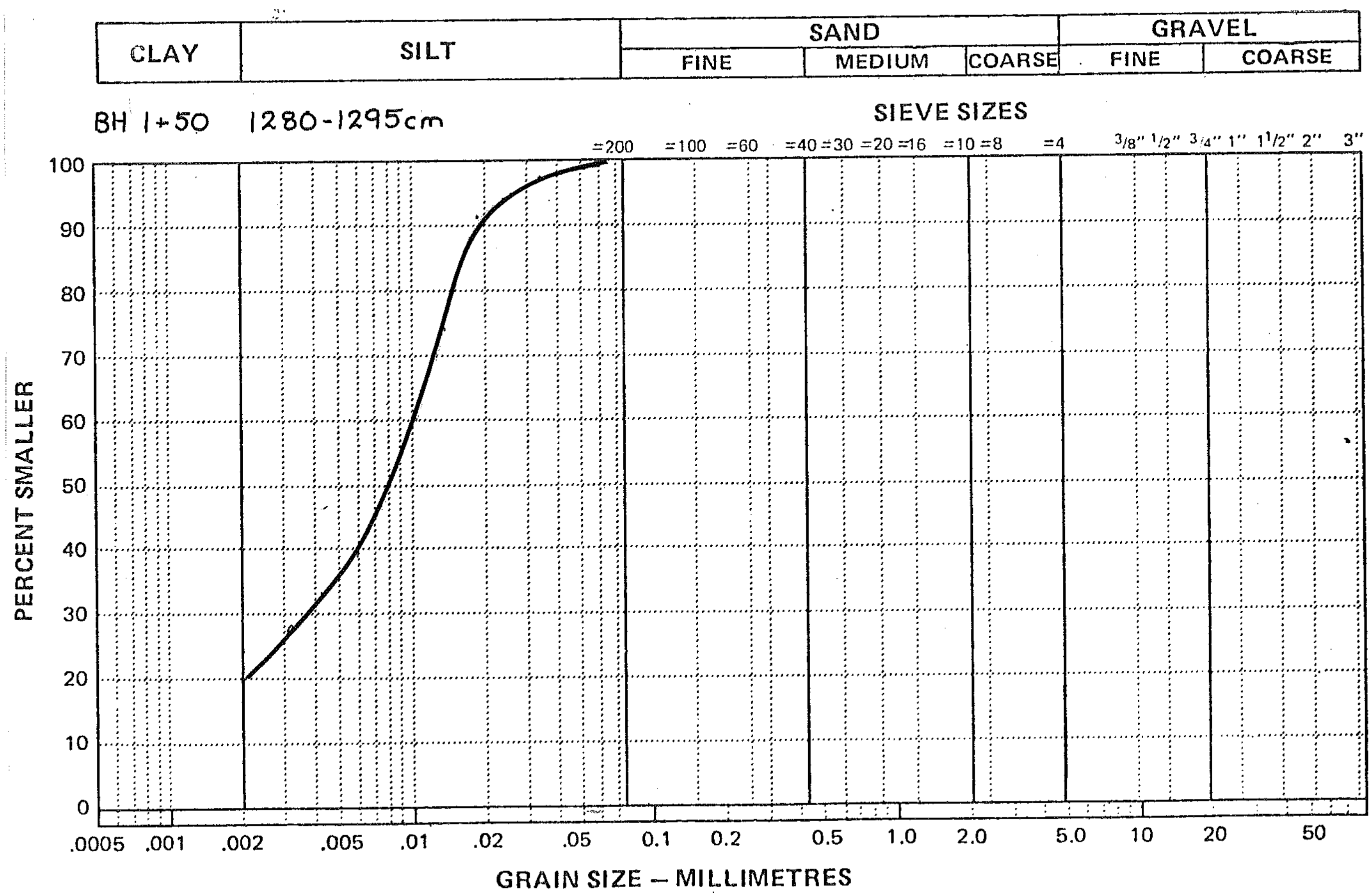
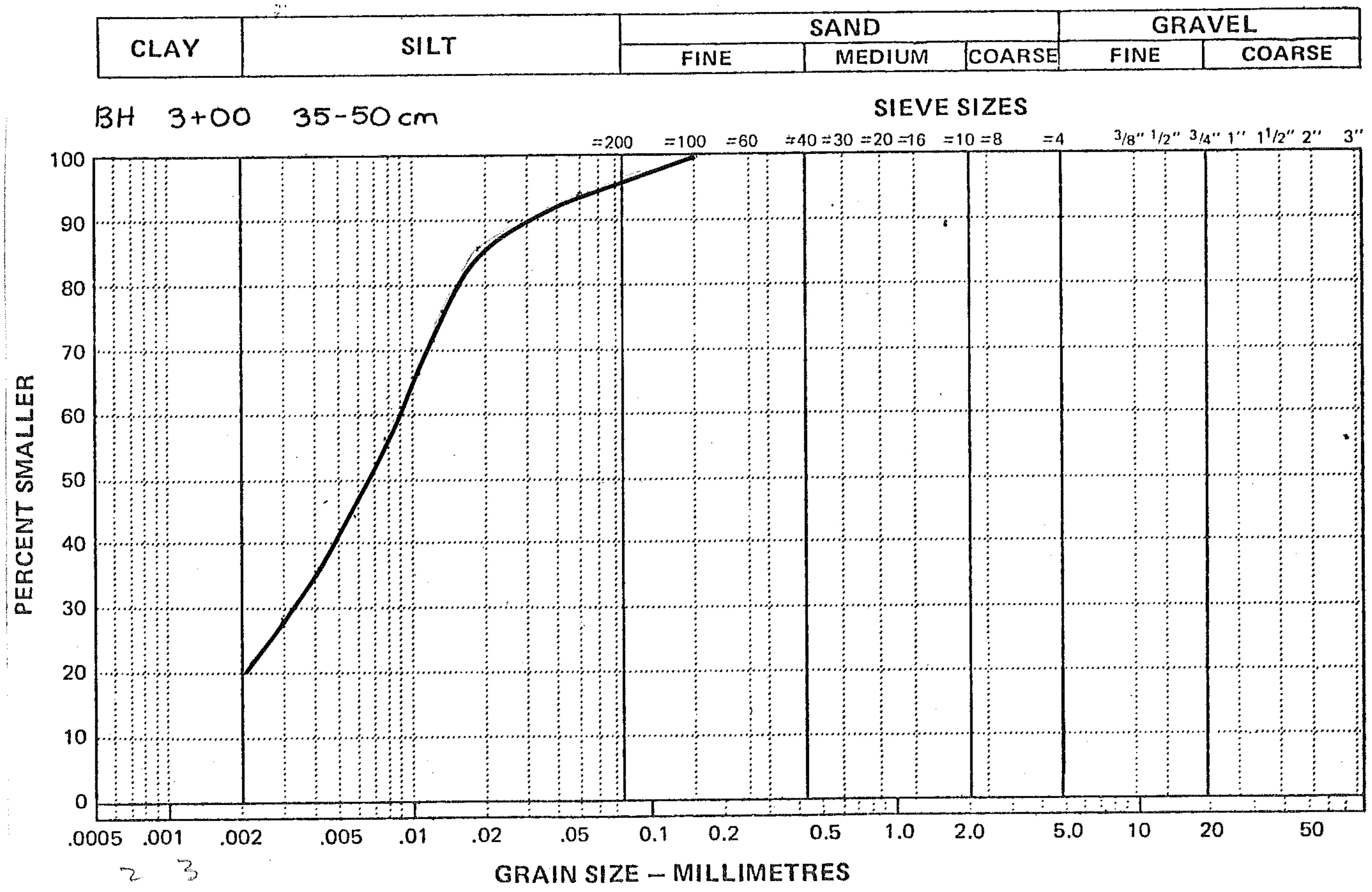
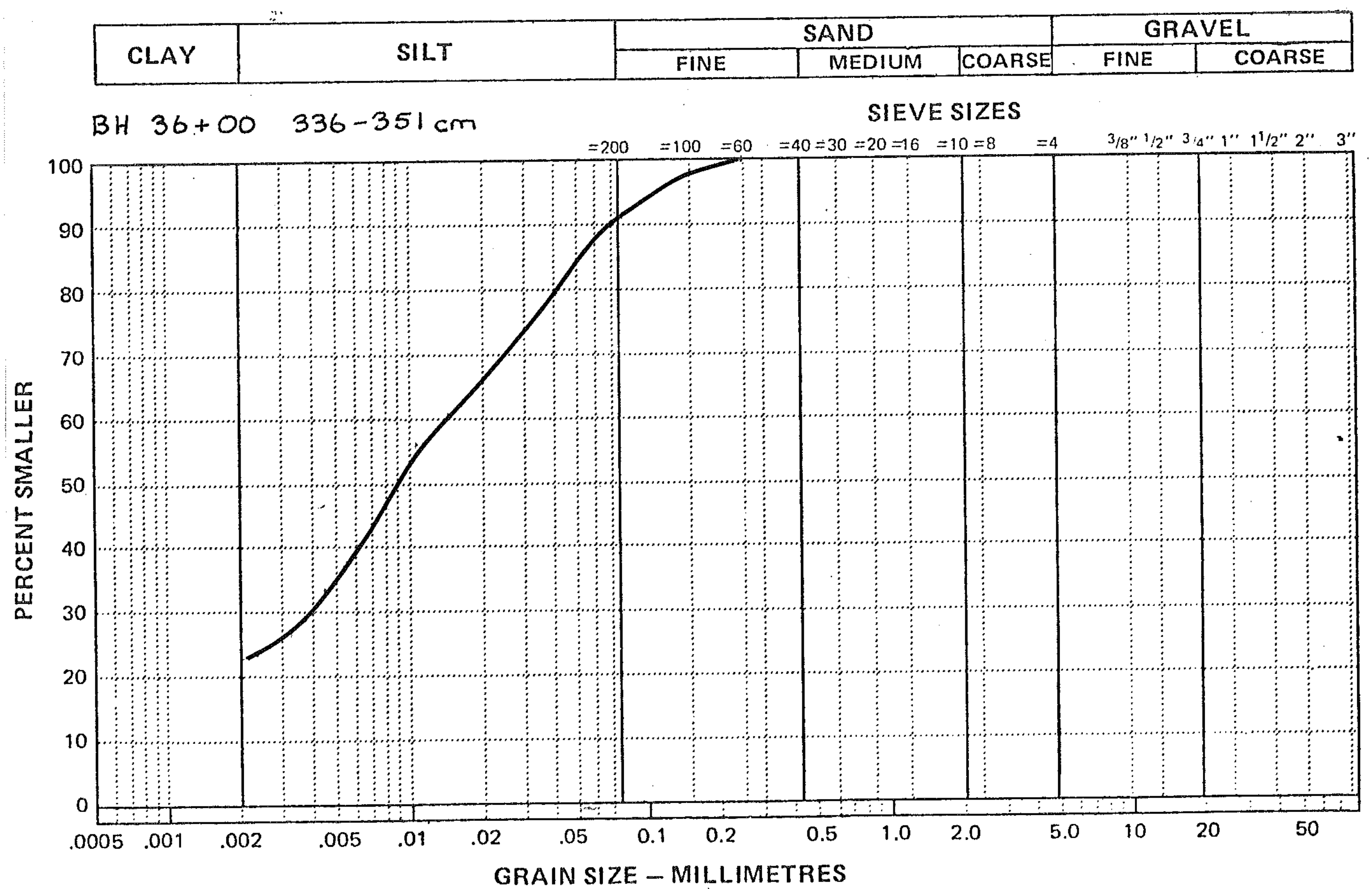

CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 43+00 1925-1940cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

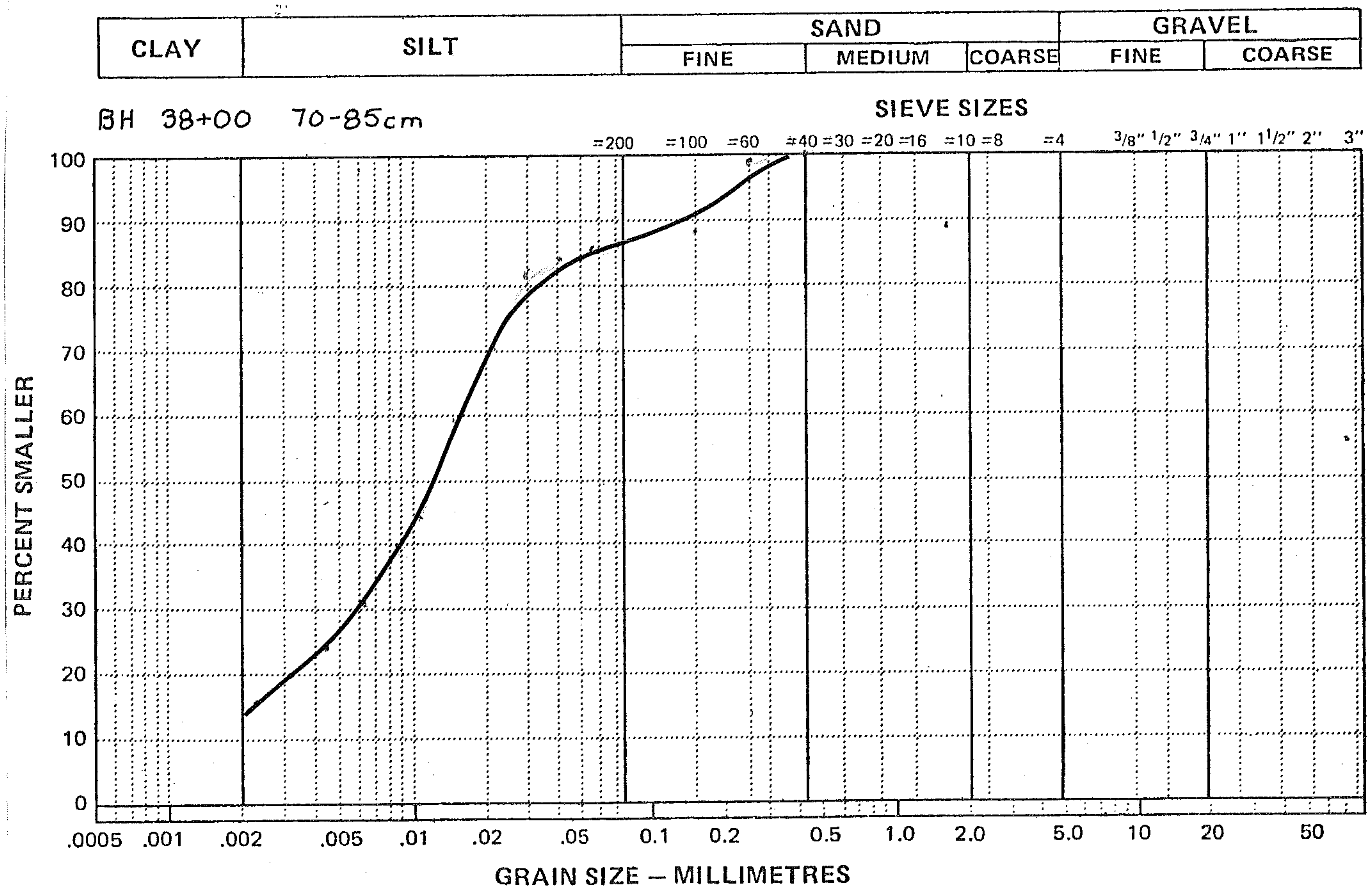
FIGURE 3 - **FACIES 2**



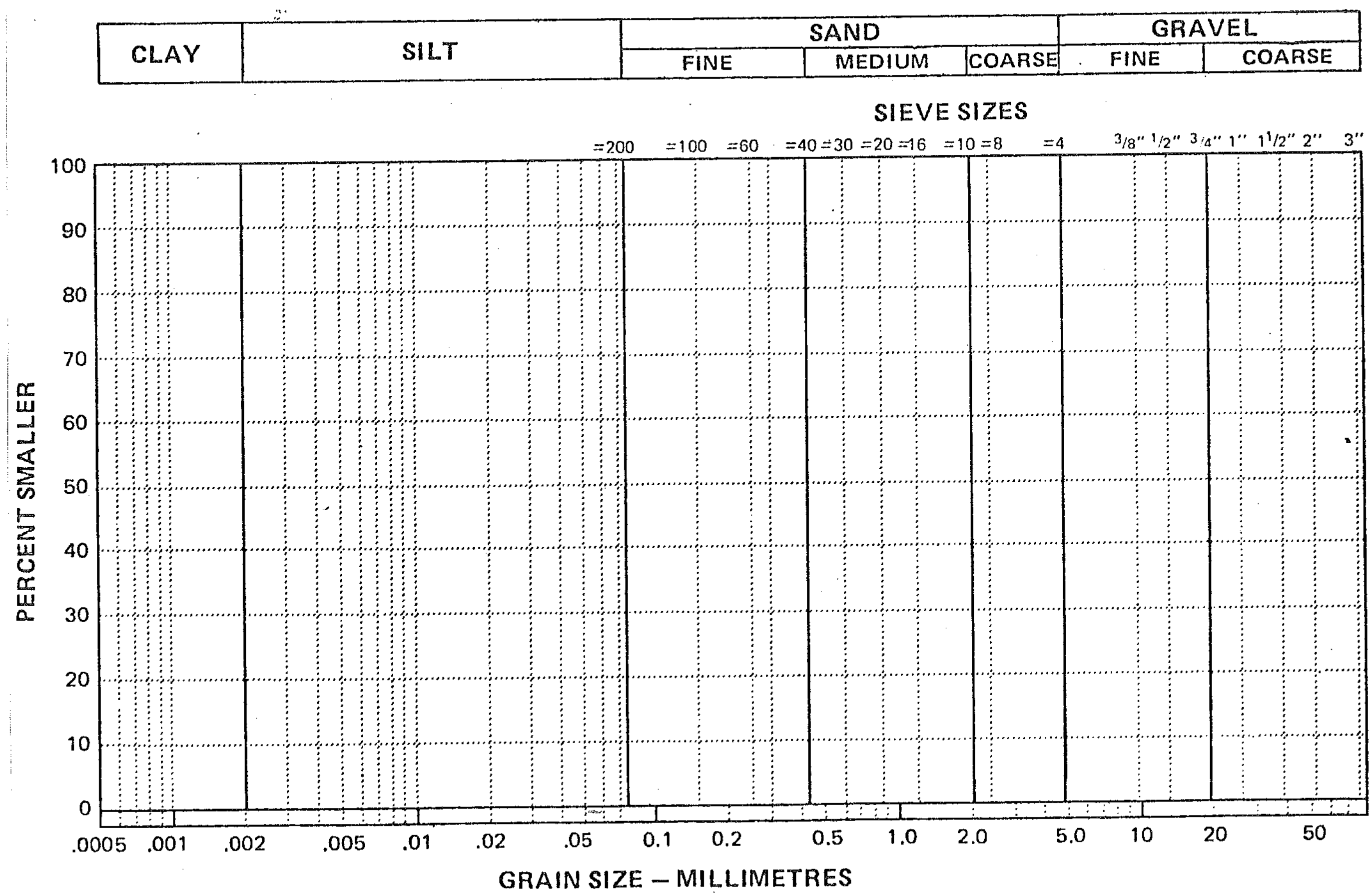



CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 3+00 35-50 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100
90
80
70
60
50
40
30
20
10
0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
2 3
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 36+00 336-351 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100
90
80
70
60
50
40
30
20
10
0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

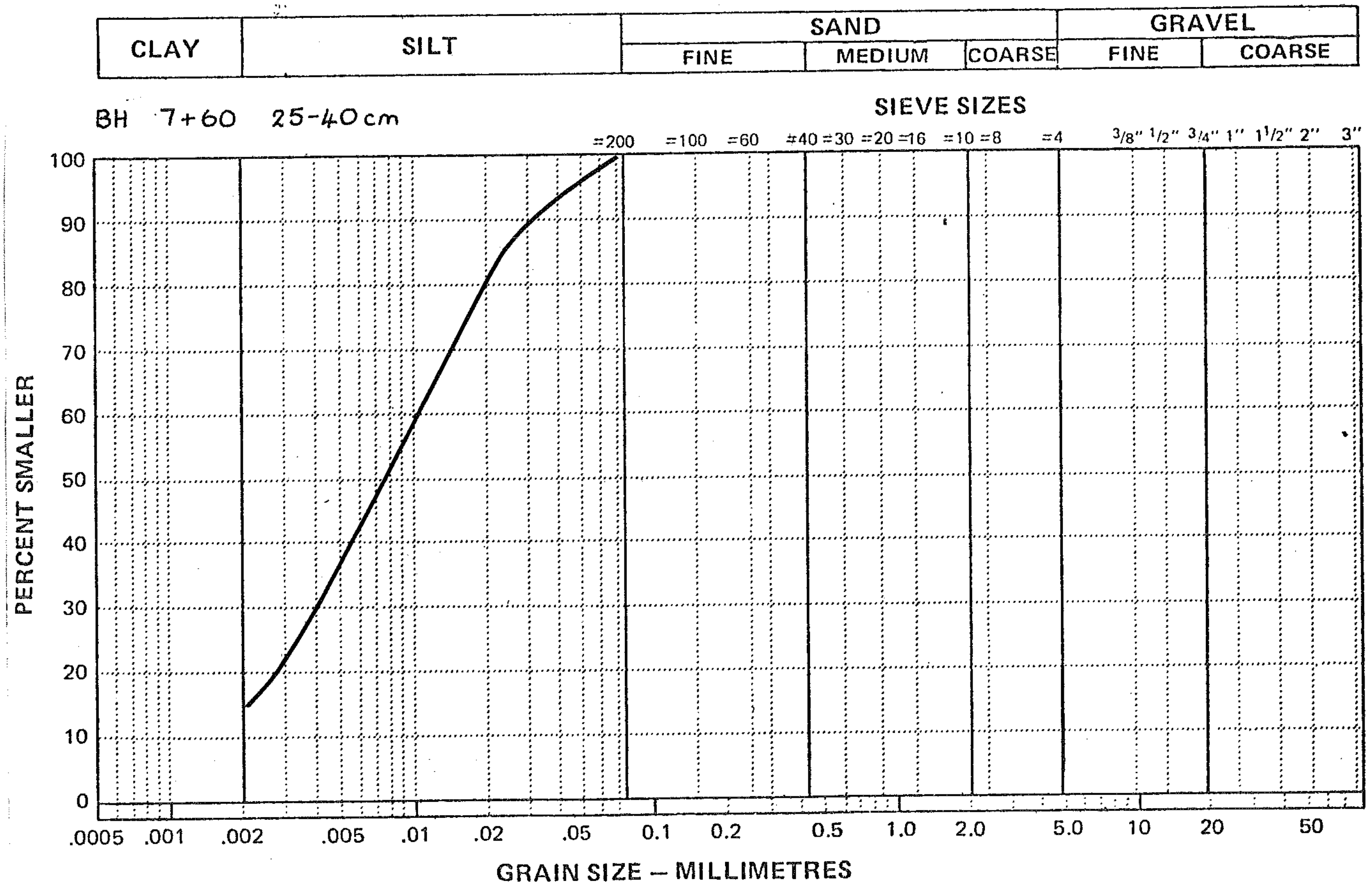


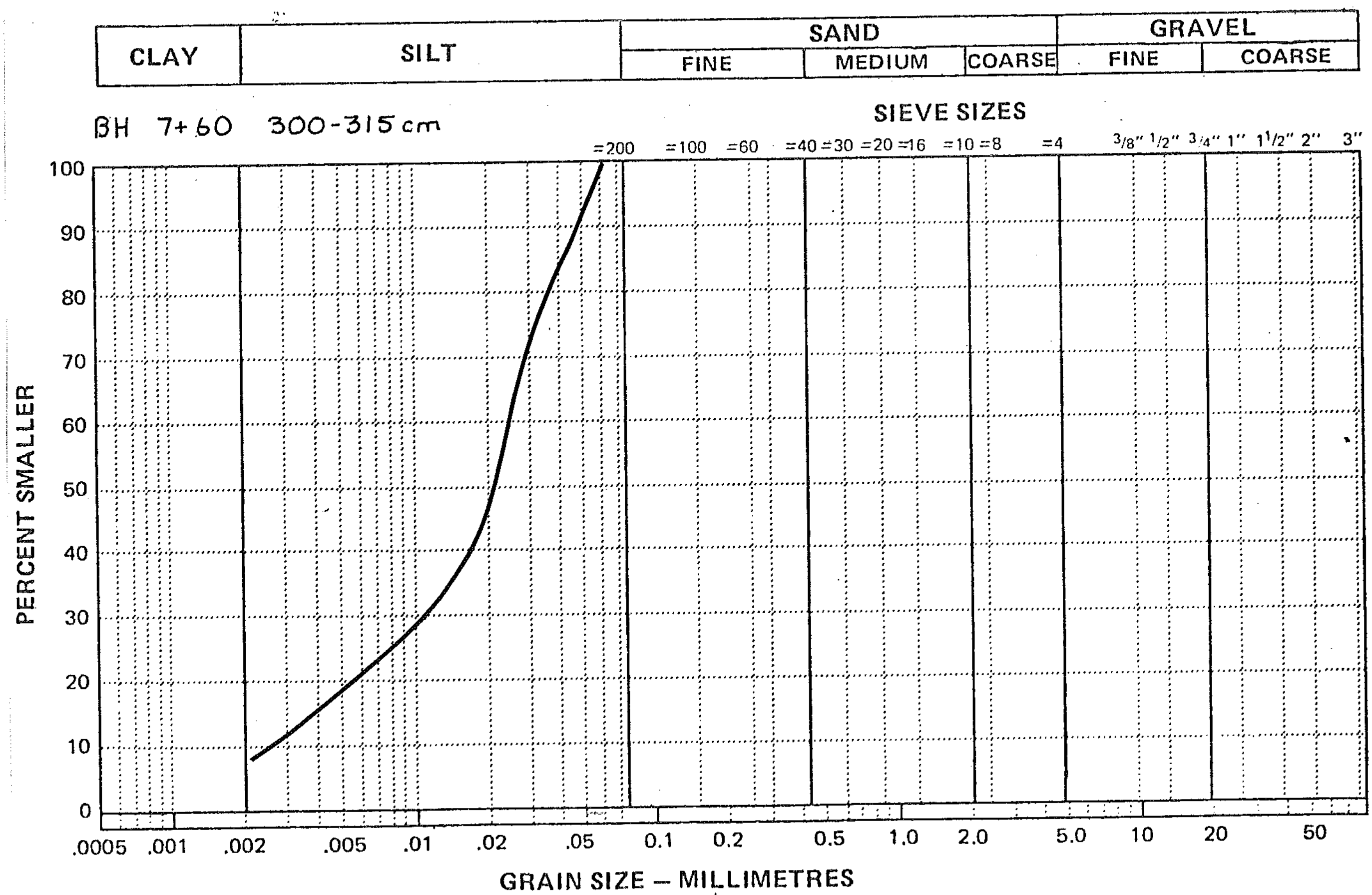
CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 38+00 70-85cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

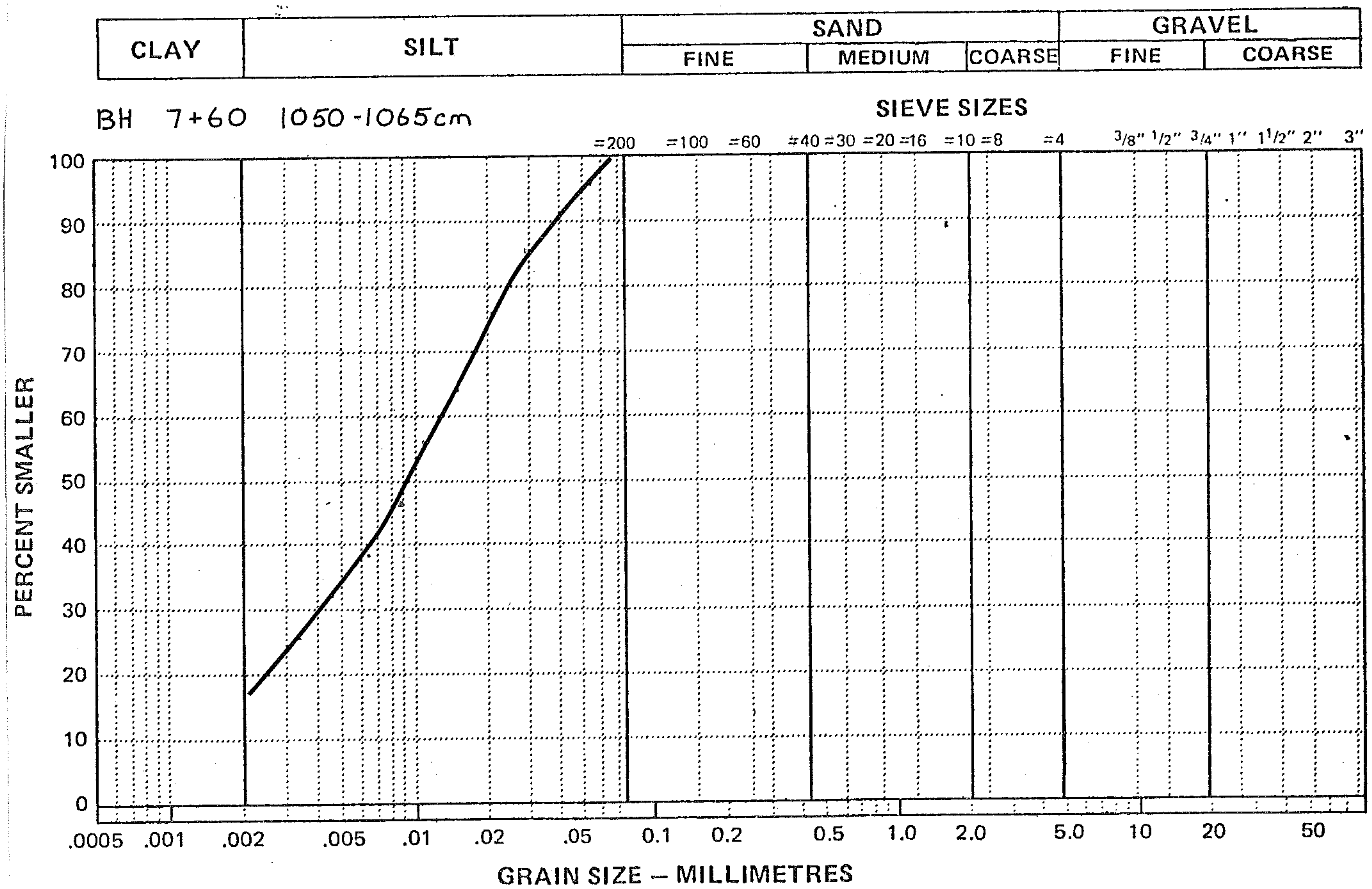


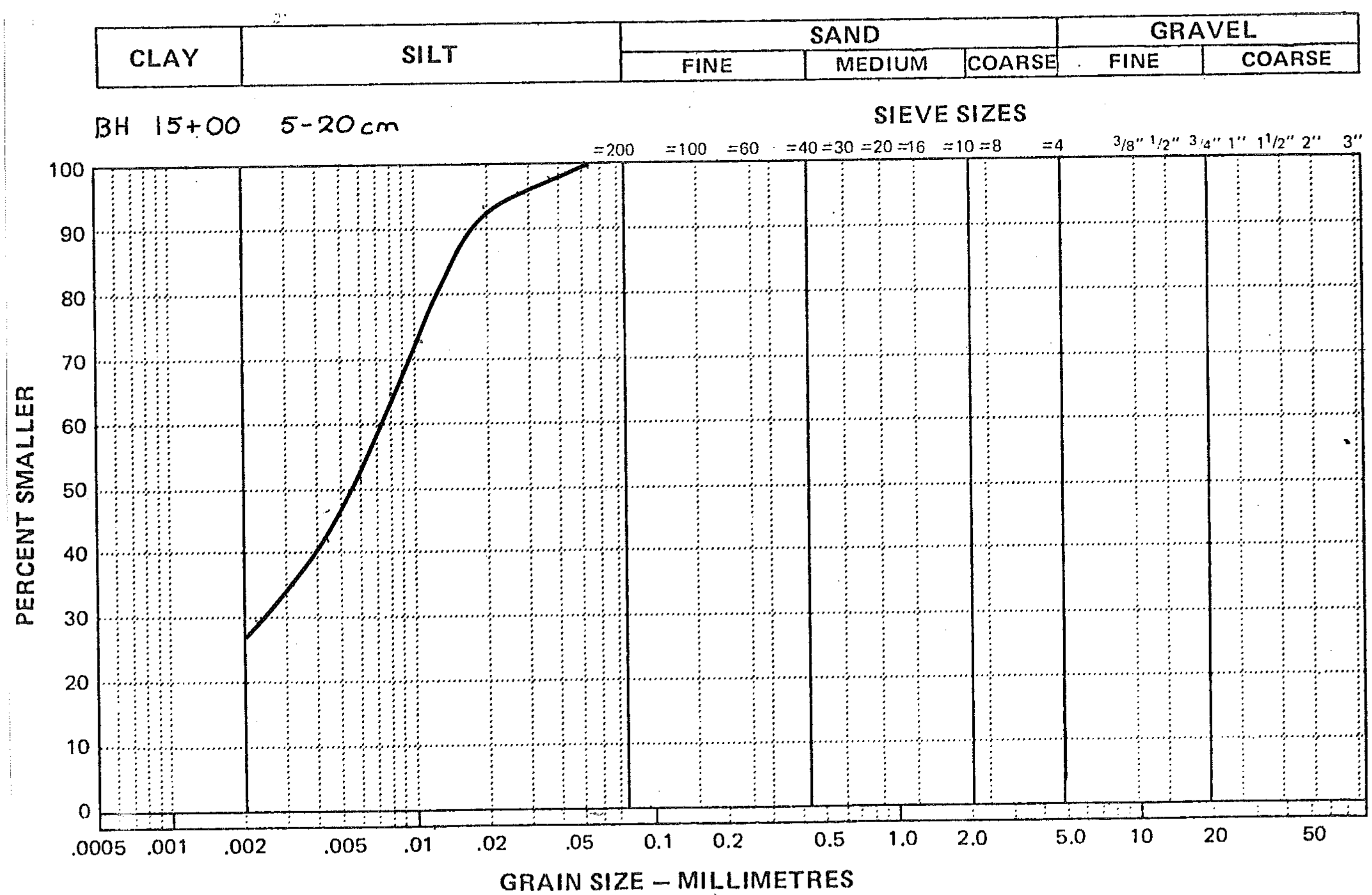
CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

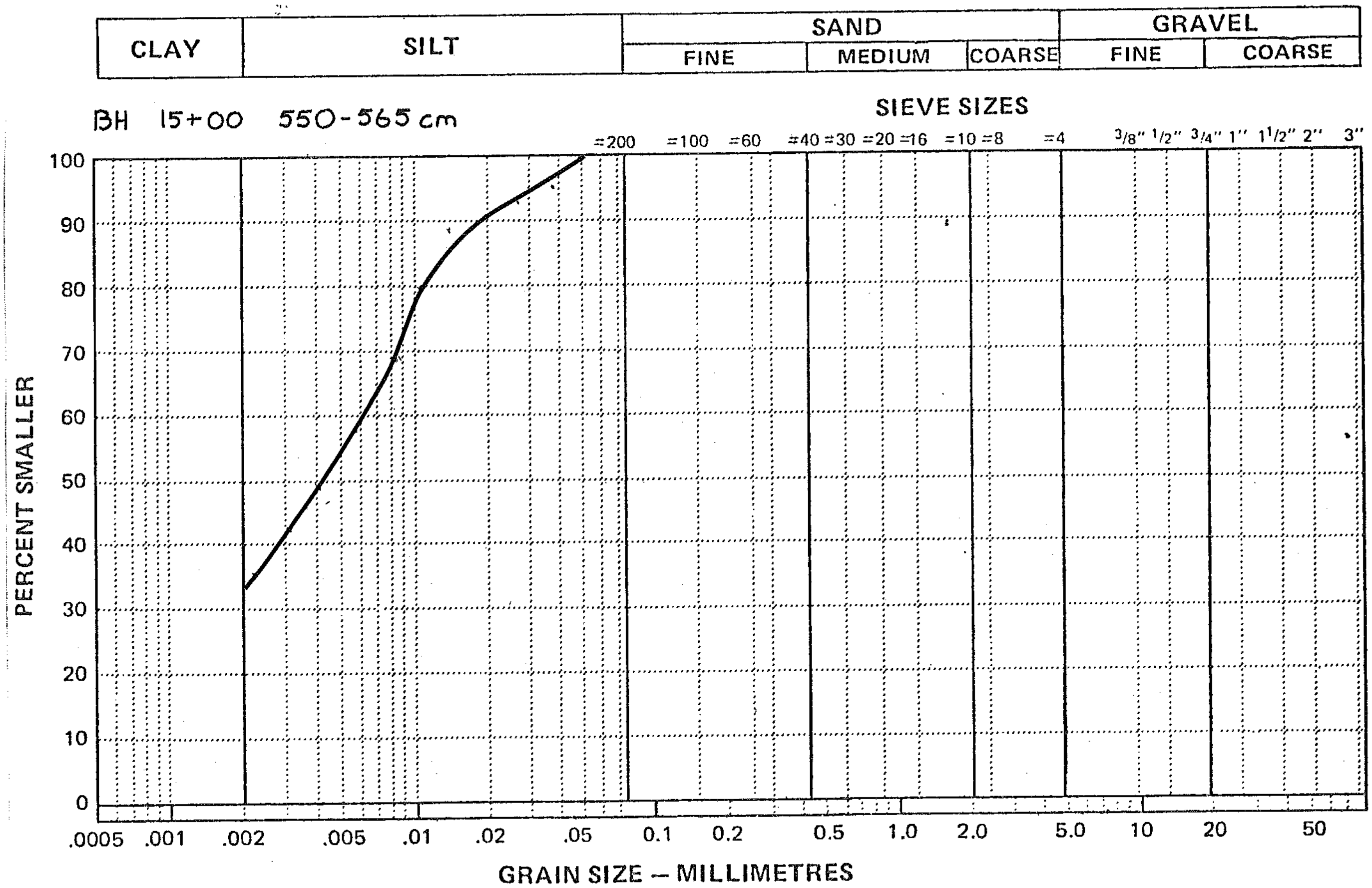
FIGURE 4 - FACIES 3

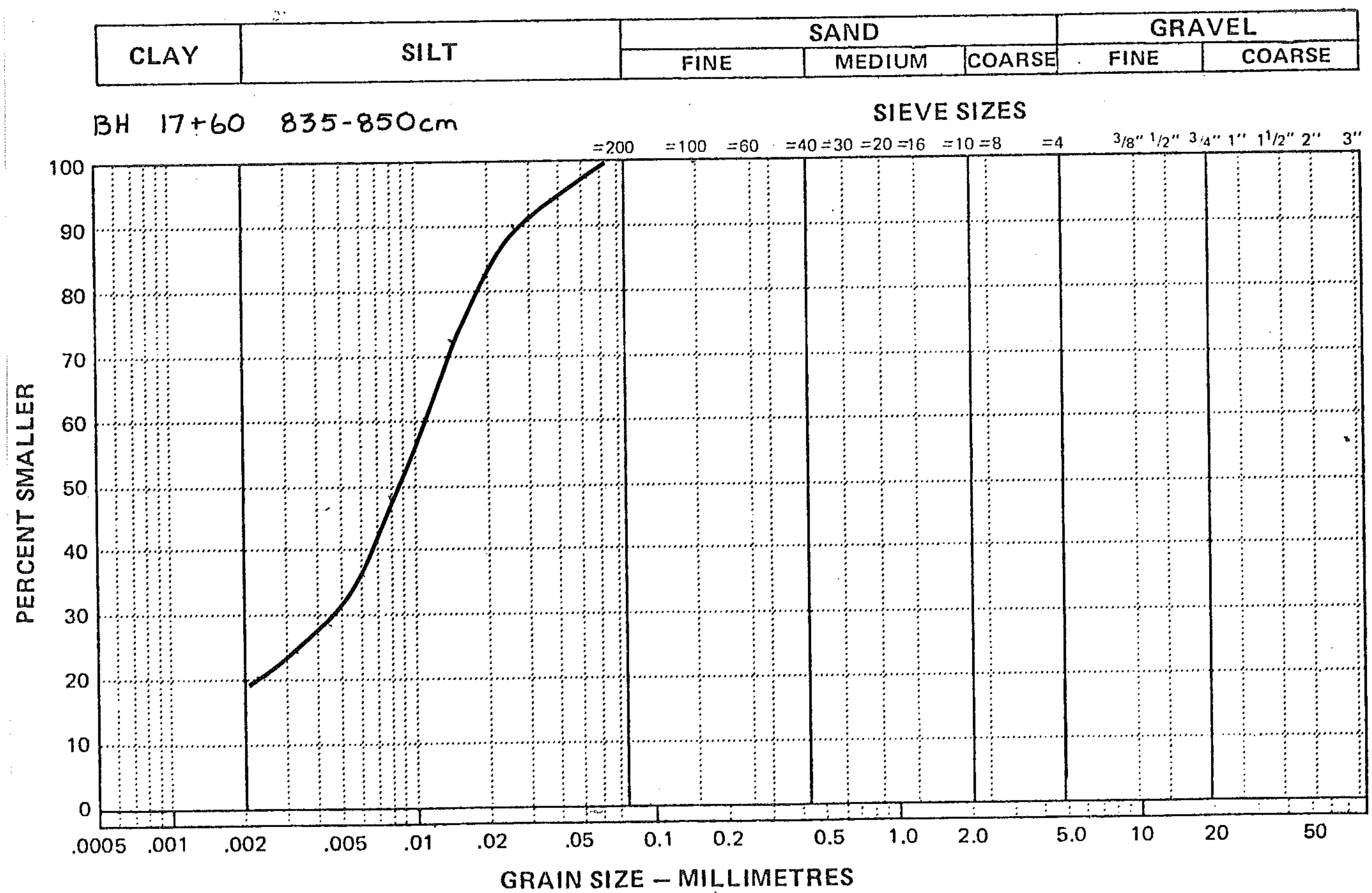


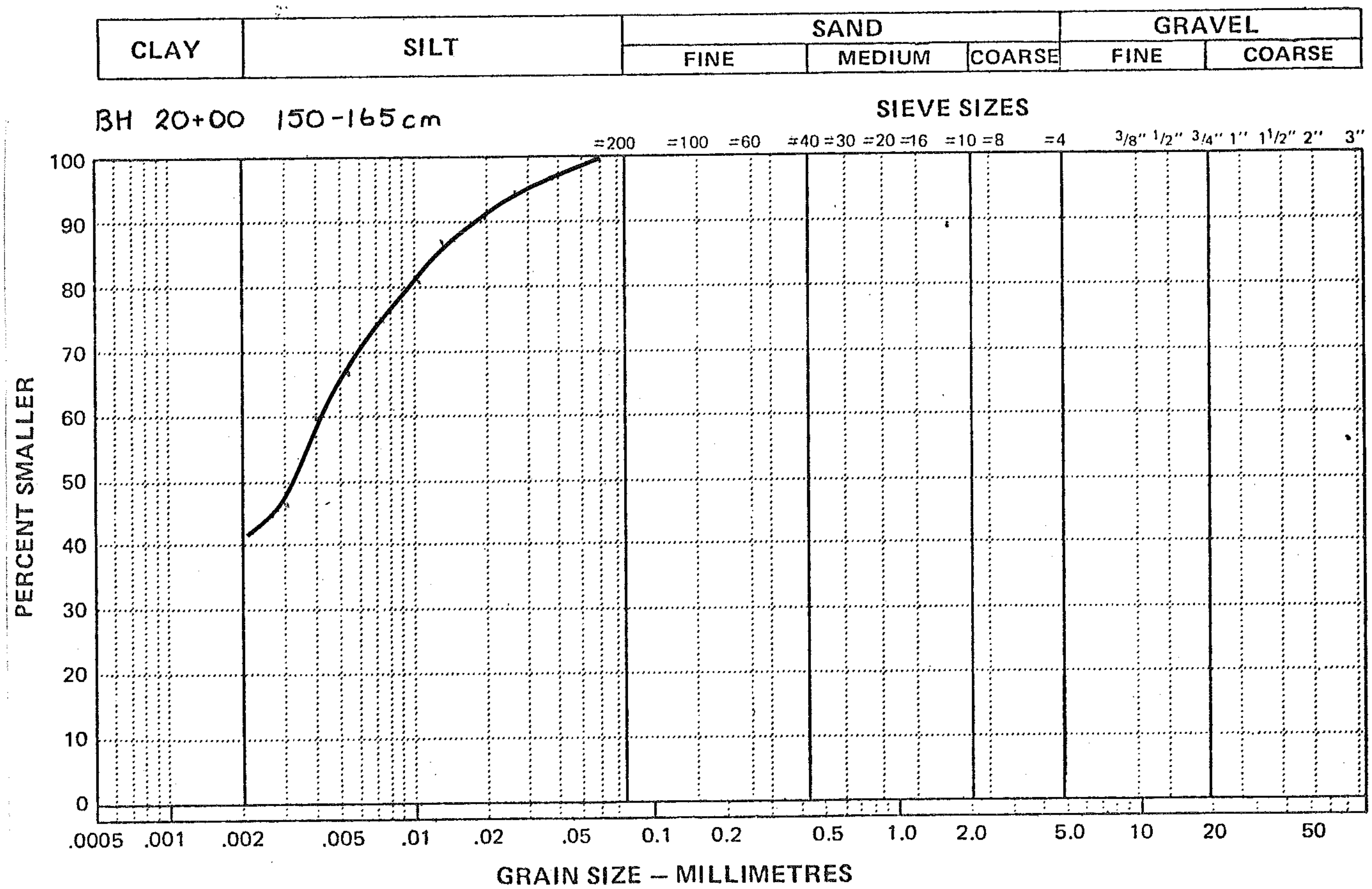


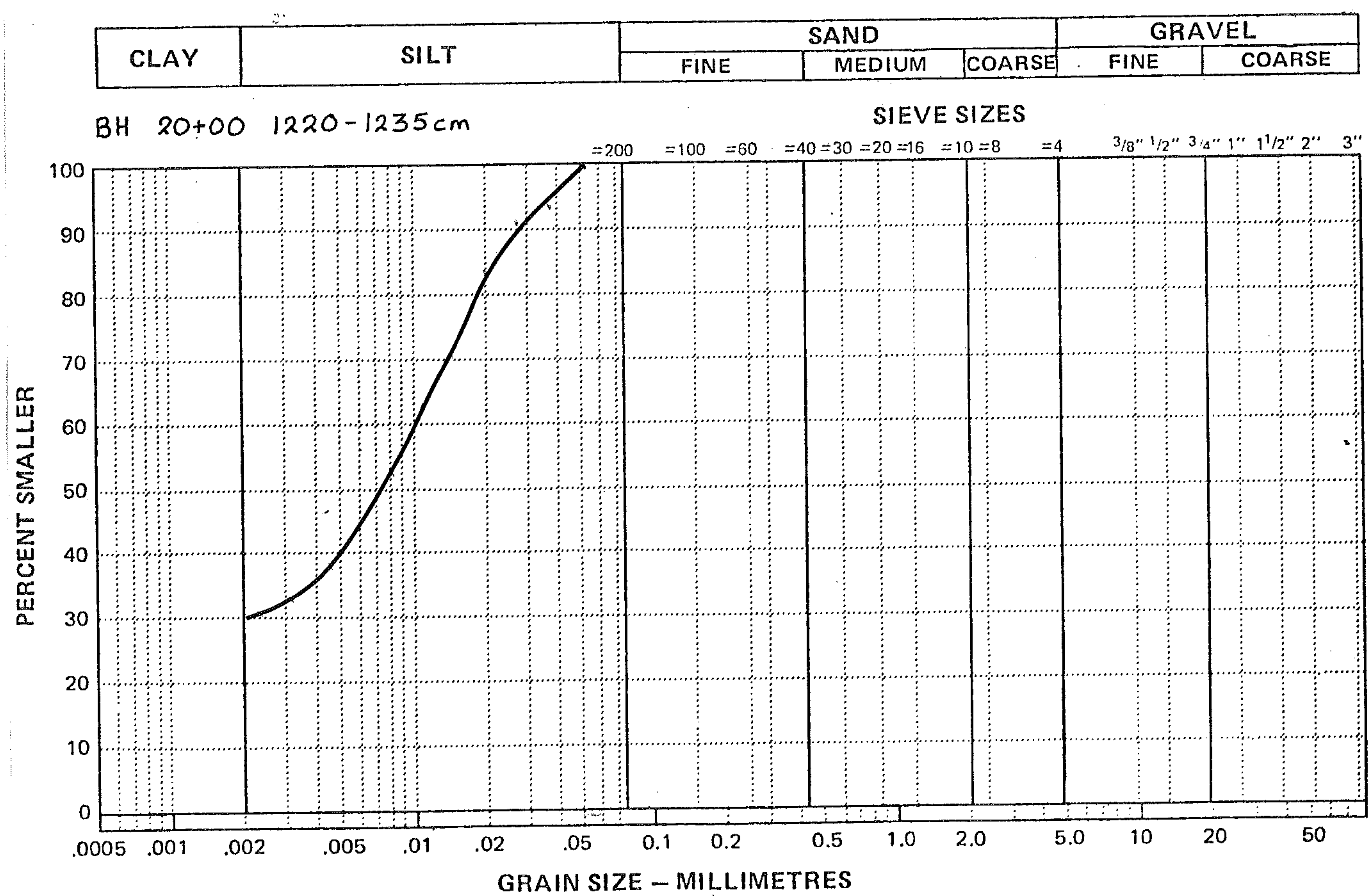

CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 7+60 1050-1065cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

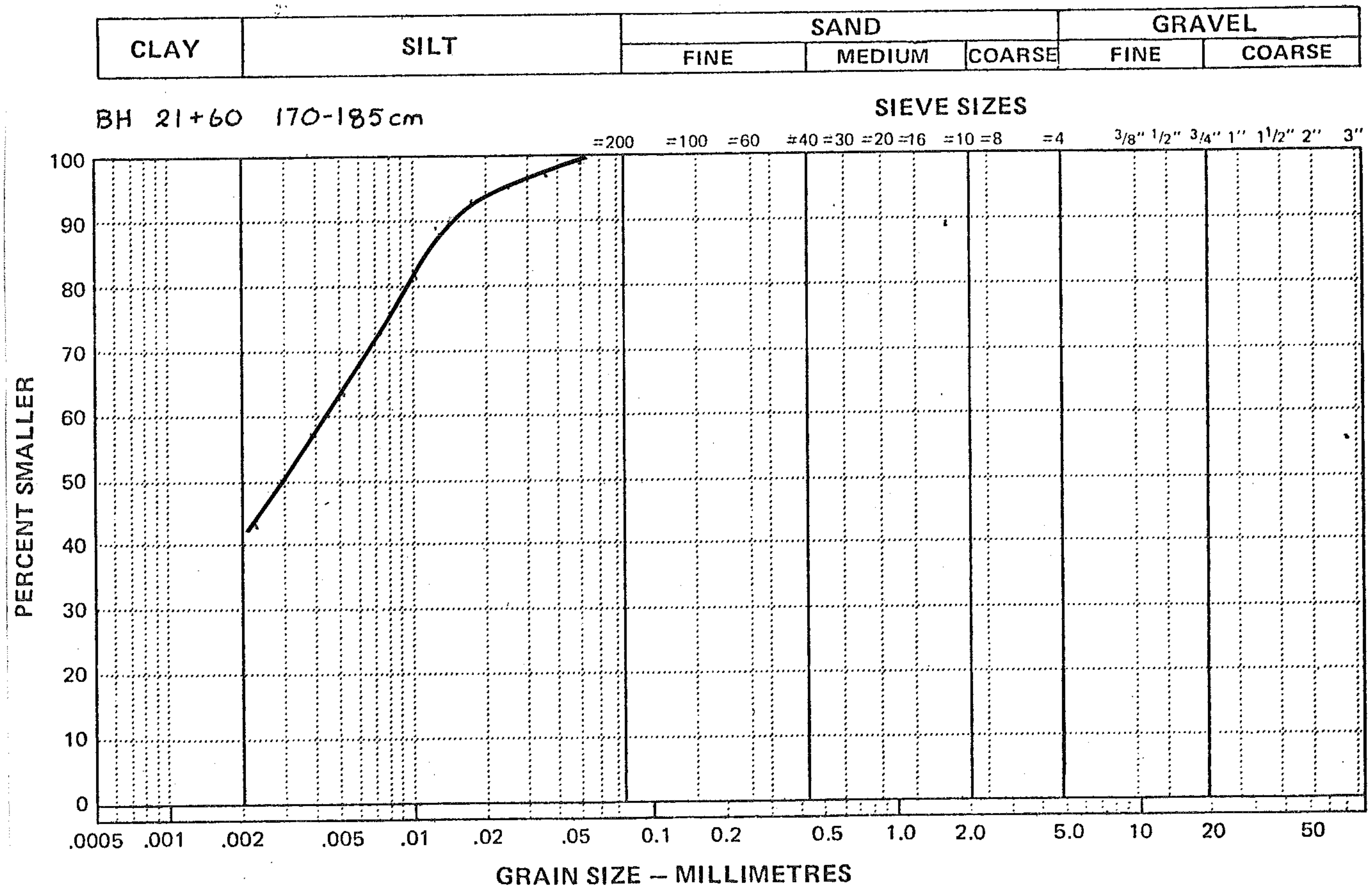

CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 15+00 5-20cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 15+00 550-565 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
0 10 20 30 40 50 60 70 80 90 100
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

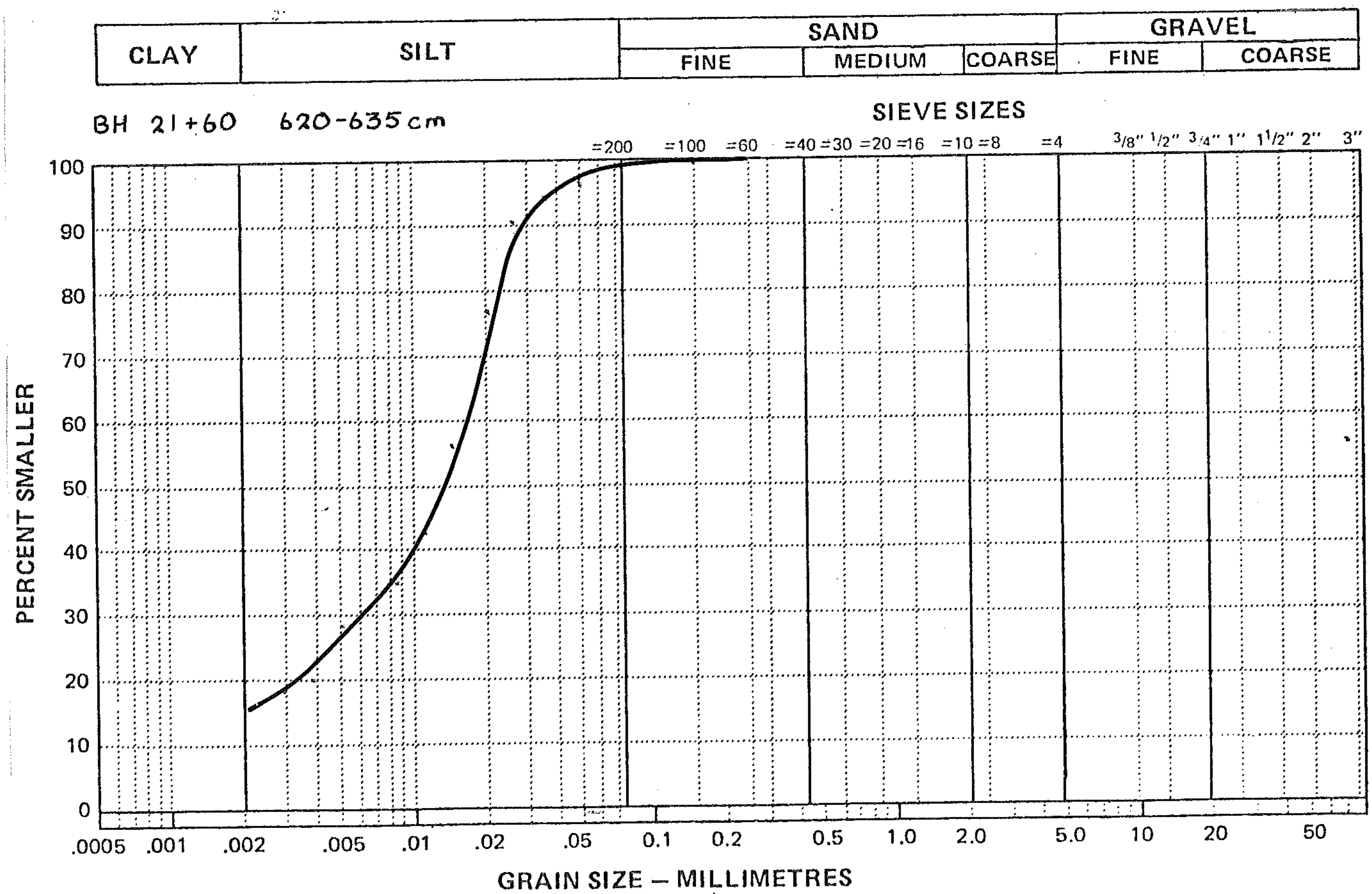

CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 17+60 835-850cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
0 10 20 30 40 50 60 70 80 90 100
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 20+00 150-165cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100
90
80
70
60
50
40
30
20
10
0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

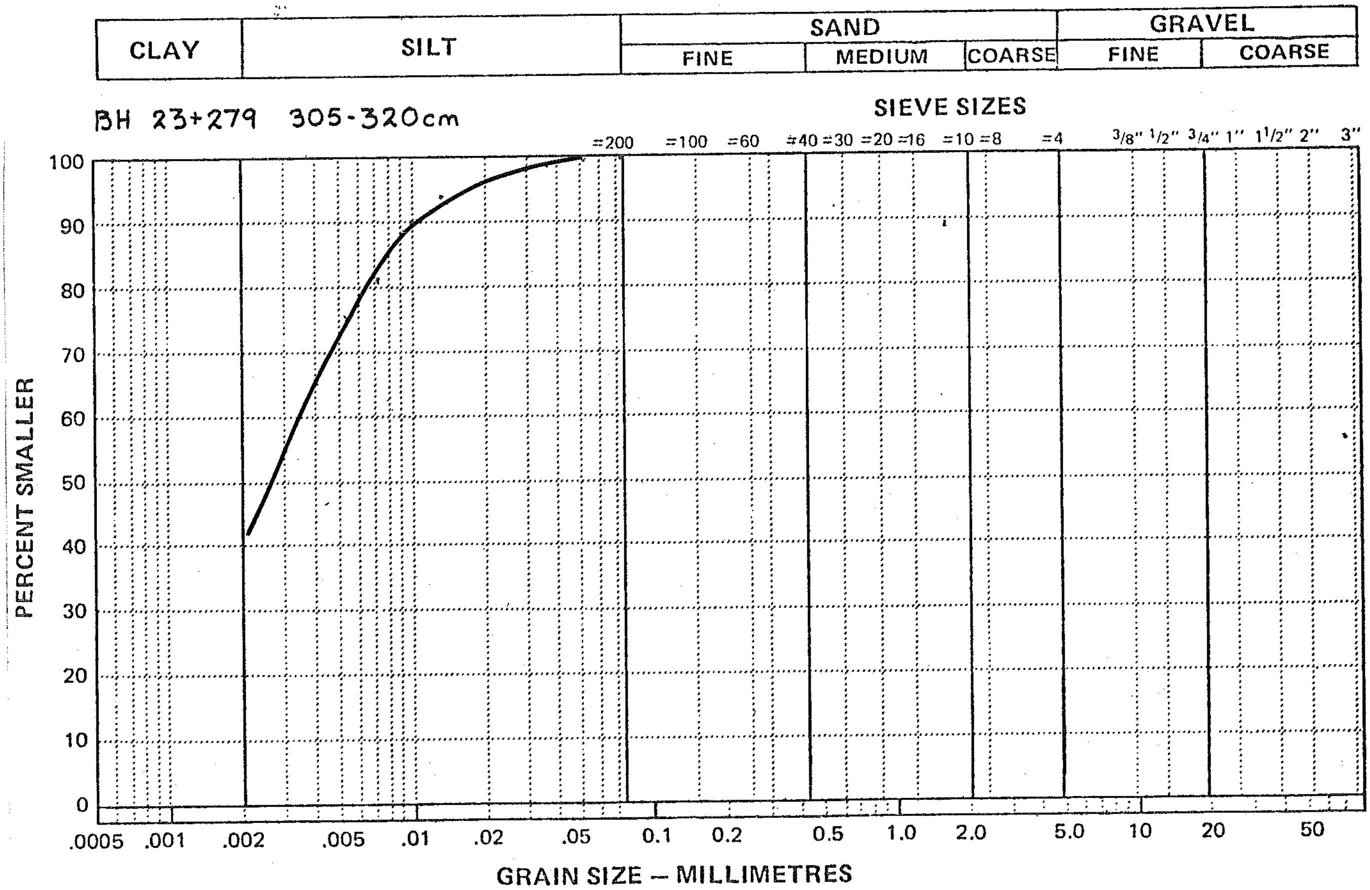

CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 20+00 1220-1235cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100
90
80
70
60
50
40
30
20
10
0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

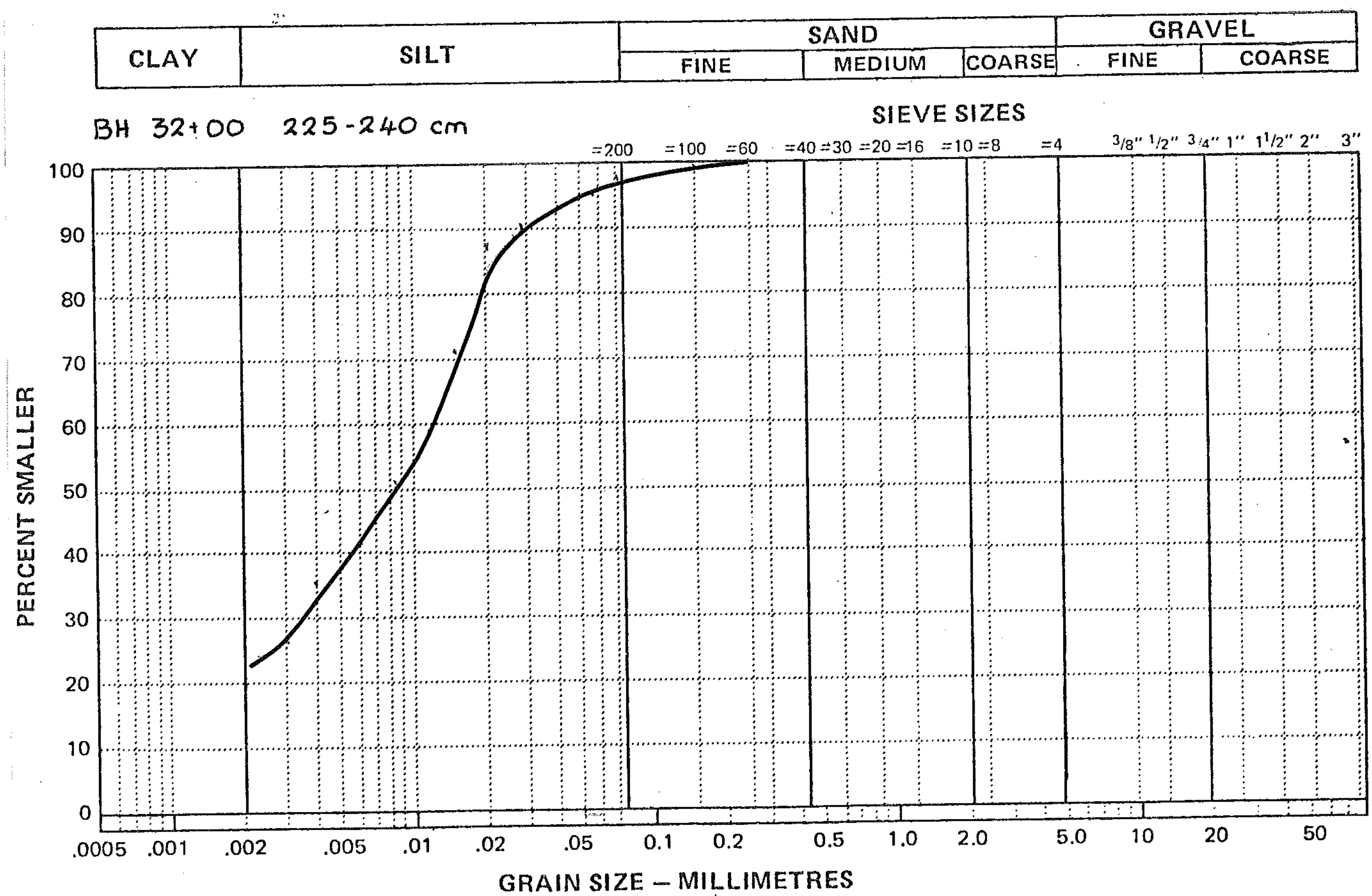


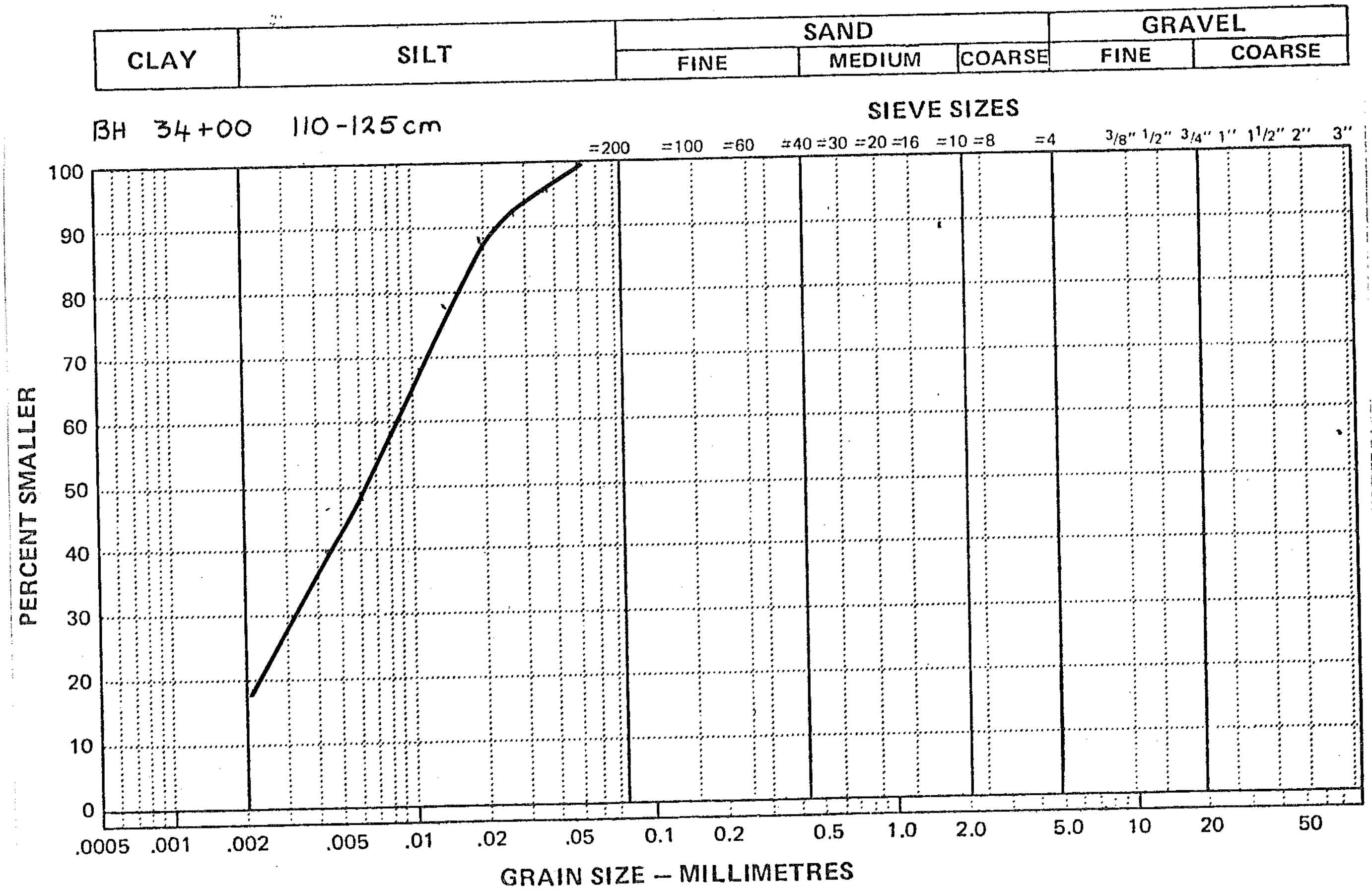
CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 21+60 170-185 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

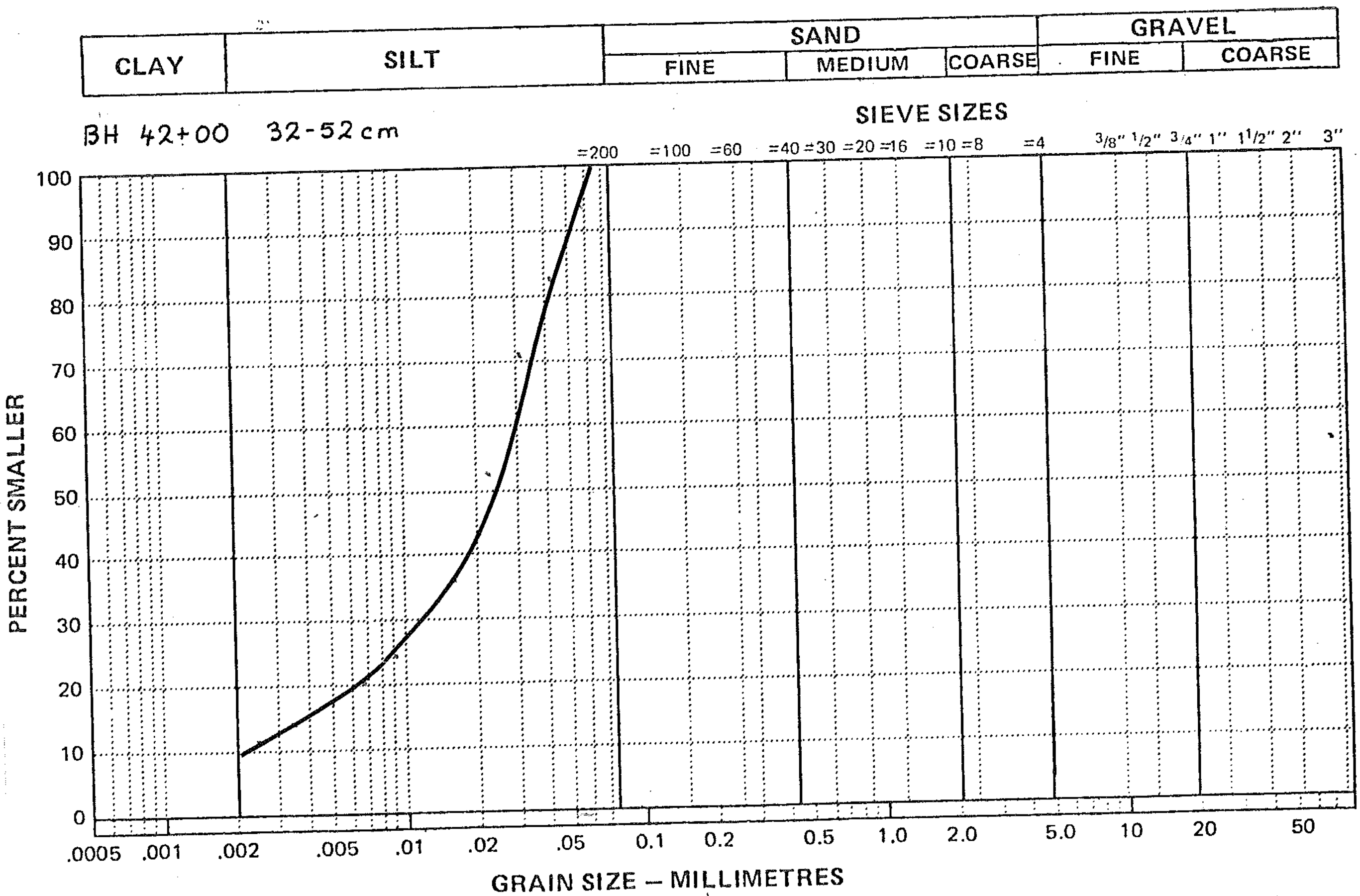


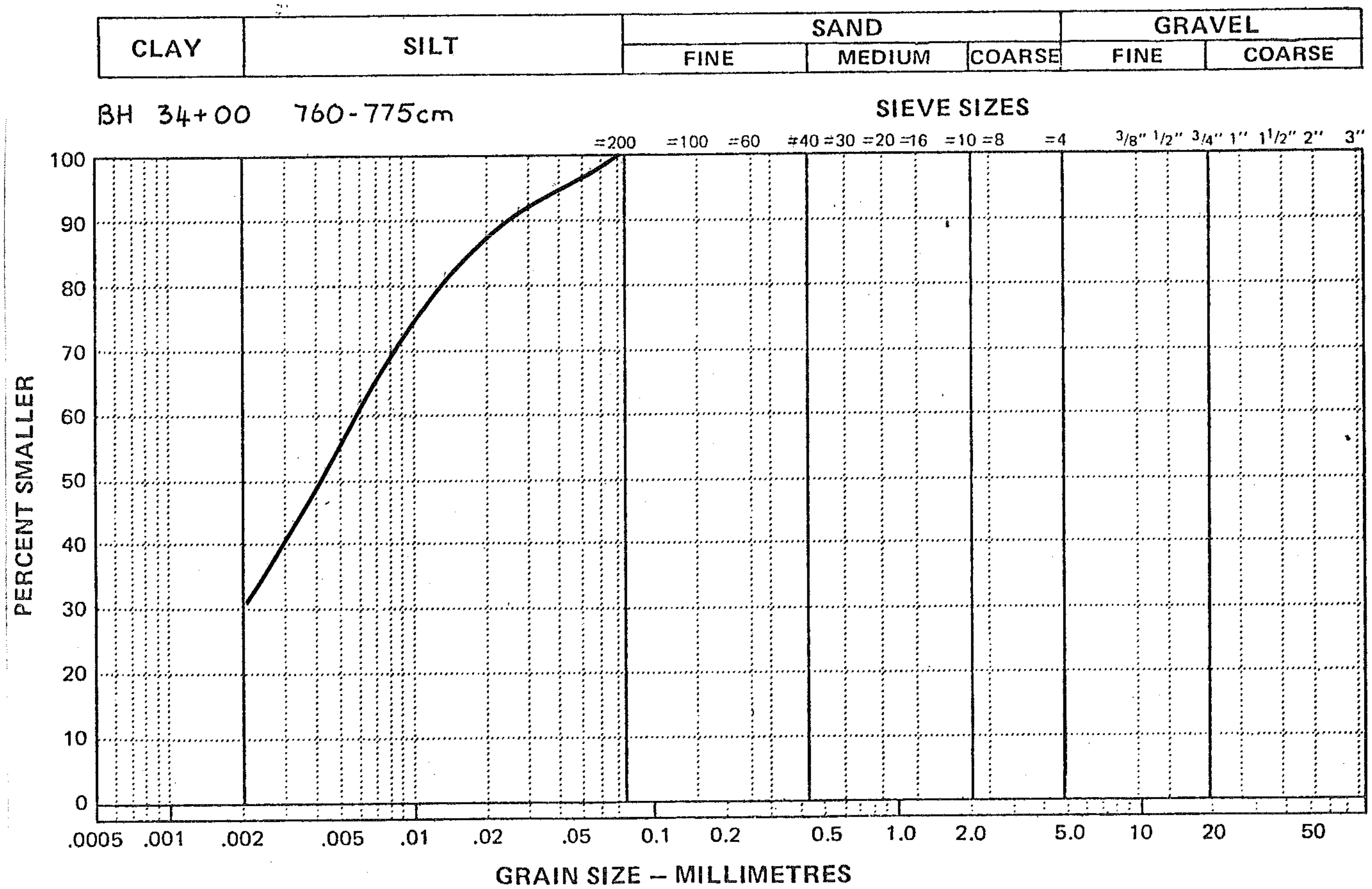
CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 21+60 620-635 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 23+279 305-320cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100
90
80
70
60
50
40
30
20
10
0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 32+00 225-240 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100
90
80
70
60
50
40
30
20
10
0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 34+00 110-125cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 42+00 32-52cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 34+00 760-775cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

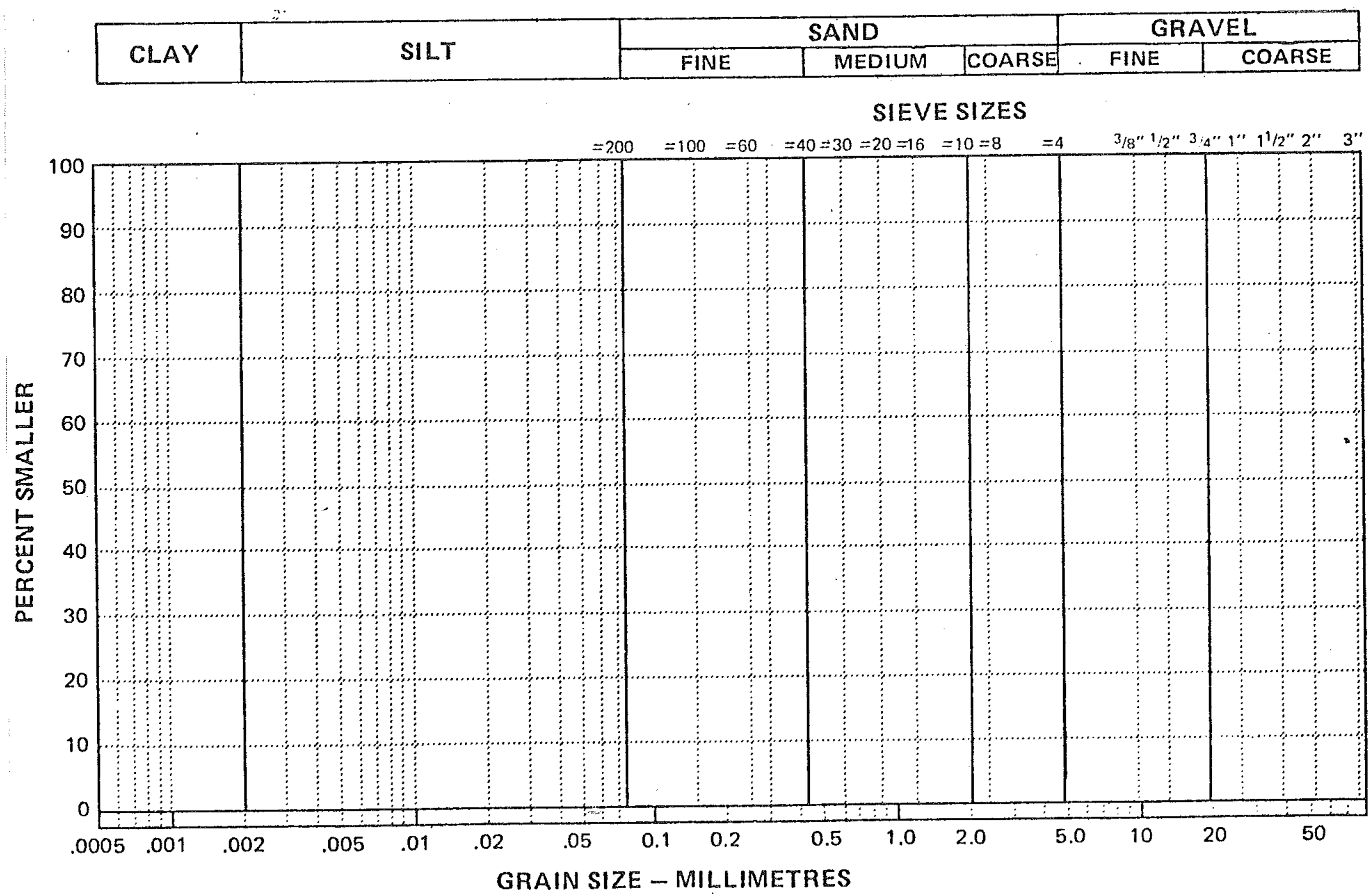
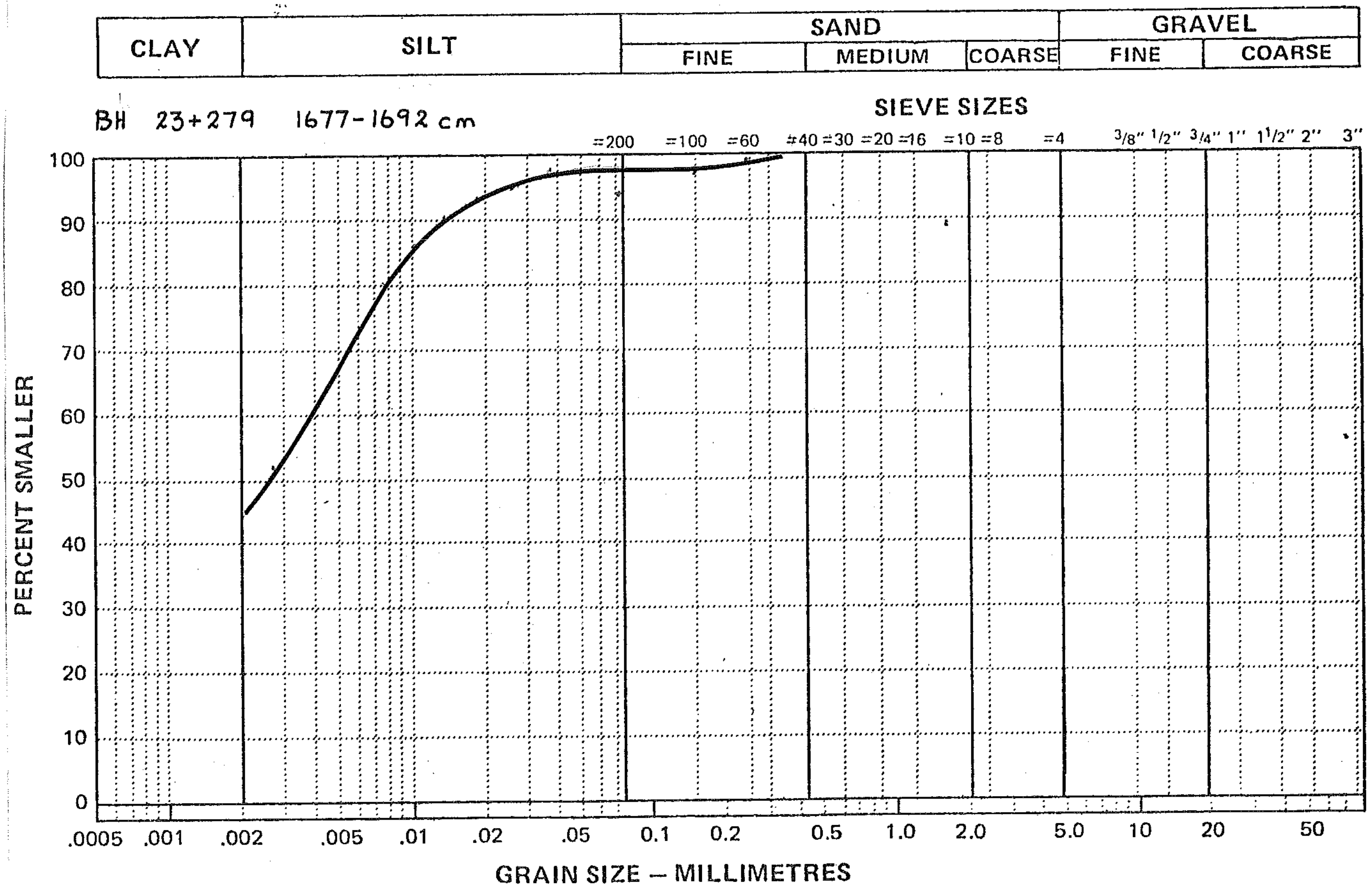
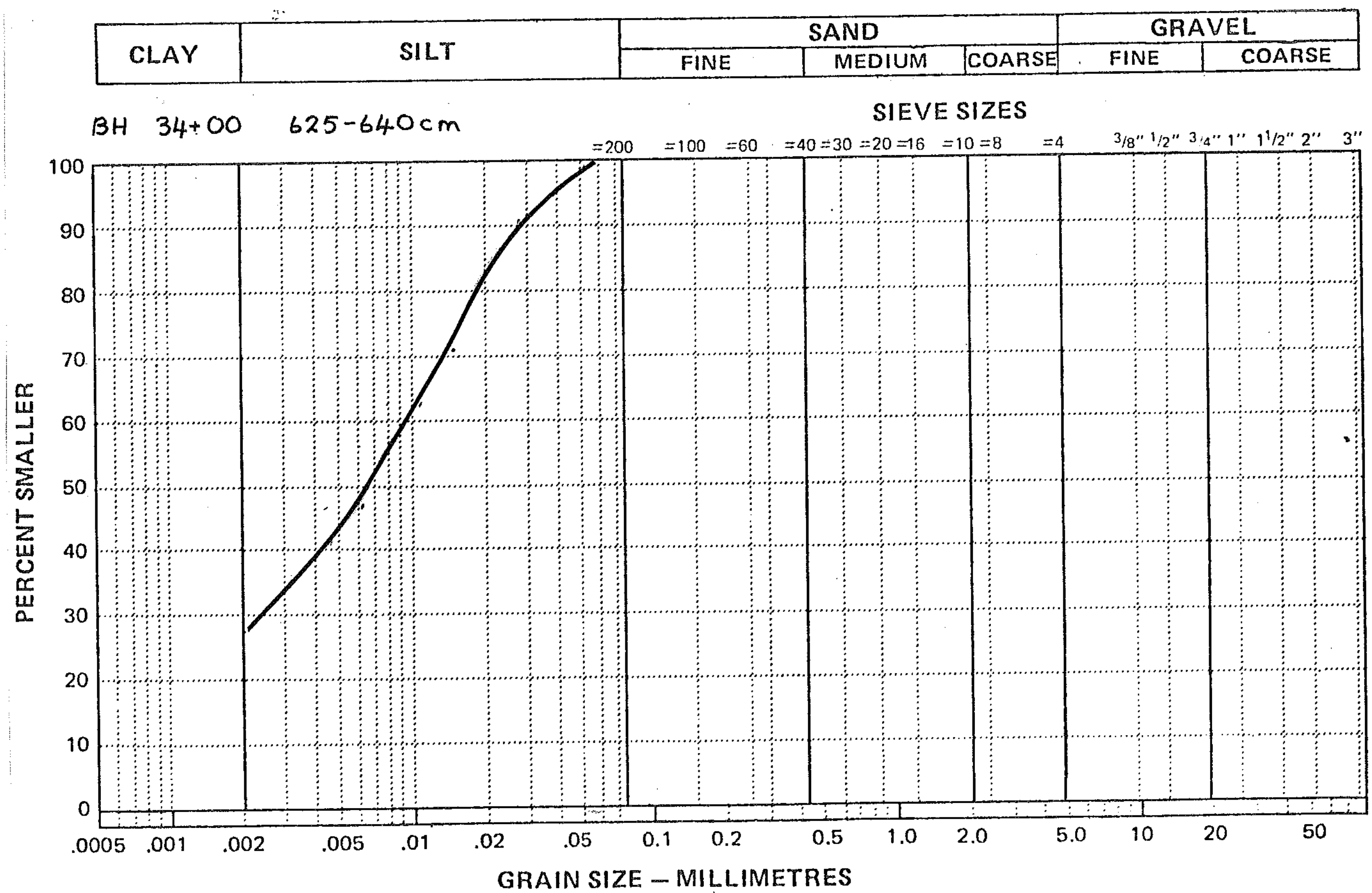
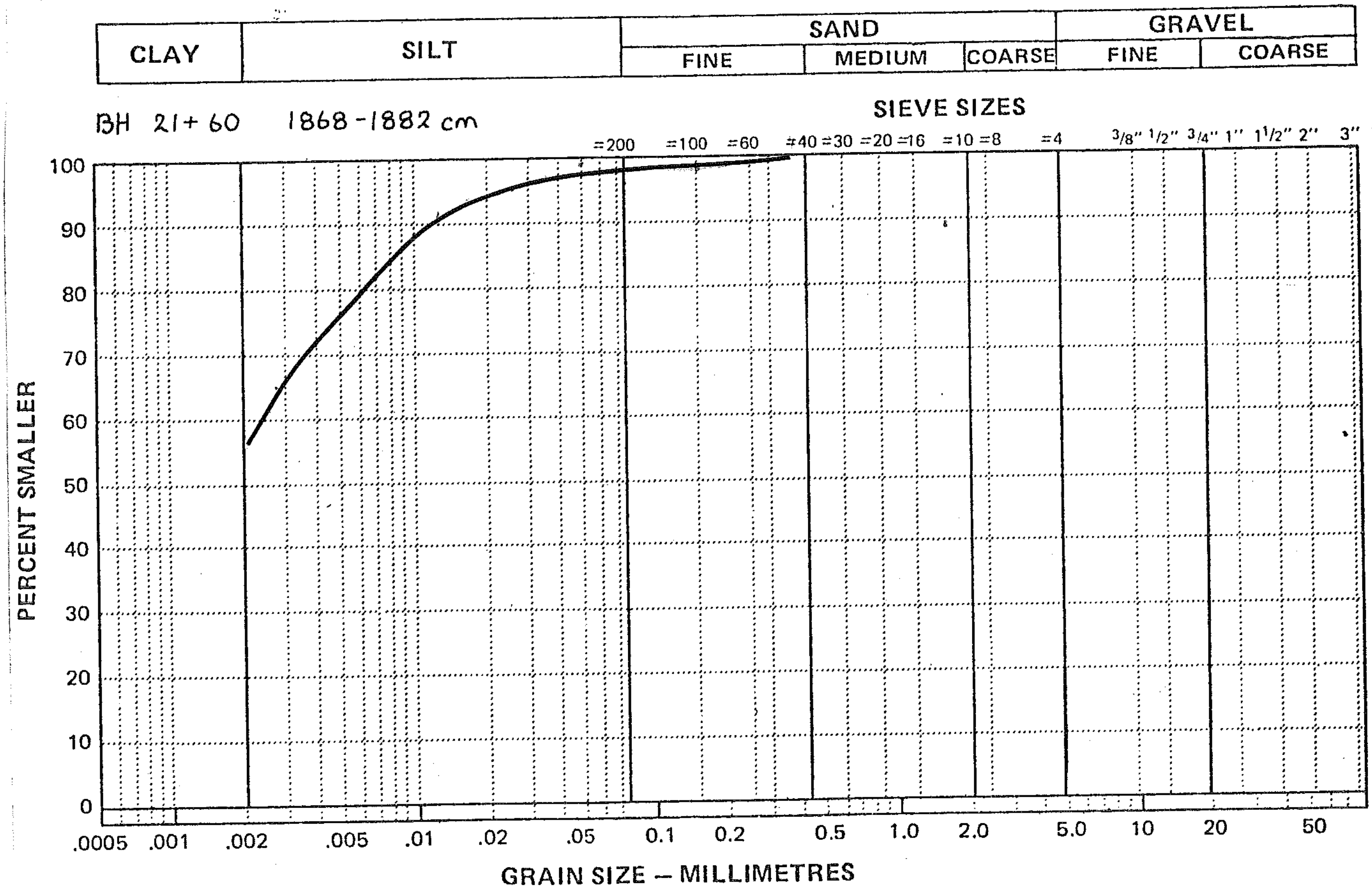
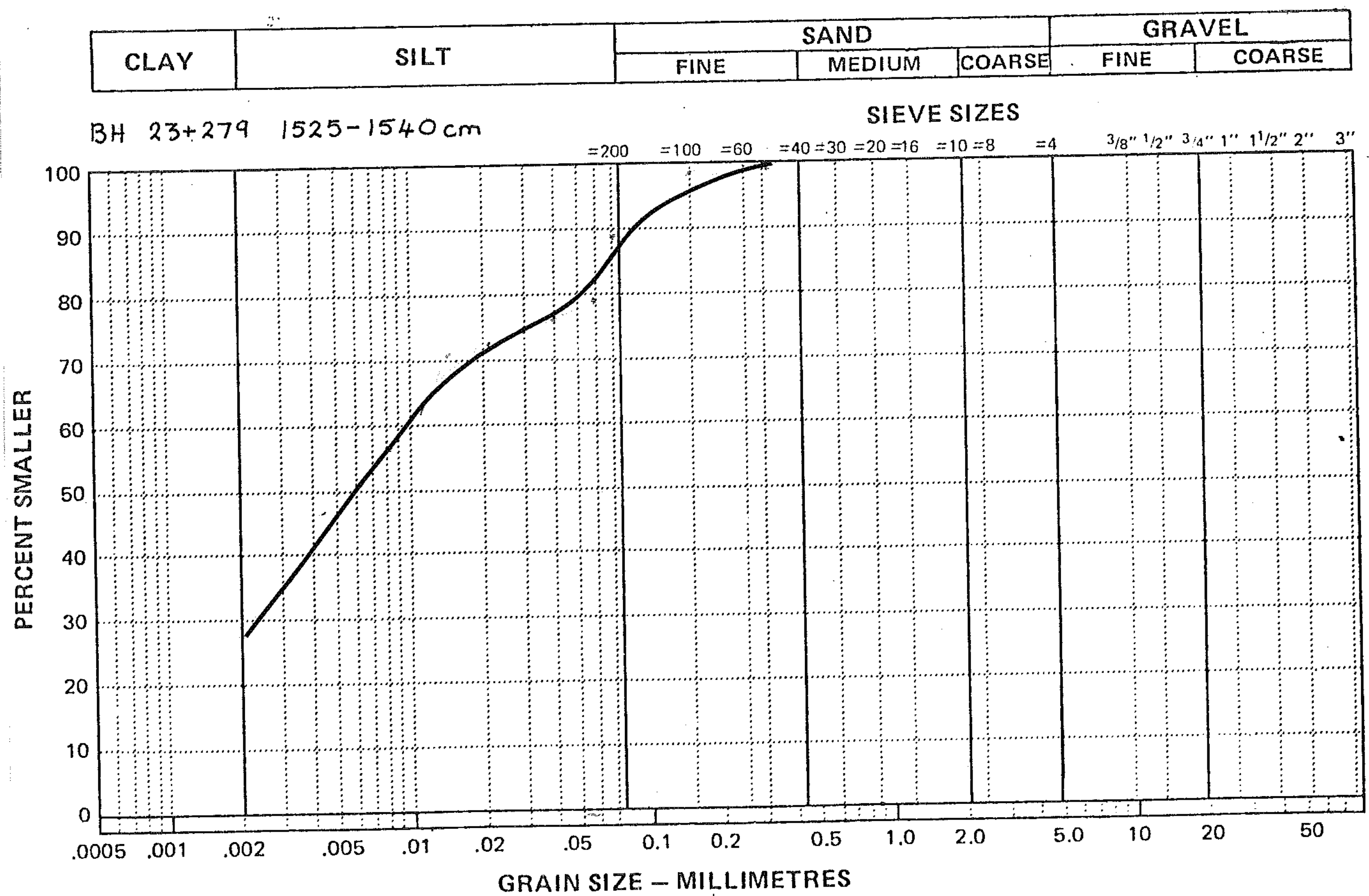

CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

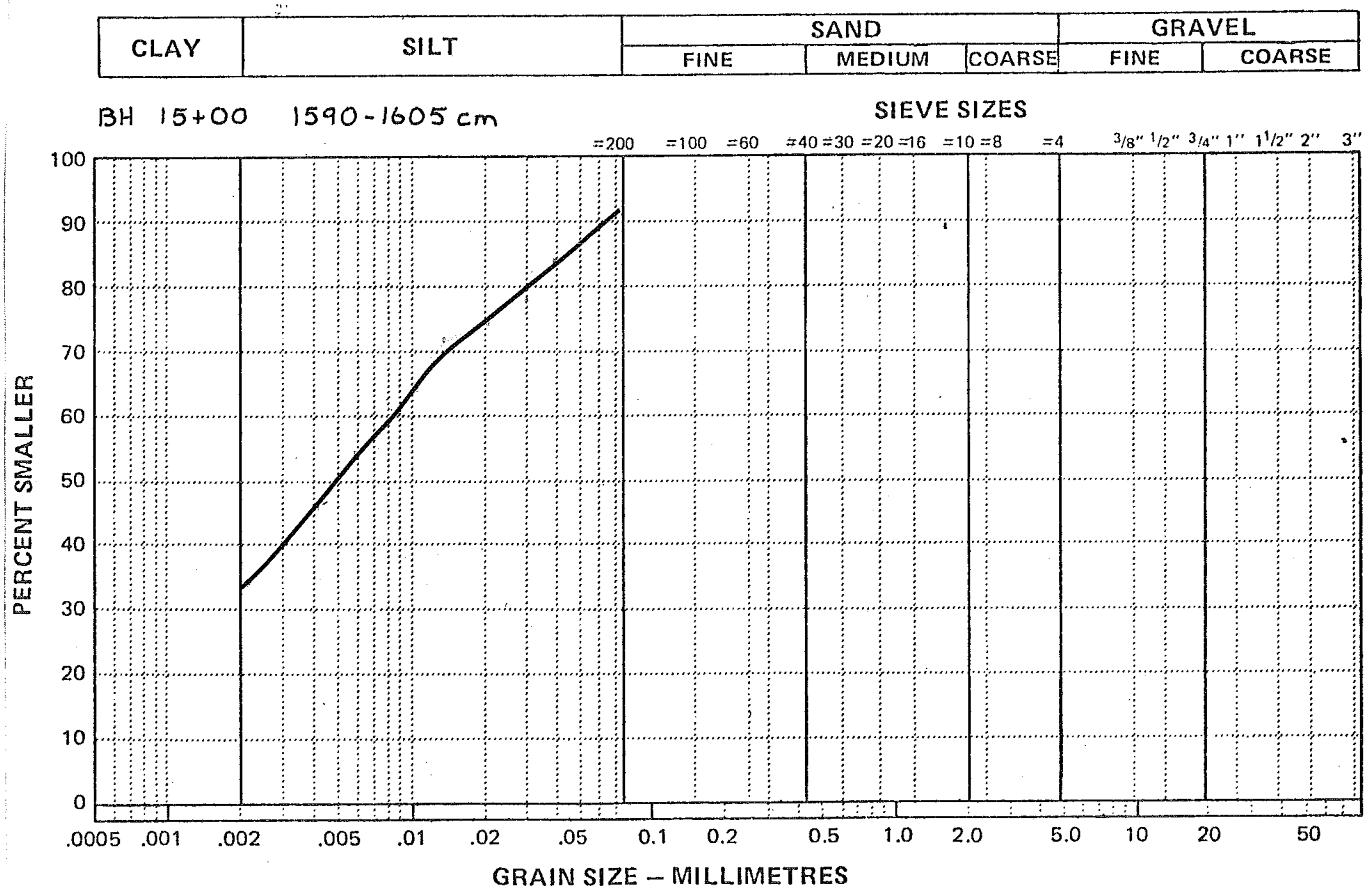
FIGURE 5 - FACIES 4



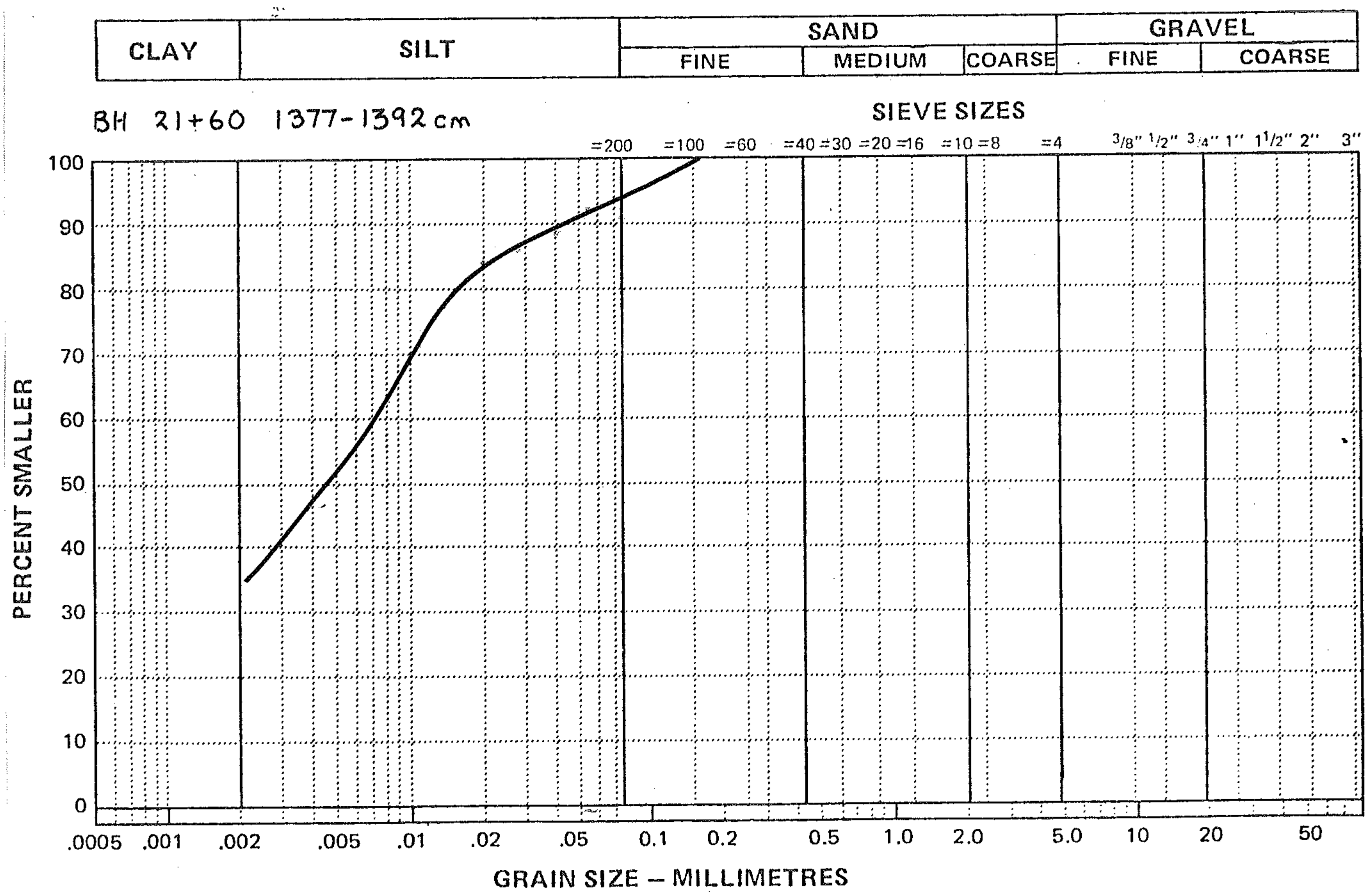



CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 21+60 1868-1882 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100
90
80
70
60
50
40
30
20
10
0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES


CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 23+279 1525-1540 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100
90
80
70
60
50
40
30
20
10
0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES



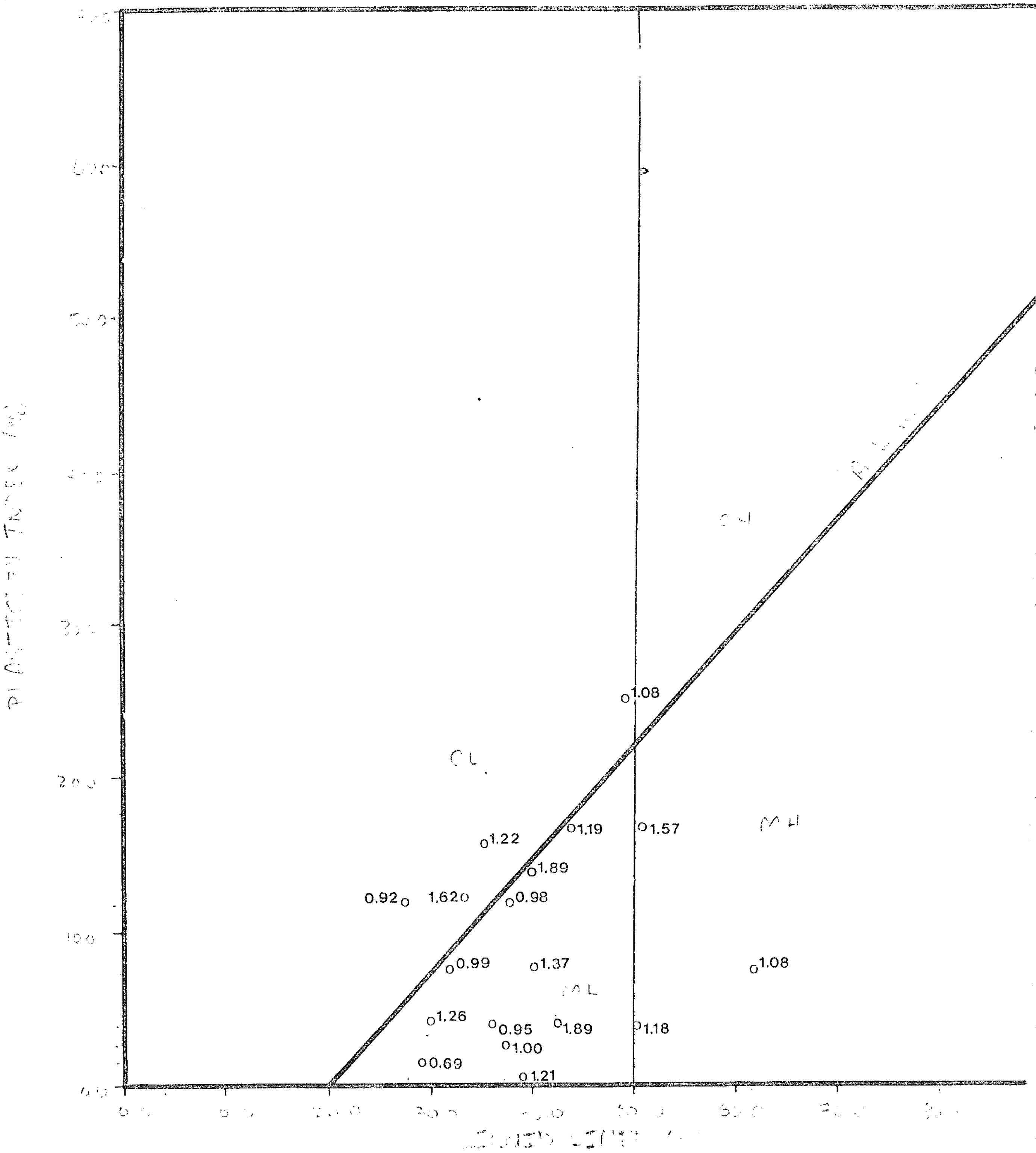
CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 15+00 1590-1605 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES



CLAY
SILT
SAND
FINE
MEDIUM
COARSE
GRAVEL
FINE
COARSE
BH 21+60 1377-1392 cm
SIEVE SIZES
=200 =100 =60 =40 =30 =20 =16 =10 =8 =4
3/8" 1/2" 3/4" 1" 1 1/2" 2" 3"
PERCENT SMALLER
100 90 80 70 60 50 40 30 20 10 0
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES

APPENDIX F

ORGANIC CONTENT



CL
ML
MH
1.08
1.57
1.19
1.22
1.89
0.92
1.62
0.98
0.99
1.37
1.08
1.26
0.95
1.89
1.18
1.00
0.69
1.21

APPENDIX G

SHEAR STRENGTH VERSUS DEPTH

SHEAR STRENGTH VS DEPTH OF FACIES 1A, NORTH POINT

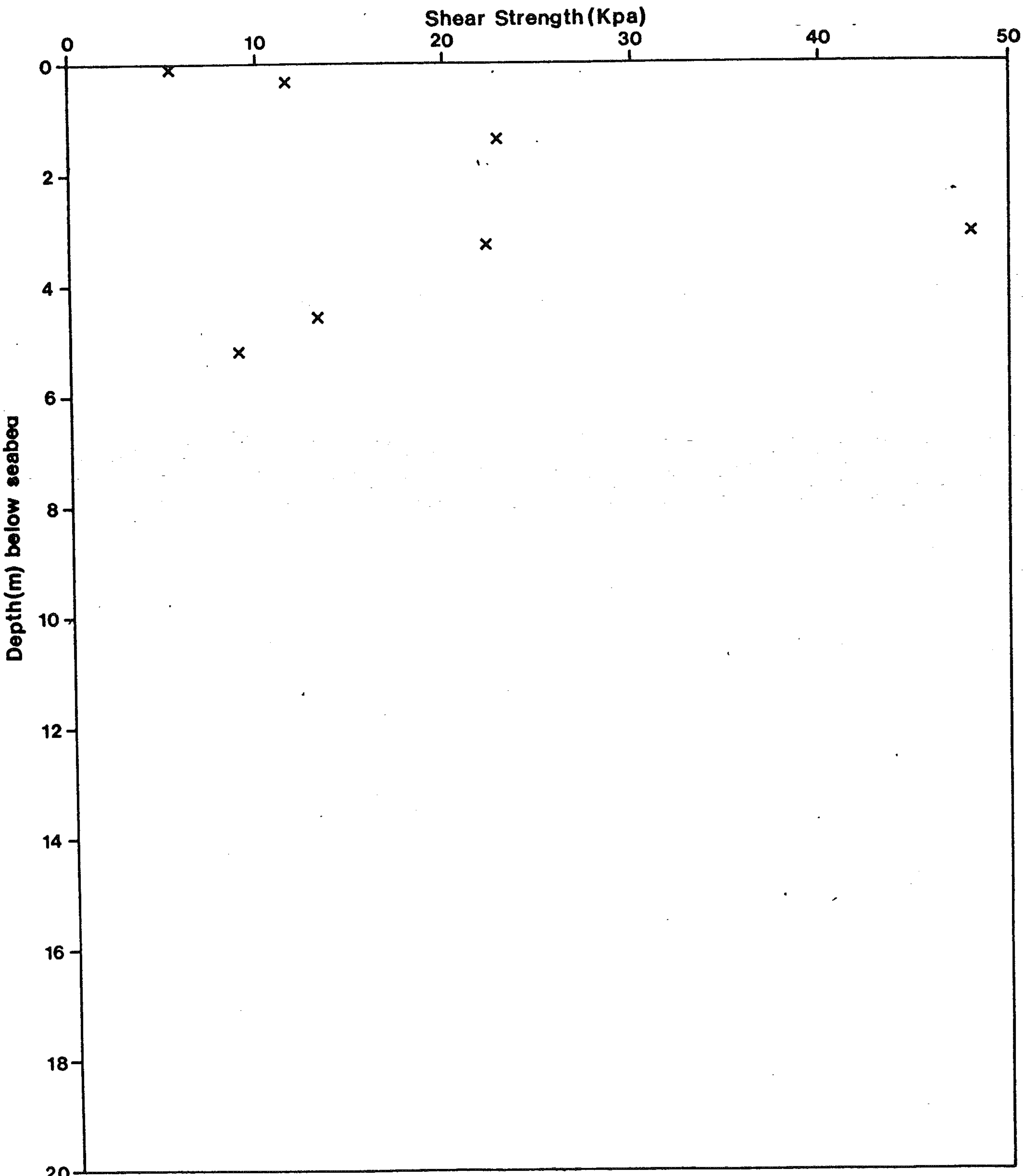


FIGURE 1

SHEAR STRENGTH VS DEPTH OF FACIES 1B, NORTH POINT

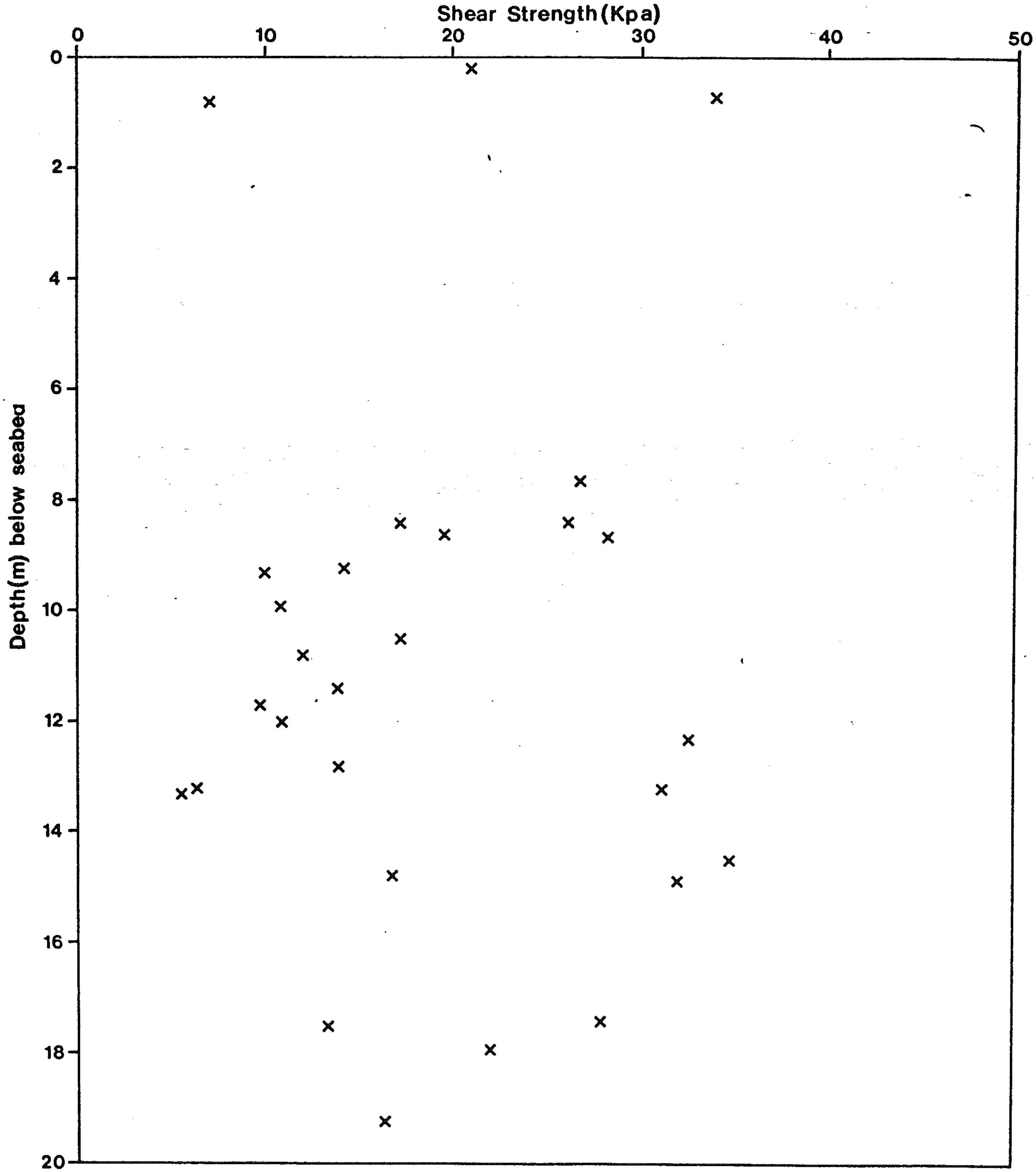


FIGURE 2

SHEAR STRENGTH VS DEPTH OF FACIES 2, NORTH POINT

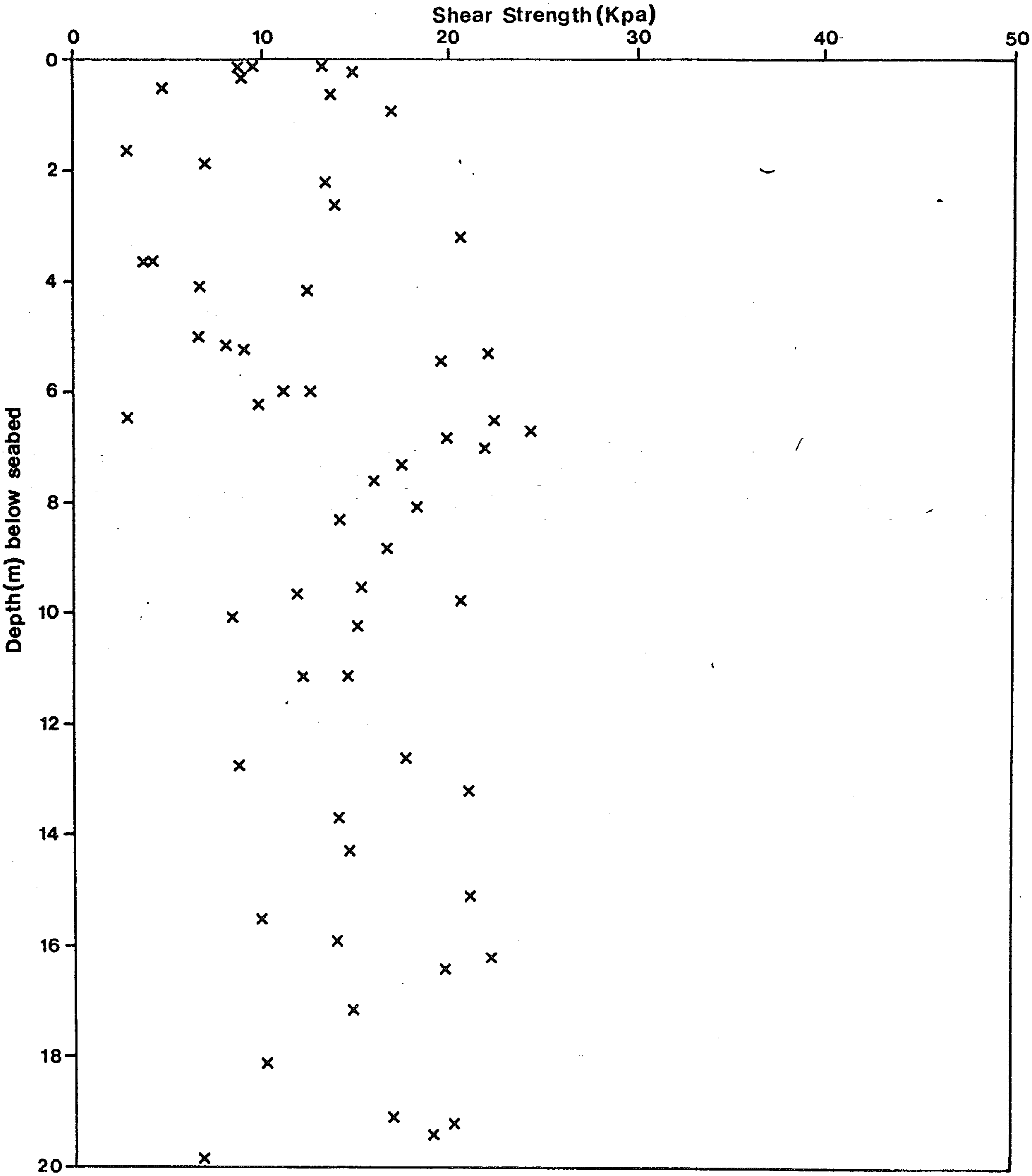


FIGURE 3

SHEAR STRENGTH VS DEPTH OF FACIES 3, NORTH POINT

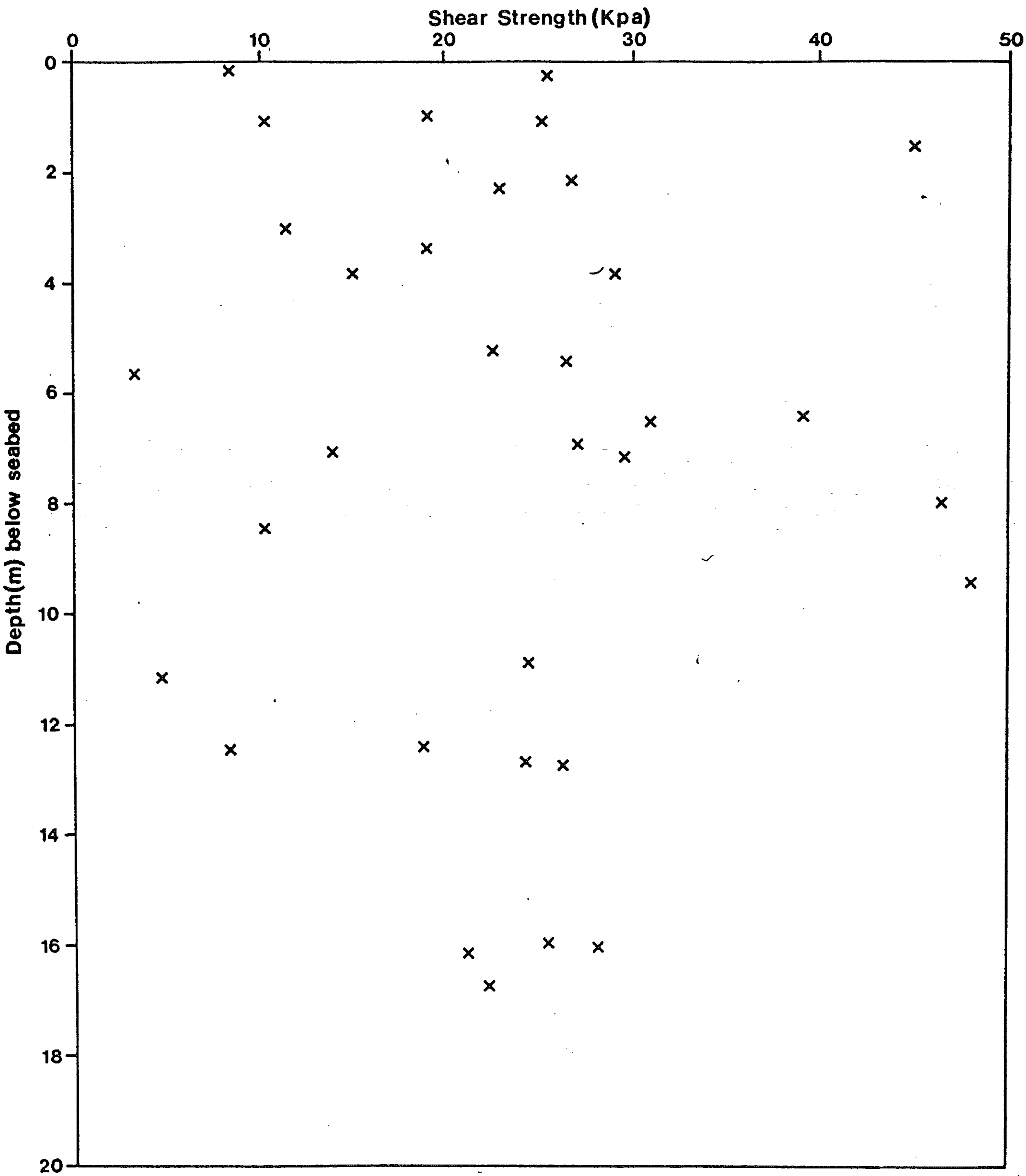


FIGURE 4

SHEAR STRENGTH VS DEPTH OF FACIES 4, NORTH POINT

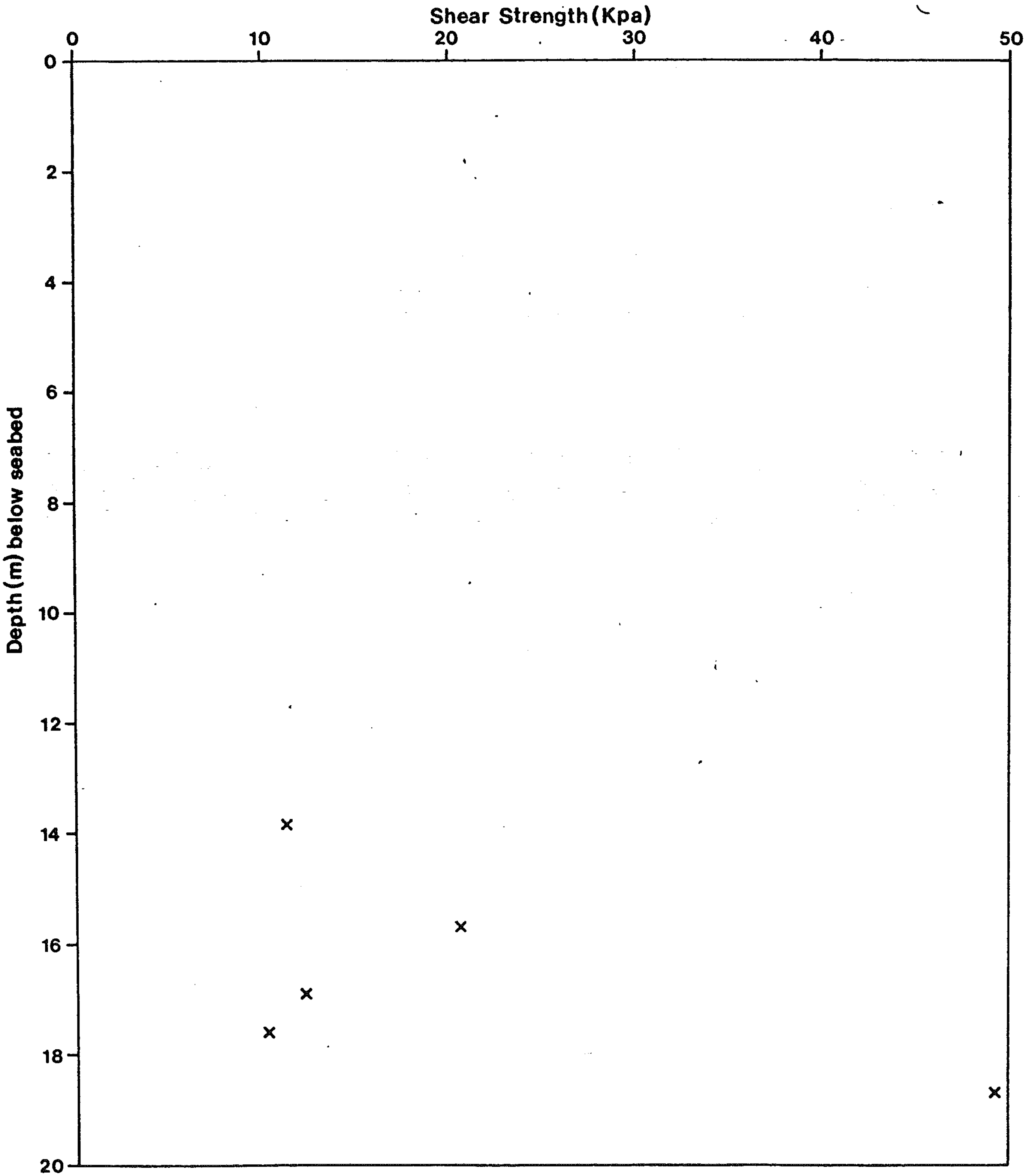
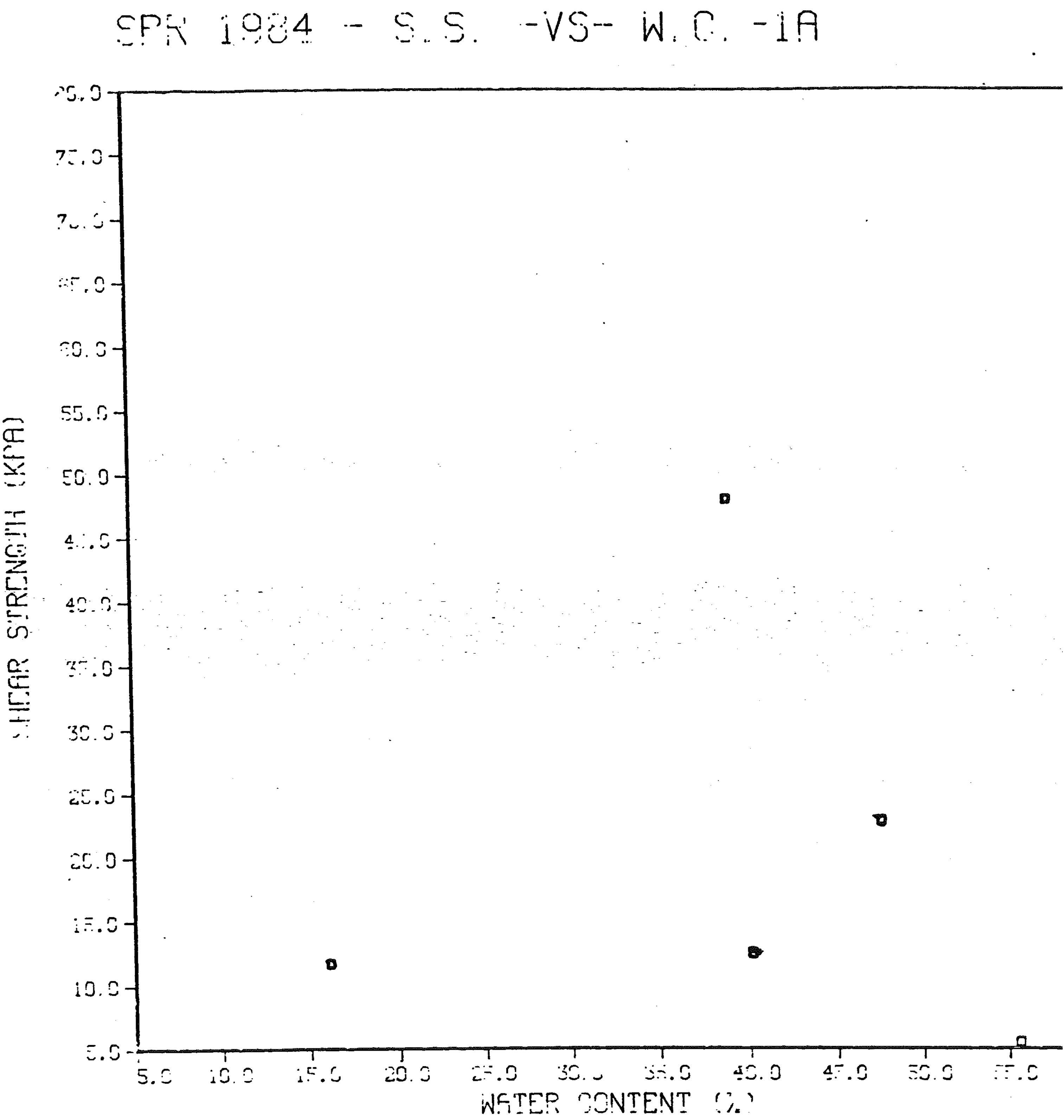


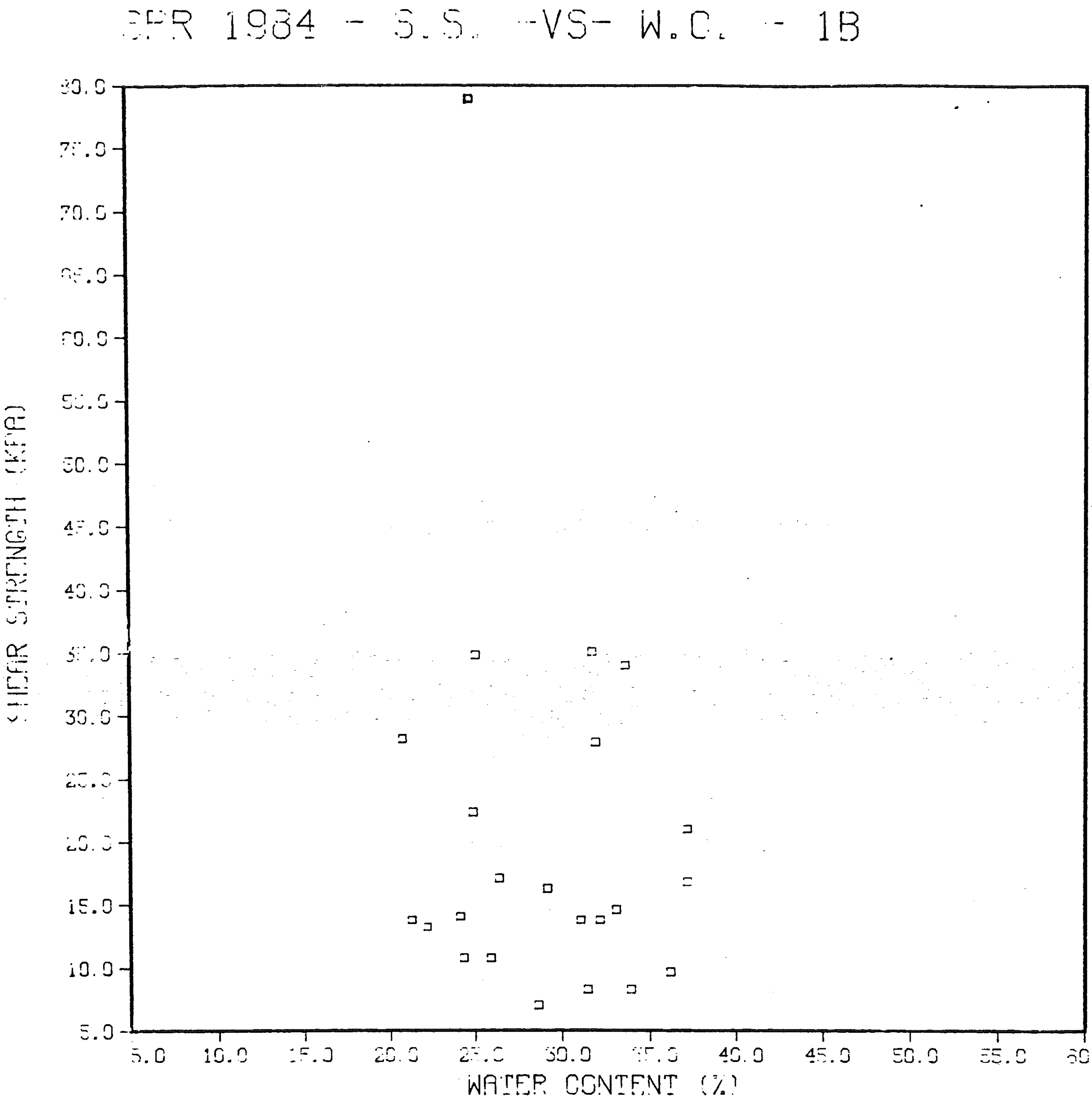
FIGURE 5

APPENDIX H

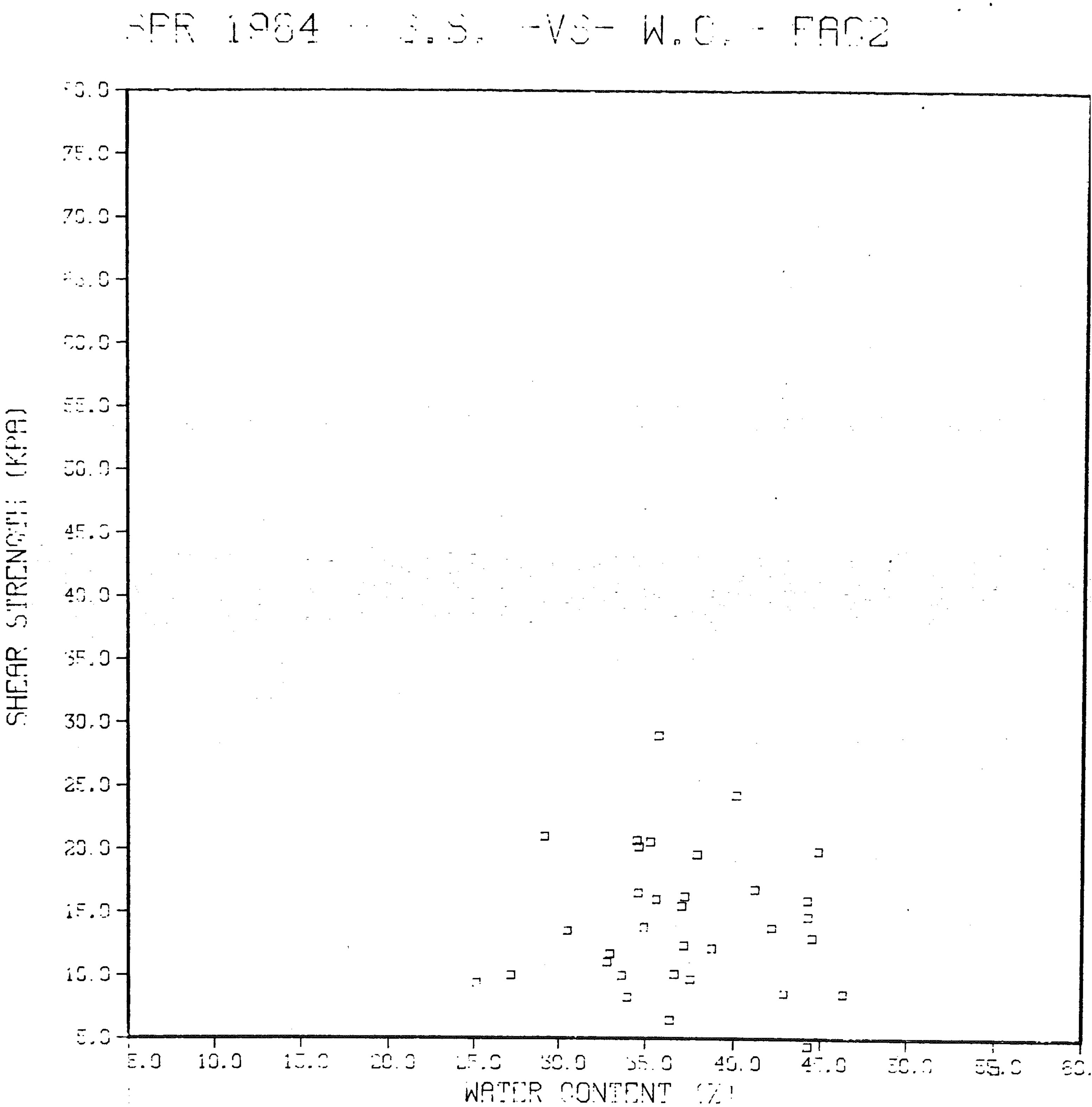
SHEAR STRENGTH VERSUS WATER CONTENT



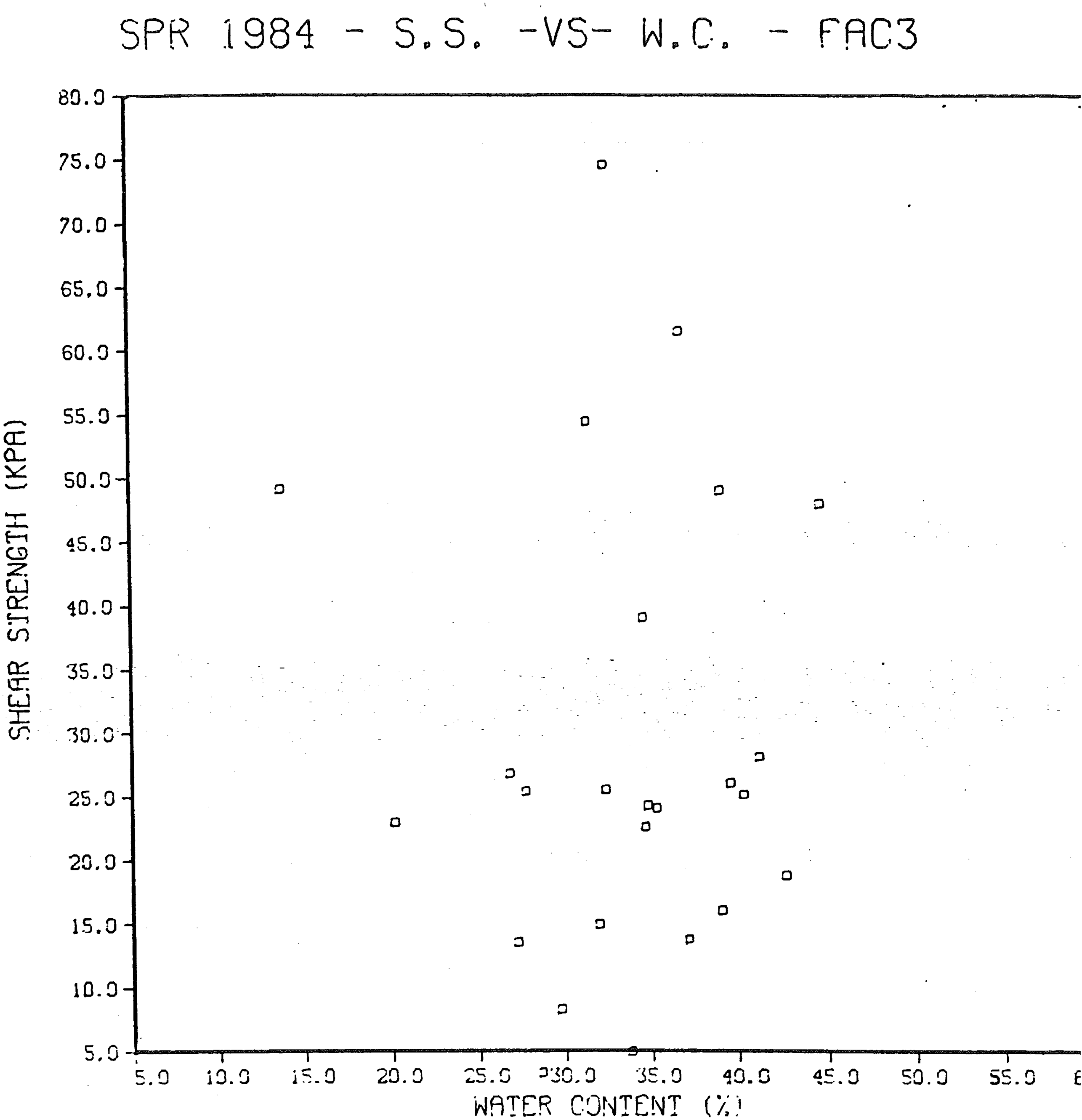
FACIES 1A– FIGURE 1



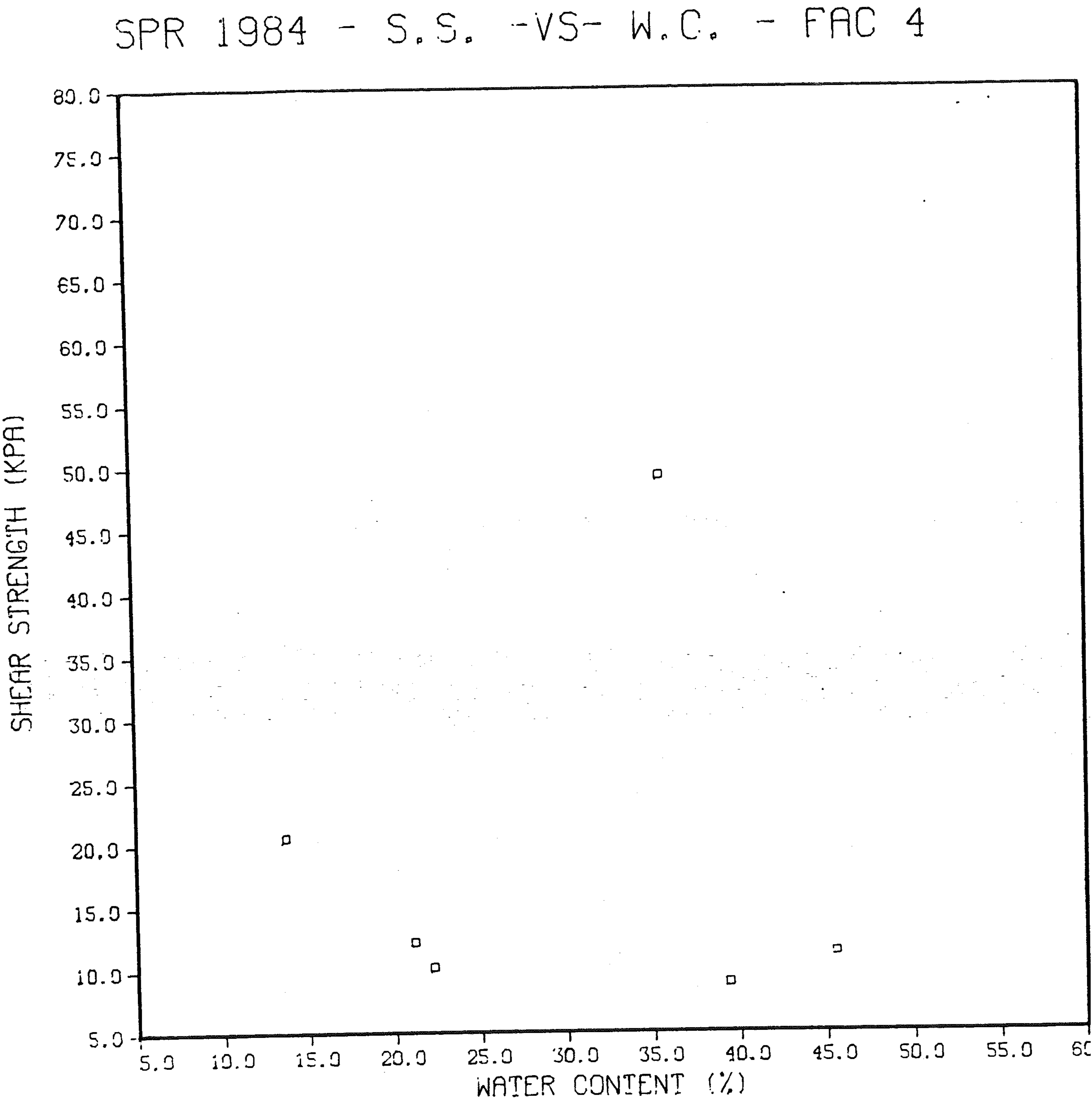
FACIES 1B — FIGURE 2



FACIES 2 — FIGURE 3



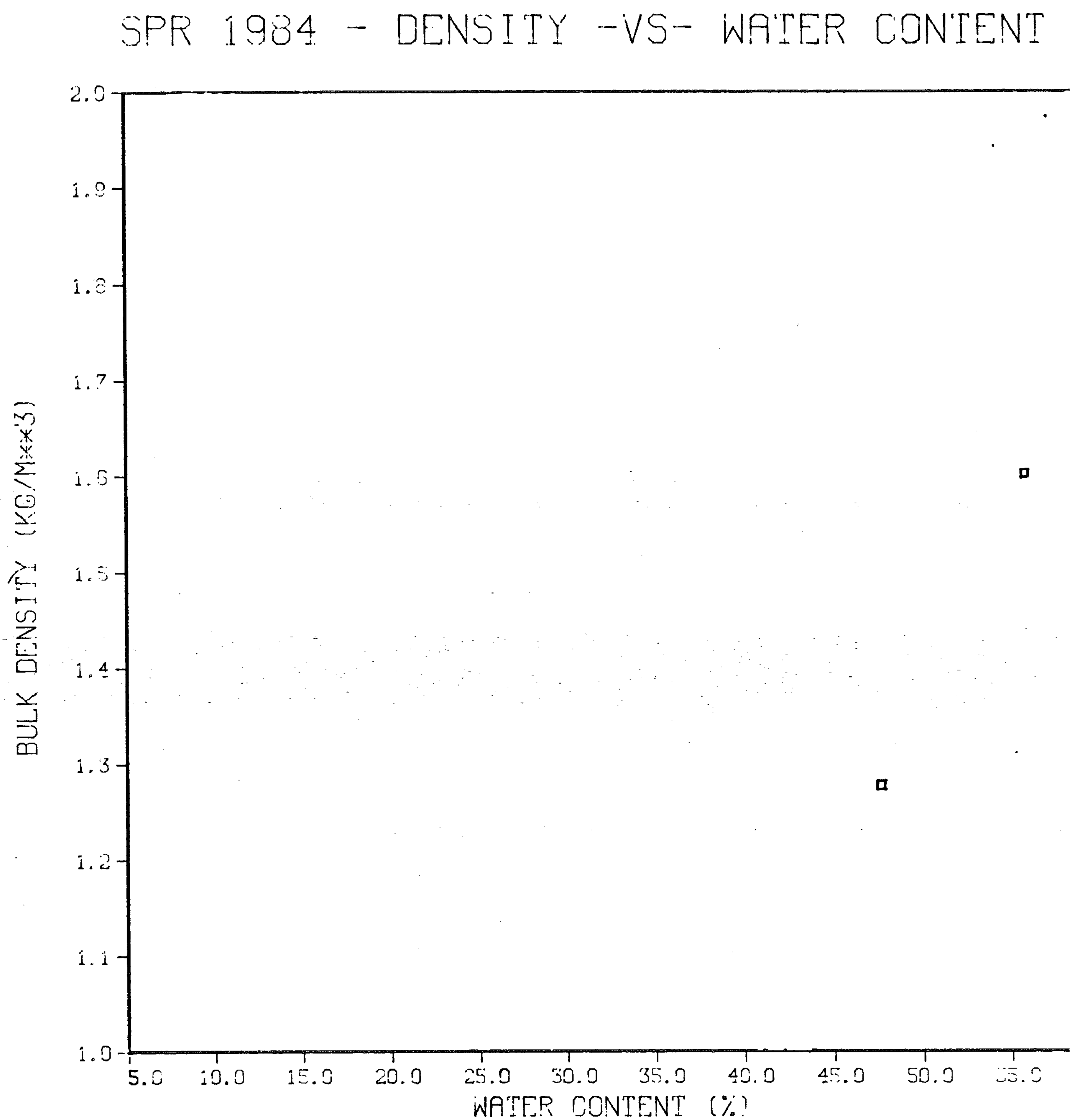
FACIES 3 — FIGURE 4



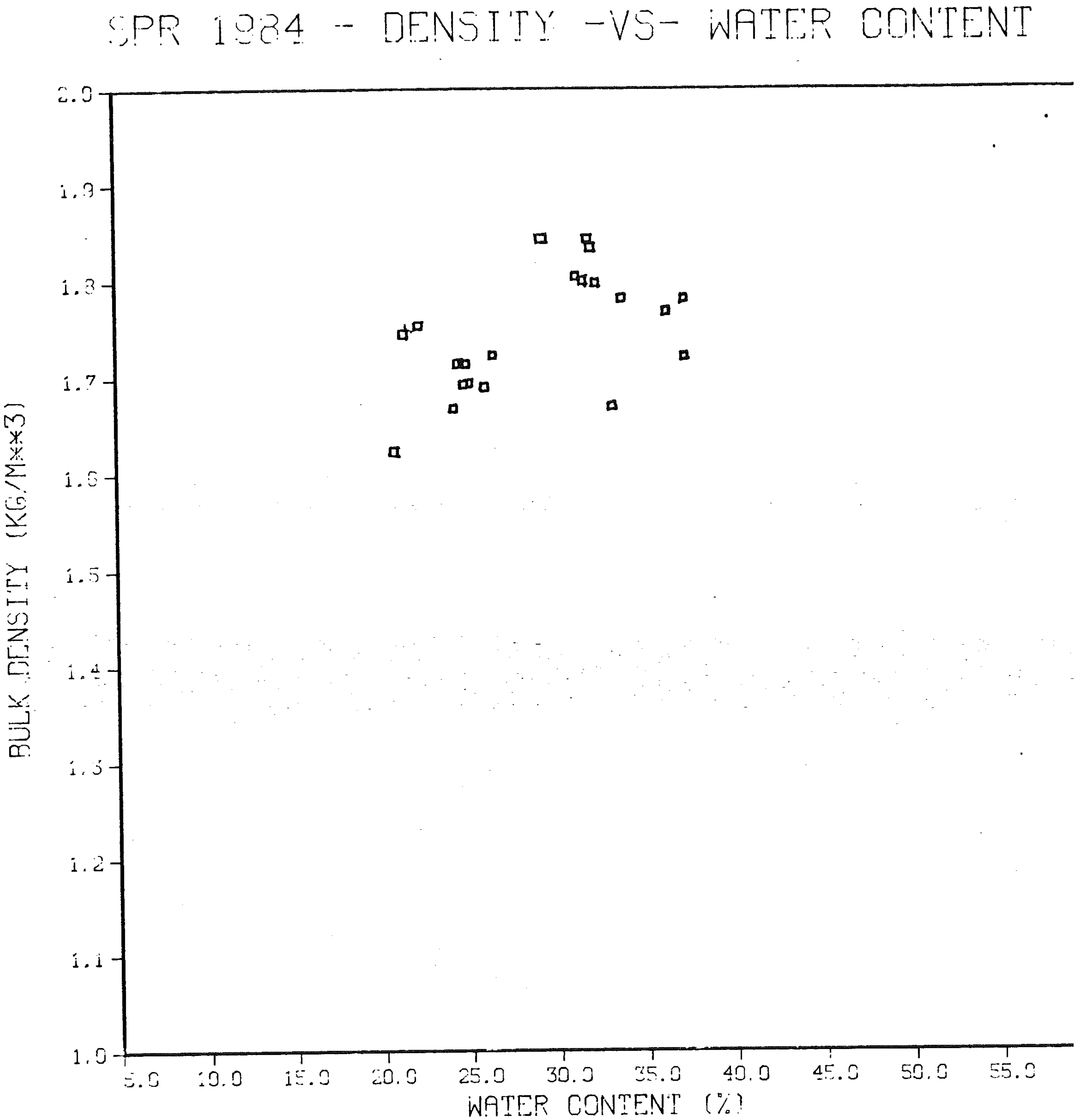
FACIES 4 — FIGURE 5

APPENDIX I

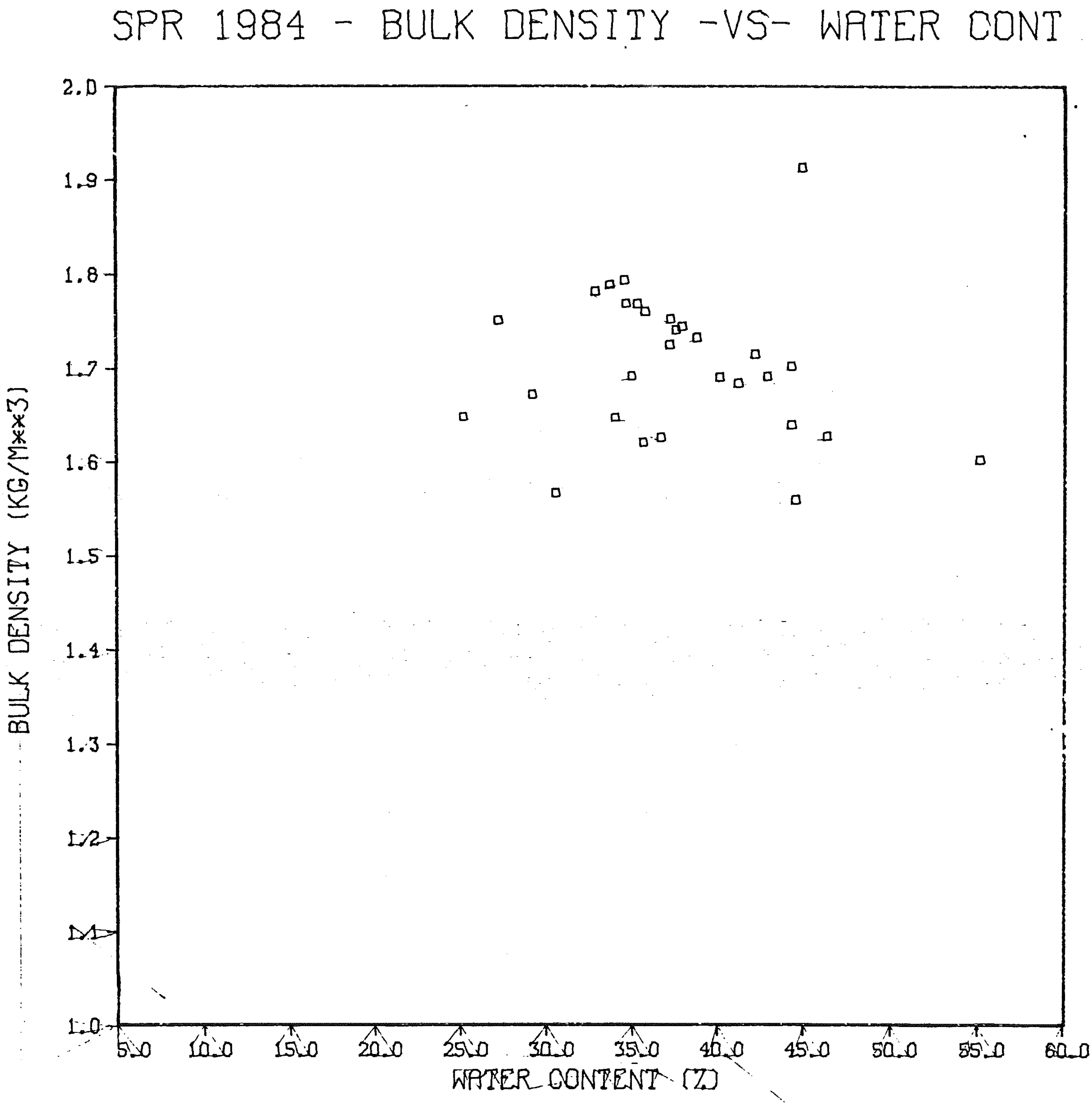
DENSITY VERSUS WATER CONTENT



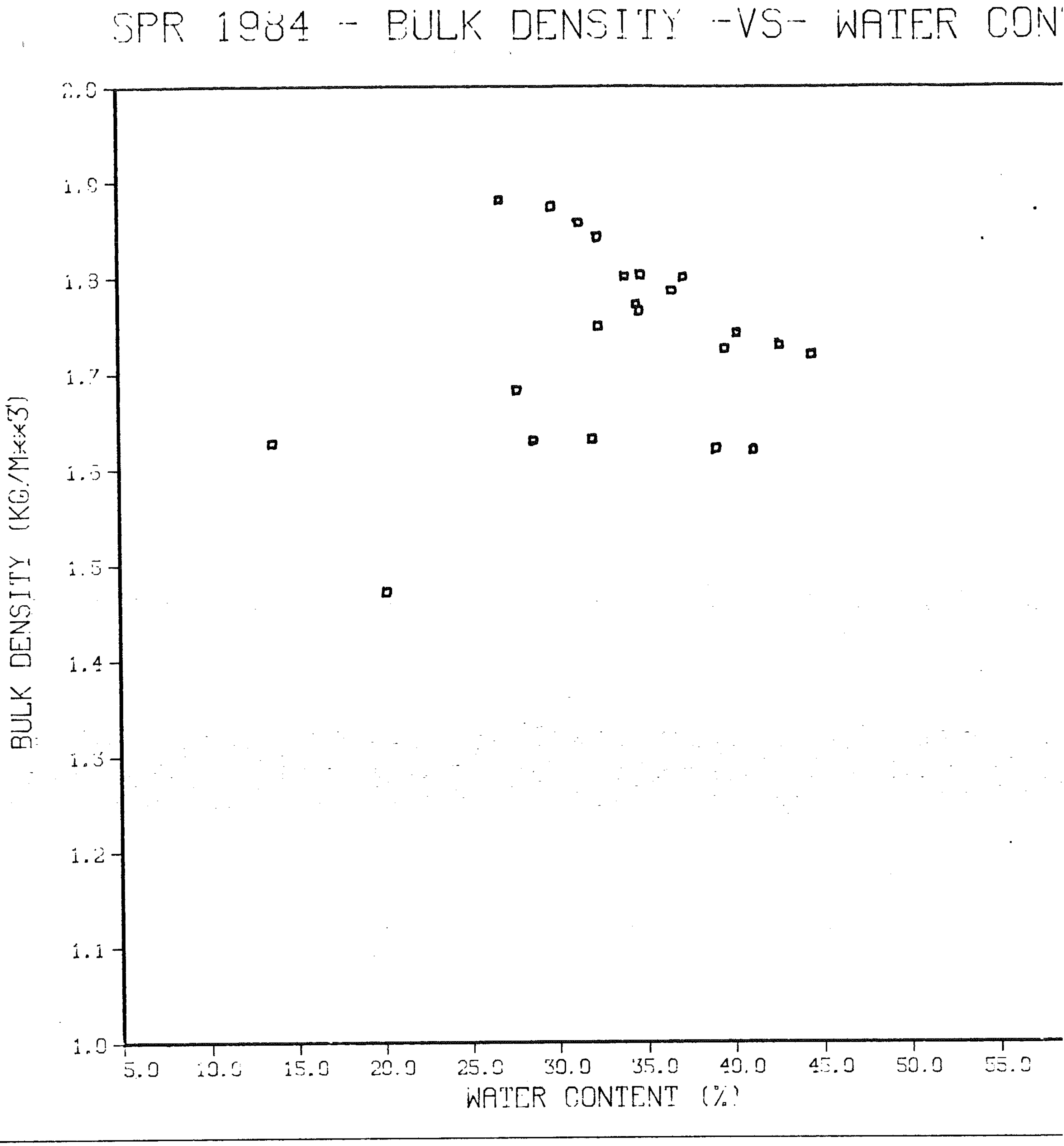
FACIES 1A- FIGURE 1



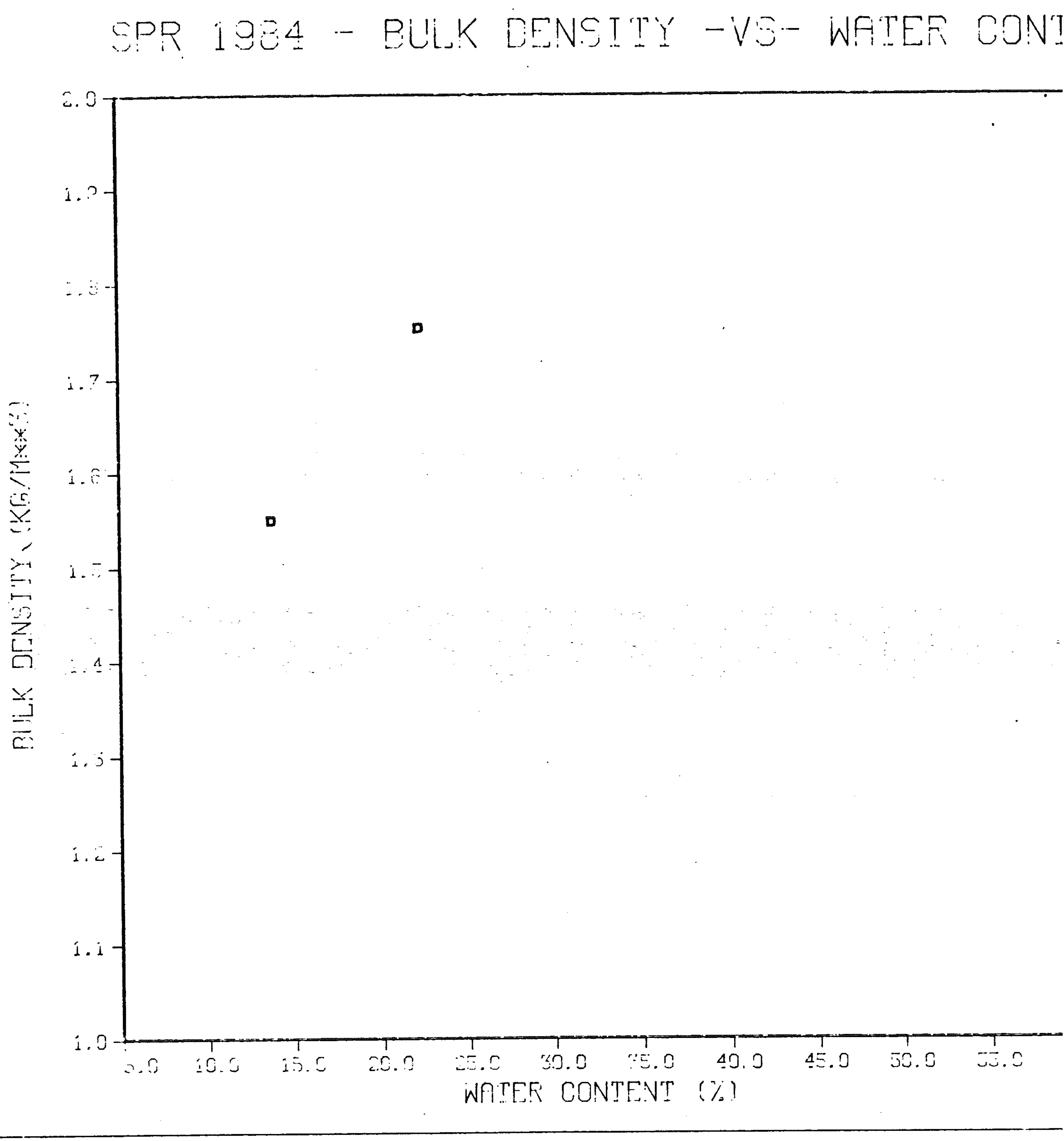
FACIES 1B — FIGURE 2



FACIES 2 — FIGURE 3



FACIES 3 – FIGURE 4



FACIES 4 — FIGURE 5

APPENDIX J

OEDOMETER DATA

PARAMETER		BOREHOLE NO.		
		BH 20+00	BH 20+00	BH 20+00
WATER DEPTH	H (m)	9	9	9
DEPTH BSB.	Z (m)	4.85	10.95	13.74
VOID RATIO	e_o	0.955	0.877	1.365
WATER CONTENT	w_N (%)	37.6	31.3	50.2
LIQUID LIMIT	w_L (%)	38.0	36.3	54.1
PLASTIC LIMIT	w_P (%)	20.8	23.1	30.0
PLASTICITY INDEX	PI (%)	17.2	13.2	24.1
LIQUIDITY INDEX	LI (%)	0.98	0.62	0.38
UNIT WEIGHT	γ (kN/m^3)	19.60	19.65	17.32
SPECIFIC GRAVITY	G_s	2.73	2.75	2.72
SAND FRACTION	%	0	2	0
SILT FRACTION	%	85	64	89
CLAY FRACTION	%	15	34	11
EFF. OVERBURDEN PRESSURE	P'_o (Kpa)	46.1	104.7	99.3
PRECONSOLIDATION PRESSURE	P_c (Kpa)	90.0	123.0	108.0
OVERCONSOLIDATION RATIO	OCR	1.94	1.17	1.09

FIGURE 1 – OEDOMETER DATA FOR BH 20+00

CHRISTIAN 1985