GEOLOGICAL SURVEY OF CANADA

OPEN FILE 4635

Digital Summary Database of Permafrost and Thermal Conditions – Norman Wells Pipeline Study Sites

S.L Smith, M.M. Burgess, D. Riseborough, T. Coultish, and J. Chartrand

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ABSTRACT

The Norman Wells to Zama pipeline, located in northwestern Canada, is the first buried oil pipeline in the permafrost zone in Canada. During its construction in 1984-1985, the Canadian government and Enbridge pipelines collaborated in the establishment of a permafrost thermal monitoring program consisting of more than 20 long-term monitoring sites. This monitoring program was designed to investigate the impact of the pipeline construction and operation on permafrost and terrain conditions. Thermistor cables were installed both on and off the pipeline right-of-way to measure temperatures to depths of 20 metres. This report provides a summary ground temperature database from 1985-2001 for the Norman Wells pipeline corridor monitoring sites in digital relational database format. Maximum seasonal thaw depth for each year, interpolated from temperature profiles, is also provided. The ground surface settlement over time has been determined from field measurements and is presented in graphical format for each monitoring site.

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1. INTRODUCTION

The Norman Wells to Zama pipeline is the first completely buried oil pipeline in permafrost terrain in North America. This small diameter (328 mm) ambient temperature pipeline began operation in 1985 and is owned and operated by Enbridge Pipeline (NW) Inc. (formerly Interprovincial Pipeline Ltd.). The 869 km pipeline route crosses the discontinuous permafrost zone and unconsolidated Quaternary deposits of the Mackenzie valley and Alberta Plateau (Fig. 1).

Since construction, in 1984-1985, the Canadian Government and Enbridge have collaborated to monitor the ground thermal regime along the pipeline route. This monitoring project contributed to a larger Permafrost and Terrain Research Monitoring Program established to improve impact evaluation and mitigation on the Norman Wells and future northern pipelines. Further information on the monitoring program can be found in MacInnes et al. (1989 and 1990). As part of this collaborative project, the Geological Survey of Canada (GSC) has maintained a network of permafrost thermal monitoring sites along the Norman Wells pipeline corridor since 1984. A total of 23 thermal fences (or instrumented cross-sections) at 13 locations (Fig. 2 and Table 1) were established in 1984-1985 to measure ground temperature both on and off the pipeline right-of-way (ROW) to depths of up to 20 m. The thermal fences were designed to allow an investigation of the effect on the ground temperature of ROW clearing, pipeline trenching, installation and operation, as well as a comparison of the thermal regime of the ROW and the surrounding terrain. All temperature data collected were compiled into digital databases. Data for the first five years of the monitoring program were published in tabular format as GSC open file reports (Burgess, 1986a, 1986b; Burgess and Naufal, 1989, 1990 and 1991).

Information on baseline ground thermal and permafrost conditions is required for design of northern infrastructure such as pipelines, buildings and roads and also for environmental assessment and regulatory purposes (Smith et al., 2001). In addition, information on the impact of existing development projects, such as the Norman Wells pipeline, on the surrounding terrain will facilitate these processes and support future project design. This report thus provides summary thermal data collected at the thermal fence monitoring sites to all stakeholders, eg. engineers, landuse planners and regulators.

A summary of the ground temperature database for the Norman Wells pipeline corridor thermal fences from 1984 to 2001 has been compiled in digital relational database format. Site descriptions for each thermal fence are also included in the database. Geotechnical logs for each borehole are presented graphically in a separate appendix, as are plots of the maximum seasonal thaw depth (interpolated from temperature profiles) and the surface settlement over time.

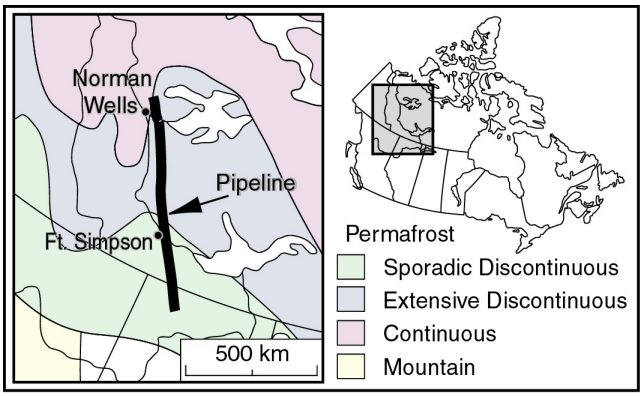

Figure 1. Location of Norman Wells pipeline and permafrost zones in the region

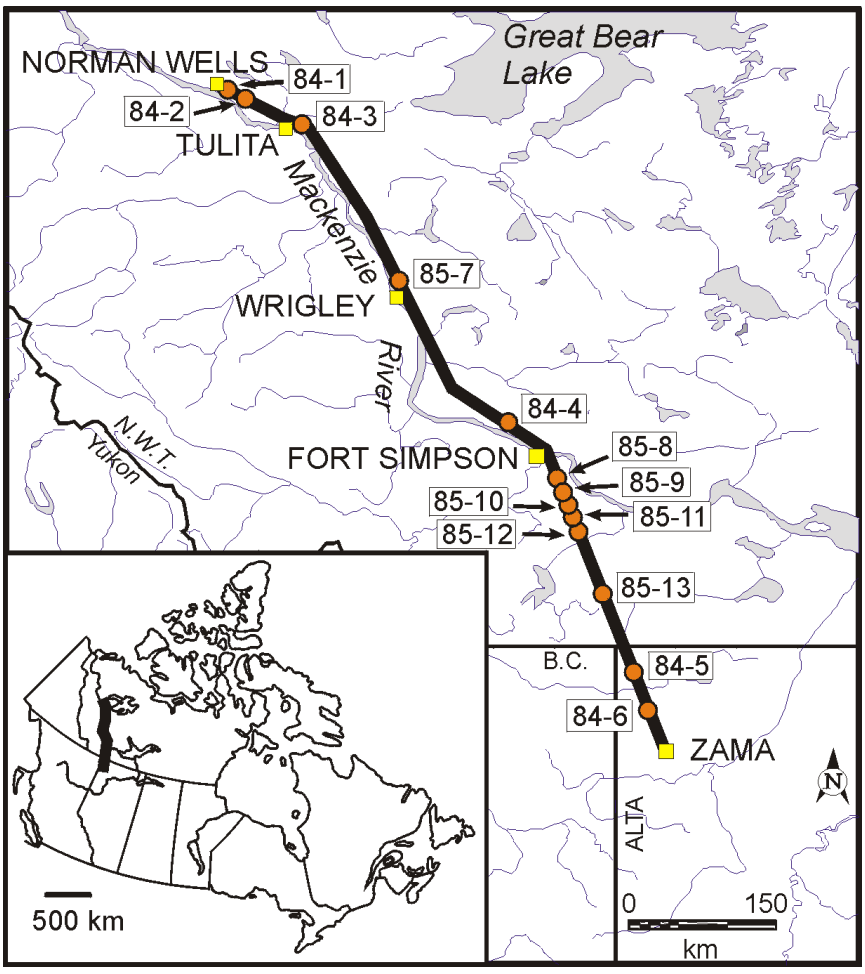

Figure 2. Location of thermal fences along the Norman Wells Pipeline route.

Table 1. Norman Wells Pipeline monitoring site descriptions

SITE NO.	NAME	KM POST	DESCRIPTION (at time of establishment)
84-1	**Pump Station 1**		**Widespread permafrost**
		0.02	Ice-rich silty clay
84-2	**Canyon Creek**		**Previously cleared alignment, thaw sensitive slopes, widespread permafrost**
	A	19.0	Level location, frozen till with low ice content
	B	19.3	East-facing slope in widespread permafrost with 1 m insulating wood chip cover on ROW
	C	19.6	Uninsulated section of west-facing slope in widespread permafrost
84-3	**Great Bear River**		**Thaw sensitive terrain (joint with Enbridge slopes)**
	A	79.2	Stratigraphically complex ice-rich alluvial terrace deposits in widespread permafrost; cliff-base
	B	79.4	Cliff-top lacustrine deposits with veneer of aeolian deposits
85-7	**Table Mountain**		**Thaw sensitive terrain (joint with Enbridge slopes)**
	A	271.2	Ice-rich lacustrine plain (old seismic line)
	B	272.0	Drillpad clearing at bend on top of north facing slope, ice-rich lacustrine plain
	C	272.3	New clearing on ice-rich lacustrine plain
84-4	**Trail River**		**Pipeline previously traversed frozen ground**
	A	478.0	Unfrozen saturated sands and silts in dune hollow
	B	478.1	Dry sands and silts in dune crest
85-8	**Manner's Creek**		**Rapidly changing permafrost conditions**
	A	557.8	Thin peat with thick (10 m) permafrost
	B	558.2	Thick (2.7 m) peat with thin (4 m) permafrost
	C	558.3	Thin peat (1 m) with thin (1 m) permafrost
85-9	**Pump Station 3**		**Pipe previously traversed frozen section**
		588.3	Unfrozen granular soils
85-10	**Mackenzie Hwy. S.**		**Unfrozen/frozen interface**
	A	588.3	Helipad clearing in unfrozen terrain
	B	588.7	Thin (3 m) permafrost with 2 m peat cover
85-11	**Moraine South**	597.4	Thin (<4 m) permafrost in helipad clearing
85-12	**Jean Marie Creek**		**Unfrozen/frozen interface**
	A	608.6	Thin unfrozen peat
	B	608.7	Thick ice-rich peat plateau; 4 m permafrost
85-13	**Redknife Hills**		**Frozen/unfrozen interface; single cables only**
	A	682.2	Frozen (6 m) terrain surrounding large fen
	B	682.4	Frozen (6 m) terrain at fen border
	C	682.6	Unfrozen terrain in fen
84-5	**Petitot River N.**		**Degrading peat plateau**
	A	783.0	Ice-rich peat (3.5 m); 15-18 m permafrost
	B	783.3	Very thick icy peat (7 m); 12 m permafrost
84-6	**Petitot River S.**		**Peat plateau preceded by unfrozen fen**
		819.5	Thick (5 m) ice-rich peat; 7 m permafrost

2. BACKGROUND

2.1 Project Setting

The Norman Wells pipeline traverses three major physiographic regions, the Mackenzie Plain, the Great Slave Plain, and the Alberta Plateau (Fig. 3). Over most of the pipeline route, the terrain is fairly level as no mountain barriers are crossed. In the north, the steepest slopes are encountered at the crossings of deeply incised streams. The highest elevation along the route occurs in the Redknife Hills about midway between Fort Simpson and the Zama pipeline terminus.

Over the northern half of the pipeline route, lacustrine soils and tills are dominant while in the south, tills and organic terrain predominate (Fig. 4). The fine-grained lacustrine soils and frozen organic soils (peat plateaus) are often ice-rich and thaw sensitive. In the northern section, frozen ground underlies more than 65% of the corridor (Fig. 5) and undisturbed permafrost temperatures range from –2.5°C to –1°C. Permafrost temperatures are warmer than –1°C in the south where frozen ground underlies 15-35% of the route.

The pipe was buried with an initial average depth of cover of about 1metre. Oil entering the line is chilled at Norman Wells with no subsequent chilling along the route. From the start of operation in 1985 through to 1993, the oil was chilled to a constant temperature and entered the line at –1°C throughout the year. A seasonal chilling cycle was introduced in 1993 with oil entering the line at a temperature ranging from –4°C in winter to +9°C in summer for an average annual temperature between 0 and –1°C.

Numerous papers and reports have been published on the project setting, design, geothermal and terrain response, on geotechnical performance and pipe-soil interaction (see for example, Burgess and Lawrence, 1997; Nixon and Burgess, 1999; Burgess and Smith, 2003). MacInnes et al. (1989, 1990) provides further information on the project setting and a monograph on the geotechnical performance (AGRA & Nixon Geotech 1999) provides a bibliography of key publications up to 1998.

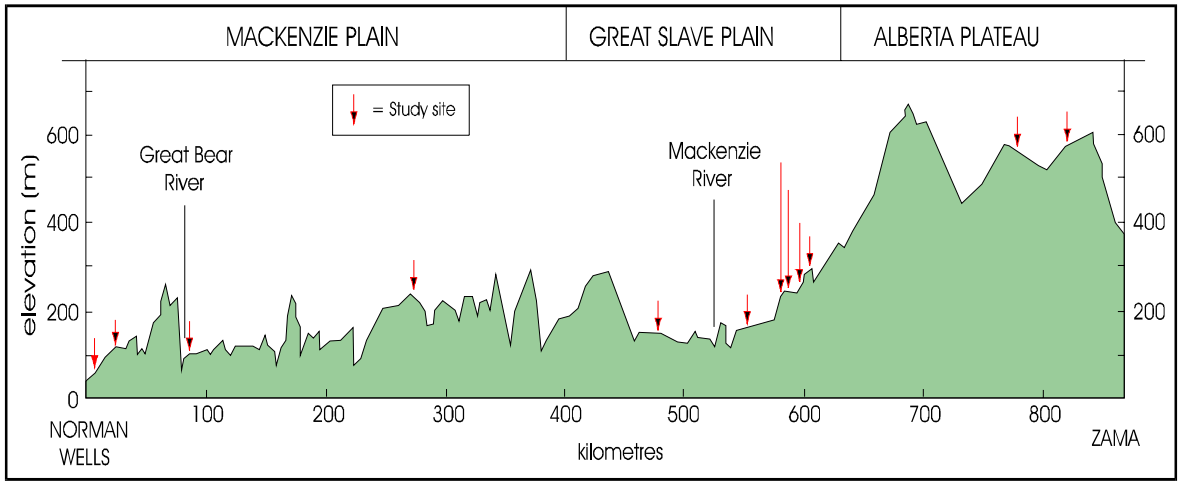

Figure 3. Physiographic zones and topography along the Norman Wells pipeline route (from Burgess and Lawrence, 2000).

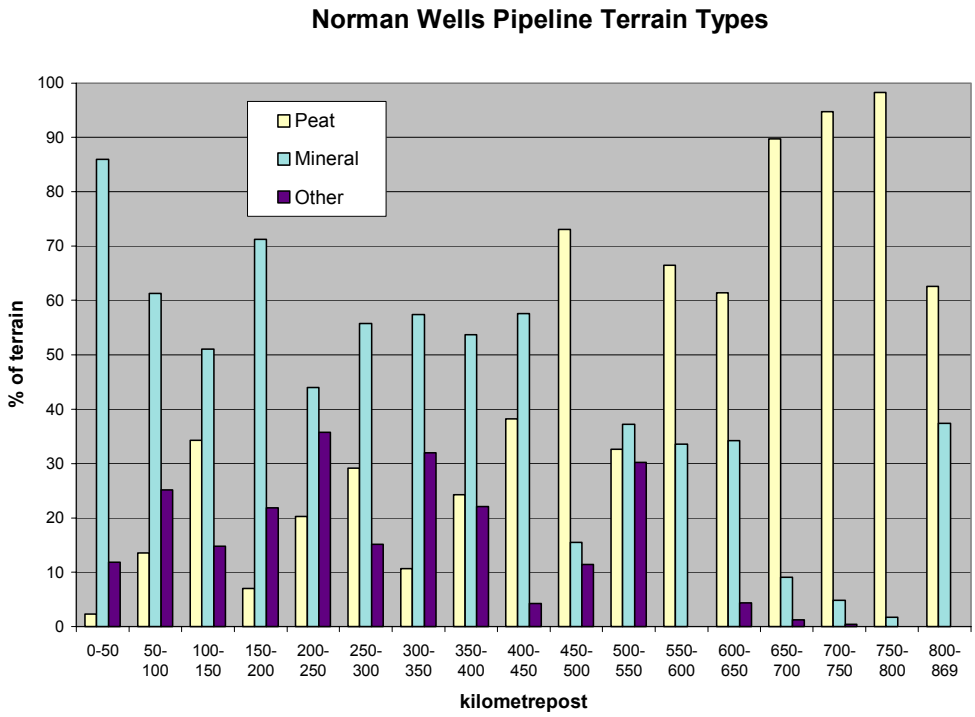

Figure 4. Terrain types along the Norman Wells pipeline route (Burgess and Lawrence, 2000).

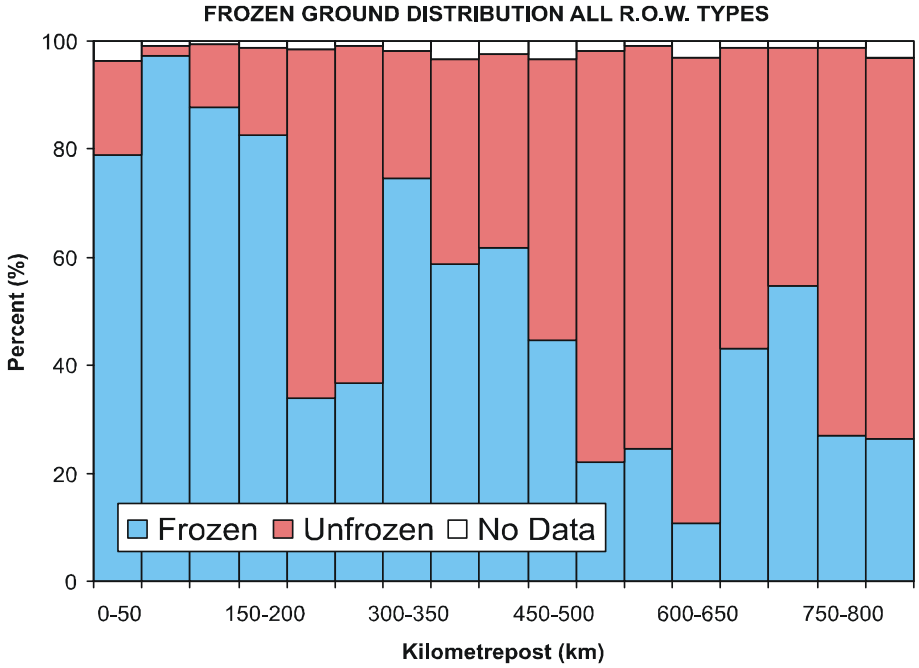

Figure 5. Distribution of frozen ground along the Norman Wells pipeline route (Burgess and Lawrence, 2000).

2.2 Thermal Data Collection

At construction, 1 to 3 study sites (thermal fences) were established at each of thirteen locations selected to provide a representation of soil, permafrost and ground ice conditions along the pipeline route. The location of each site is provided in figure 2 and Table 1 gives a brief site description. The borehole logs in Appendix 2 provide more information on the soil and ground ice conditions at each thermal fence.

Initially, each thermal fence (instrumented cross-section) generally initially consisted of 4 ground temperature cables: two 5 m cables close to the pipe, one 20 m cable on the pipeline right-of way (ROW) located 4 to 10 m from the pipe, and a 20 m cable off the ROW. All cables were placed in PVC casing installed in the boreholes and filled with silicone oil. The accuracy of the temperature sensors is ± 0.1 K, while the measurement system allows for a resolution of ±0.01 K. Five temperature sensors were also strapped to the external wall of the pipe. Details on the site establishment and initial instrumentation are provided in Pilon et al. (1989). The accompanying database (see section 3) provides detailed site description and information on instrumentation.

Initial manual data collection occurred at monthly to bi-monthly intervals decreasing to 1 to 3 times annually in later years. In the mid 1990s, a number of temperature cables were connected to data loggers to provide high frequency measurements. In the late 1990s, monitoring of some selected sites or cables was discontinued. Since 1996, at least one complete site visit has occurred each fall, close to the time of maximum active layer development, to collect data from cables that continue to operate and to service data loggers.

3. DATABASE STRUCTURE

All site description information and ground temperature data have been compiled into a digital relational database (NWsumthermdb.mdb) that is provided in MS Access format. The database consists of a series of tables as described below.

3.1 Site and Instrumentation Description

This portion of the database comprises eleven tables that include information concerning the site characteristics of the thermal fences along the Norman Wells Pipeline. Much of this information has been extracted from Pilon et al. (1989), and MacInnes et al. (1989 and 1990). The field name, "SiteID", is the primary key that links each table to one another. Below is a description of each table and their associated fields. Where data are not available or applicable for a certain field, the cell has been left blank. The first letter of a word in brackets, e.g. (N)orth, indicates that the first letter is the code used for that word.

Location
This table provides information on the location for each thermal fence

SiteID - Unique identifier for each thermal fence site, e.g. 84-2A. This acts as the primary key.

PlaceName - Local name given to the thermal fence.

KP – Kilometer Post (distance from start of pipeline in Norman Wells)

Lat - Latitude given in decimal degrees (°N)

Long - Longitude given in decimal degrees (°W)

Elevation - Elevation in metres above sea level

UTMzone - The Universal Transverse Mercator zone the site is located within.

Easting - The UTM easting coordinate for the site

Northing - The UTM northing coordinate for the site

Slope - A verbal description is given concerning the slope of the site

Aspect - The aspect of the slope given in the eight major cardinal directions; (N)orth, (S)outh, (E)ast, (W)est, NE, NW, SE, and SW.

SiteDescription
A general description of the site is provided in this table.

SiteID - The unique identifier for each thermal fence.

Origin (Genetic Origin) - This refers to the genetic description of the surficial geology. See Table 2 for code descriptions.

Landform (Landform Type) - The surface morphology as it relates to the genetic origin of the site. See Table 2 for code descriptions.

Texture (Overburden Texture) - Describes the dominant grain-size textures of the surficial material at the site. See Table 2 for code descriptions.

IceCondition (Basic Ice Content) - The basic ice content or ground ice conditions for the sites are as follows: ir = ice rich; ip = low or ice poor; uf = unfrozen, sat = saturated; unsat = unsaturated; t=thermokarst or a combination of any two connected with a dash.

GroundCover - The basic type of vegetation found at ground level at the site (Note: exact species are not identified). These include: m = moss; l = lichen; lf = leaf litter; s = sedge; g = grass; h = herbaceous plants; v = vascular plants; w = typical wetland plants

PctGroundCover – A visual approximation of the percent coverage of ground vegetation, represented by either a percent value or (i)ncomplete, (p)artial, or 100% for complete coverage.

ShrubType (Shrub cover vegetation) - A basic description of the shrub-type vegetation at the site. The shrubs are classified as (e)ricaceous shrubs, (t) for shrub tundra and low shrub tundra, and (s) for unspecified shrub cover. Where shrub or dwarf tree species are identified, the species code will be presented in lowercase, (see tree species list in field below).

DominantTrees (Dominant tree species) - The codes for the dominant tree species at the site as follows:

BS = black spruce	BC = birch
WS = white spruce	WL = willow
AD = alder	MS = mixed / misc. spruce
TM = tamarack	MP = mixed / misc. pine
JP = jack pine	HW = misc. hardwood
AS = aspen	M = mixed trees

CanopyDensity- A visual approximation of the canopy density.

0 = open
1 = low
2 = low to moderate
3 = moderate
4 = moderate to high
5 = high or closed

DescriptiveModifiers **-** Additional information about the site: (h)ummocky; (f)en; (w)etland; (r)iparian; and (p)olygons.

Thermal
This table provides information on the availability of climate and ground temperature data for the site.

SiteID **-** The unique identifier for each thermal fence.

MetStnCode **-** The nearest Environment Canada Meteorological Station that has at least a 30 year record of temperature data. These meteorological stations were found using Environment Canada's Canadian Climate Normals search engine. Note: this field links to the MetStations table.

MetStnDist **–** The approximate distance between the monitoring site and the nearest Environment Canada Meteorological Station.

CliStnCode – The nearest Environment Canada Climate Station. Note: this field links to the ClimStations table.

CliStnDist – The approximate distance between the monitoring site and the nearest Environment Canada Climate Station.

AirOnSite **–** Is air temperature measured at the site, (Y)es or (N)o?

SnowDepthOnSite **-** The years of available snow depth records for the site are listed.

NstOnSite **–** Is the near surface ground temperature measured at the site, (Y)es or (N)o?

GrCableOnSite **–** Is ground temperature at depth measured at the site, (Y)es or (N)o?

PipeTempOnSite **–** Is pipe temperature available for the site, (Y)es or (N)o?

ThawTubeOnSite – Is there a thaw tube for measuring maximum summer thaw penetration at the site (Y)es or (N)o?

MetStations
This table provides information on the location of the Environment Canada Meteorological Stations referred to in the Thermal table

MetStnCode – The meteorological station code

StnName – The name of the meteorological station

StnLat – The latitude of the meteorological station (°N)

StnLong – The longitude of the meteorological station (°W)

StnElev – The elevation of the meteorological station in metres above sea level

ClimStations
This table provides information on location of the Environment Canada Climate Stations referred to in the Thermal table.

ClimStnCode – The climate station code

StnName – The name of the climate station

StnLat - The latitude of the climate station (°N)

StnLong – The longitude of the climate station (°W)

StnElev – The elevation of the climate station in metres above sea level

Normals
Air temperature and snow depth data based on 1971-2000 Environment Canada Climate Normals are provided in this table.

ClimStnCode – The station code for the climate station.

JanTDD, FebTDD, etc. – The thawing degree days for each month.

YearTDD – The annual total thawing degree days.

JanFDD, FebFDD,etc. – The freezing degree days for each month.

YearFDD – The annual total freezing degree days.

JanSnowDepth, FebSnowDepth, etc. – The snow on the ground (cm) at the end of each month.

YearSnowDepth – Average annual snow depth (cm) based on the month end snow depths.

JanTemp, FebTemp, etc. – The mean air temperature for each month (°C).

YearTemp – Mean annual air temperature (°C)

Geotech
The type of geotechnical information available for each site and individual boreholes is summarized in this table. Borehole logs constructed for each borehole are provided in Appendix 1. In the fields described below a "Y" indicates that the information is available and a "N" indicates no information is available.

Borehole – The unique identifier for individual boreholes, e.g. 84-2C-T3.

SiteID **-** The unique identifier for each thermal fence site.

Grain Size - Refers to information on the grain size distribution.

Atterberg Limits - Includes liquid and plastic limits.

Moisture Content - Gravimetric moisture content data.

Density - Includes information on any of: dry density, natural density, frozen density, specific gravity.

Other Geotechnical - Includes information related to Proctor-Compaction (maximum density and optimum moisture content) or Standard Penetration tests.

Permafrost Info - Includes any of: ground ice description, ice content, excess moisture content.

Soil Type - Includes a description of soil material, lithology and/or USC code.

InitialConditions
This table provides information on the initial permafrost and active layer conditions at each site.

SiteID **-** The unique identifier for each thermal fence site.

InitialPF (Initial permafrost conditions) **–** Indicates whether the ground before construction was frozen or unfrozen where PF = permafrost and UF = unfrozen

PFThickness (Permafrost thickness) **-** The thickness of permafrost in metres, determined either by interpolation or extrapolation of the ground temperature profile.

ALonROW (Active Layer thickness on ROW) **-** At those sites with permafrost, the thickness of the active layer (AL) (i.e. depth to the frost table) on the right-of-way (ROW) is given in metres.

ALoffROW (Active Layer thickness off ROW) **-** At those sites with permafrost, the active layer thickness off the ROW is given in metres.

FrostonROW (Frost penetration on ROW) - At sites without permafrost, the maximum depth the freezing front penetrated the ground (i.e. the maximum thickness of the seasonally frozen layer) on the ROW is provided in metres.

FrostoffROW (Frost penetration off ROW) - At sites without permafrost, the maximum depth of the freezing front off the ROW is given in metres.

Site History
Information related to clearing and construction at each site is provided in this table.

SiteID - The unique identifier for each thermal fence site.

PriorClearing - Was the location of the thermal fence site previously cleared for another purpose, (Y)es or (N)o?

ClearingPurpose - The purpose of prior clearing is either (C)NT (Canadian National Telecommunications), (H)elipad, or (S)eismic and the year it was cleared is noted as well.

ClearingDate – The year that the site was previously cleared.

PipelineDate - The year the site was cleared for the installation of the pipeline.

ClearingWidth - The total width of clearing in metres. A "+" sign indicates that the measurement might be a little greater than what was measured.

TravelSide - The side of the pipeline used as the travel side (or work side) is given as (E)ast or (W)est, relative to pipeline north.

TravelWidth - The width of the travel side (or work side) in metres.

SpoilSide - The side of the pipeline used as the spoil side is given as E or W.

SpoilWidth - The width of the spoil side in metres.

CoverDepth - This refers to the depth of cover material over the pipeline in metres. It is essentially the depth of the top of the pipe from the ground surface.

PipeinAL - This refers to whether or not the pipeline when installed was within the active layer: (Y)es; (P)artly; or n/a as not in an area with permafrost.

DitchSoil (ditch soil type) - The general grain-size or type of material used to fill the ditch with: (c)lay; (m)silt; (s)and; (g)ravel; (t)ill; (p)eat; or (i)ce. Note: it can be a combination of any two of these soil types where s/g = sand and gravel, and sg = sandy gravel.

Backfill (ditch material) **-** This refers to where the material used to fill the ditch came from, either nt = native, sl = select, or rm = remedial backfill occurring in 1986 and in brackets what type of backfill (from ditch soil type field), e.g. rm(m) is a remedial backfill of silt.

Restoration **-** The restoration and revegetation efforts on the sites at the time of site establishment were only partially recorded. For the sites that did have some restoration noted, it occurred in March 1984. They can be either f&s = fertilized and seeded, ecb = erosion control berms, or nr = not restored.

Instrumentation (On site Instrumentation)
The instrumentation installed at each site is provided by this table.

SiteID - The unique identifier for each thermal fence site.

NGroundCables **–** The number of Multi-thermistor cables for measuring ground temperature installed at each site.

DitchT (Ditch thermistor) **–** The number of thermistors installed in the ditch.

PipeTemp **–** The number of pipe thermistor strings at each site.

PipeTLocation (Location of pipe thermistor string) **-** The distance in metres away from the thermal fence along the pipeline and the direction, i.e. (N)orth or (S)outh (relative to pipeline north).

Cables (Cable Sensor Depths and Data Collection)
Information on the location of temperature cables, sensor positions for each cable and the period of data collection is provided in this table.

CableID **-** The unique identifier for the cables (individual boreholes), e.g. 84-2C-T3.

SiteID **-** The unique identifier for each thermal fence site.

FromPipe (Distance from Pipe) **-** The distance of the borehole from the pipeline in metres.

PipeSide – The side of the pipe where the borehole is located (E or W).

OnROW – This indicates whether the borehole is located on the ROW, either (Y)es or (N)o.

nSensors – The number of sensors on the temperature cable.

depth1, depth2 etc. – These fields give the nominal depth below the ground surface for each sensor (i.e. the depth of the sensor at installation).

ManualStart **-** The date (dd/mmm/yyyy) that manual temperature measurements started.

ManualEnd **-** The date (dd/mmm/yyyy) that manual temperature measurements ended.

LoggerStart – The beginning of the period for which data loggers were used for data collection (dd/mmm/yyyy)

LoggerEnd – The end of the period for which data loggers were used for data collection (dd/mmm/yyyy)

Table 2. Genetic Origin and Landform Type modified from the Terrain type classification system (MacInnes et al. 1989). The features in italics have been added to the original list.

O – Organic Landforms

b	patterned bogs lands, peat plateaus and palsas
f	ribbed (string), reticulated and horizontal fen lands
u	undifferentiated and transitional bog-fen complexes
v	organic veneer

A – Alluvial (*Fluvial*) Landforms

b	*bar*
c	channel, wholly or partly water covered
d	delta
f	fan
p	flood plain (may or may not be inundated)
t	terrace (not flooded)
v	alluvial veneer

C – Colluvial Landforms

a	apron
f	flow side (mudflow and debris flow)
m	slopewash and rill sheet wash
s	slide
t	talus slope
v	slopewash veneer

E – Eolian Landforms

b	sand and loess blanket
d	dunes
v	eolian veneer

G – Glaciofluvial Landforms

d	delta
e	esker, esker complex
k	kame, kame complex, kame terrace
p	outwash plain
r	*ridge*
t	terrace
v	glaciofluvial veneer

L – Lacustrine and Glaciolacustrine Landforms

b	post glacial basin
d	deltaic plain
p	nearshore and offshore lake plain
r	raised beach ridge
v	glaciolacustrine veneer

M – Moraine

a	ablation moraine
c	crevasse filling
d	drumlin, drumlinoid moraine
e	end moraine
g	ground moraine
h	hummocky moraine
p	*plain*
r	ridged
v	moraine veneer

R – Bedrock (undifferentiated)

S – Coastal

c	*cliff, bluff*
d	*delta*
p	*plain*
t	*terrace*

Overburden Texture

b	boulders and/or angular blocks
c	clay, clay and silt and/or sand
g	gravel, including sandy and cobbly mixtures
m	silt, including minor clay and/or sand mixtures
o	organic component
p	peat
s	sand
t	till

Note: the "Modifiers" in the MacInnes et al. 1989 version were not needed in this database for landform classification. A "descriptive modifiers" field has been created in its place which includes hummocky terrain, fen, wetland (unspecified), riparian, and polygons.

3.2 Ground Temperature Database Component

This portion of the database provides the annual maximum, minimum and mean ground temperature determined for each sensor position over the period of record. These values are calculated from monthly mean temperatures that were either determined from the monthly manual observations collected early in the monitoring program or from data collected by data loggers. The data provided may be used to construct the annual ground temperature envelopes. Later in the monitoring period, when the frequency of manual measurements declined, insufficient data were available at a number of manual sites for calculating maximum, minimum and mean annual temperature. Thus the fall (usually September) temperature profile is also provided in the database. The tables included in this component of the database are as follows:

Envelopes
This table provides ground temperature data that can be used to define annual ground temperature envelopes.

CableID - The unique identifier for the cables (individual boreholes), e.g. 84-2C-T3.

Year - The period for which the temperature statistics are calculated

Depth - Nominal depth (m) of the measurement

MAGT - Mean annual ground temperature (°C)

MaxT - Maximum annual ground temperature (°C)

MinT - Minimum annual ground temperature (°C)

Quality - This refers to the number of measurements per year on which the temperature statistics are based where:
A = 6 or more measurements per year
B = 2 to 5 measurements per year (note only annual maximum and minimum temperature are given when less than 6 measurements are available)

Septembers
This table includes a single ground temperature profile for each year. Most profiles are for late September, with some in early October. This temperature profile may be used to determine the depth of maximum thaw.

CableID - The unique identifier for the cables (individual boreholes), e.g. 84-2C-T3.

Date - The date (dd/mm/yyyy) on which the measurement was made.

Depth - Nominal depth (m) of the measurement.

SeptT - The fall temperature (°C)

4. THAW DEPTH AND THAW SETTLEMENT

Thaw depths at monitoring sites, based on the maximum annual depth of the 0°C isotherm, were determined by interpolation of the ground temperature profile between sensors. Where data are insufficient to determine the maximum annual ground temperature profile, the fall temperature profiles have been used to determine the thaw depth. The maximum thaw depth however, may not be captured in the fall temperature profile as the ground at depth may not have warmed to its maximum temperature, or in some cases, cooling and freeze-back at shallower depths had occurred at the time of measurement. A linear temperature gradient is assumed between sensors for the interpolation of ground temperatures. Graphs showing the maximum summer thaw penetration for each year throughout the monitoring period are presented in Appendix 2. The position of the sensor above and below the base of the active layer is also shown on the graphs.

Surface settlement related to thawing of ground ice may occur as seasonal thaw depth increases over time. Significant surface settlement occurs on the cleared right-of-way where ice-rich soils are present. Surface settlement at each borehole has been determined by measuring the height of the top of the PVC casing above the ground surface each fall (Burgess and Lawrence, 1997) and comparing to the reference height in 1986. The estimated accuracy of these measurements is ±10 cm. The change in position of the ground surface is shown on the graphs in Appendix 2. It should be noted that the position of the sensors given in the accompanying database are nominal depths and change in their position relative to the ground surface has not been accounted for in the database. The graphs provided in Appendix 2 may be used to determine the position of sensors relative to the ground surface and also to determine if sensors at shallow depths, remain below the ground surface throughout the monitoring period.

5. SUMMARY

A relational database compilation of site descriptions and summary ground temperature data for the Norman Wells pipeline corridor thermal fences from 1985 to 2001 has been provided. In addition, information on maximum summer thaw depth and surface settlement has also been presented. This data compilation provides both baseline information on permafrost conditions for representative conditions along the pipeline route and information on the change in permafrost conditions associated with pipeline construction and operation. The information provided meets the needs of a number of users such as those involved in planning northern development, infrastructure design including pipelines and also regulatory agencies.

6. ACKNOWLEDGEMENTS

Funding and support from this project has been received from: the federal departments of Natural Resources Canada and Indian and Northern Affairs Canada, federal programs of Panel on Energy Research and Development and Northern Oil and Gas Action Plan, and Enbridge Pipeline (NW) Inc. (formerly IPL). Assistance in the field, with database compilation or project management has been provided by numerous colleagues, notably K. MacInnes (DIAND, coordinator of the broader government Permafrost and Terrain Research and Monitoring Program, 1984-1996), J. Naufal, V. Allen, T. Lawrence and S. Robinson. The summary database development and format benefited from discussions with geothermal engineers for the Mackenzie Gas Project, notably Chris Heuer of Exxon Mobil/Imperial Oil Resources Venture Limited.

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APPENDIX 1

GEOTECHNICAL BOREHOLE LOGS

Based on information provided by:

Hardy Associates (1978) Ltd., 1984. 1984 EMR Instrumentation Program Norman Wells to Zama Pipeline. Report prepared for Energy Mines and Resources Canada, Ottawa.

Hardy Associates (1978) Ltd., 1985. 1985 EMR Instrumentation Program Norman Wells to Zama Pipeline. Report prepared for Energy Mines and Resources Canada, Ottawa.

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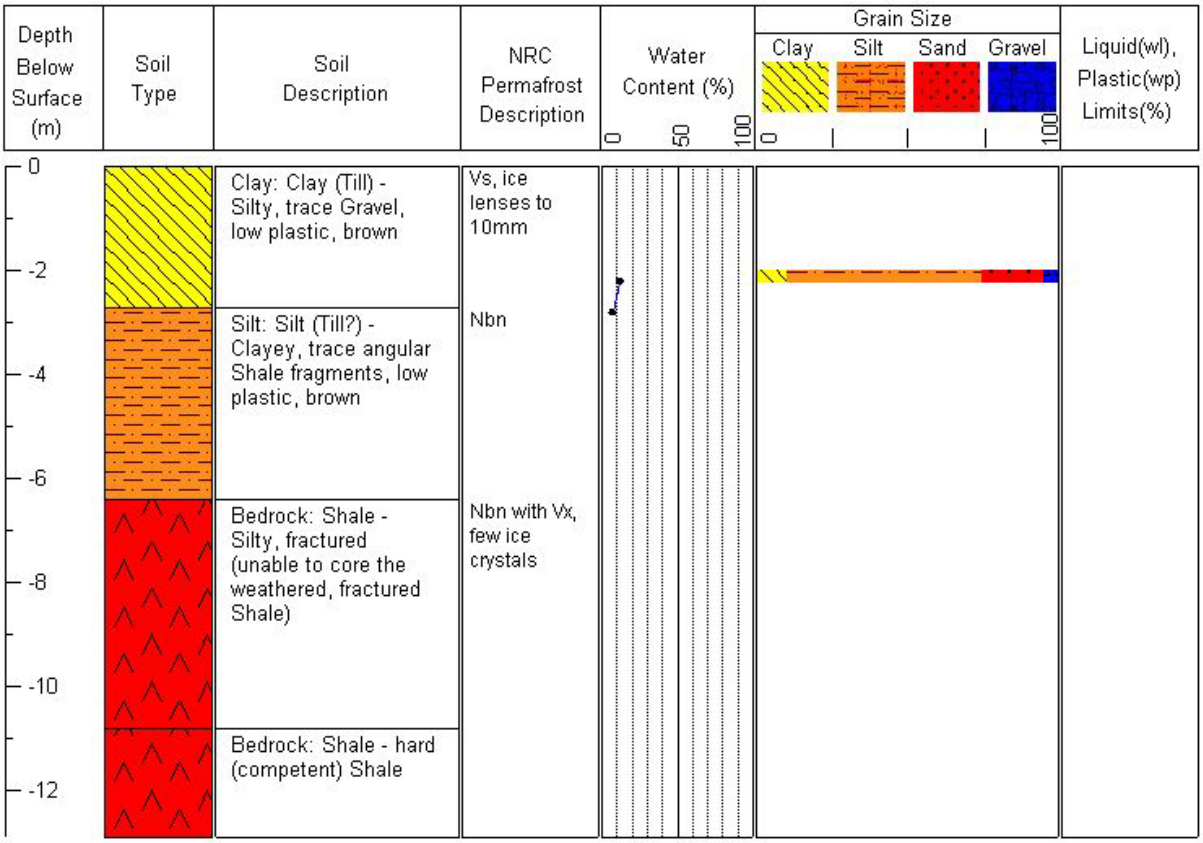
Patterson, D.E., Riseborough, D.W. and Smith, M.W. 1988. Analysis of Norman Wells core samples Final Report. Geological Survey of Canada Open File 1897.

Patterson, D.E., Warner, R. Wright, F. 1991. Physical properties testing Norman Wells Pipeline permafrost samples – 1991. Geological Survey of Canada Open File 2401.

Borehole # : EMR84-1-T3	Date: 04-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7242178
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 598728
Original Borehole # : EMR-84-1-T-3	Zone: 9
Report# : HAL84NWZM	Elevation(m): 61
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/silt/shale, glacial till



Borehole # : EMR84-1-T4	Date: 04-Mar-84
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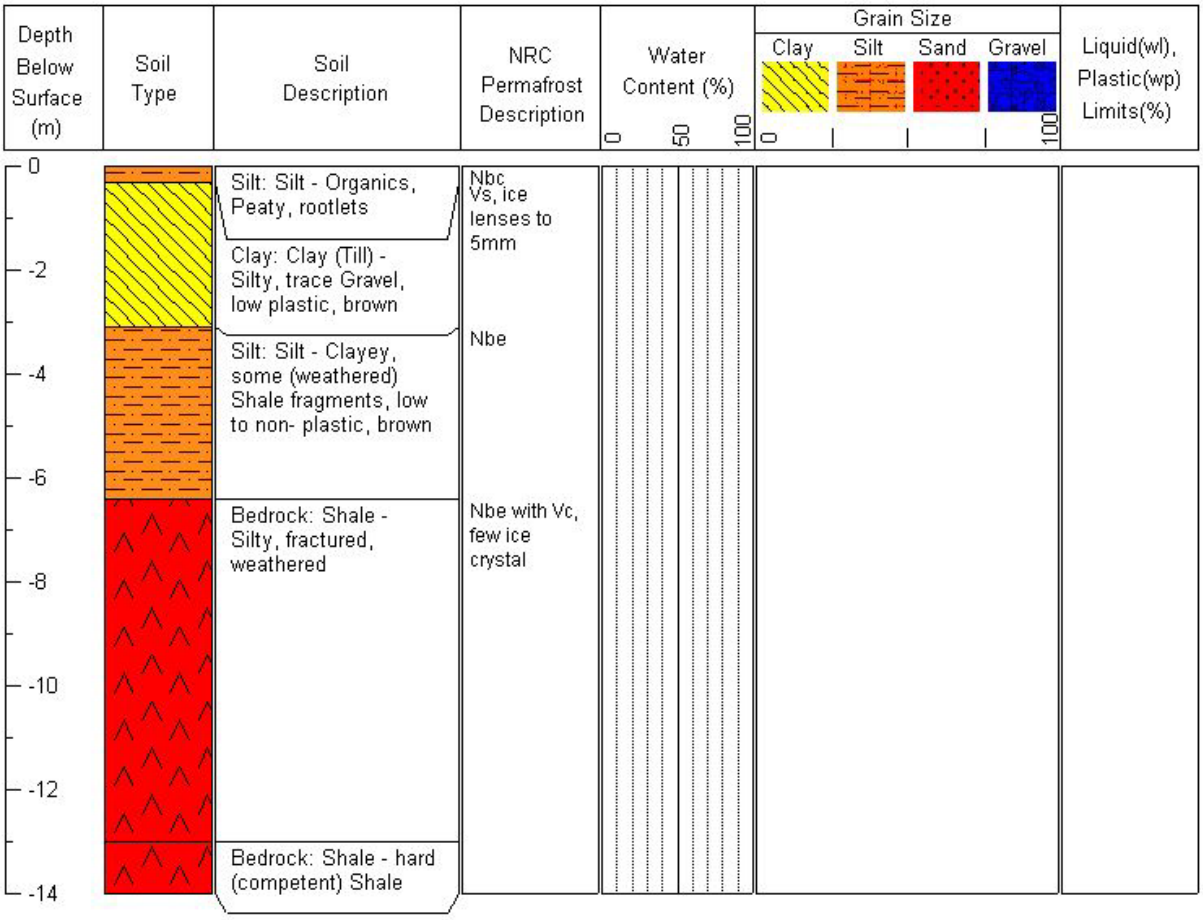
Original Borehole # : EMR-84-1-T-4	Zone: 9
Report# : HAL84NWZM	Elevation(m): 61
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/silt/shale, glacial till



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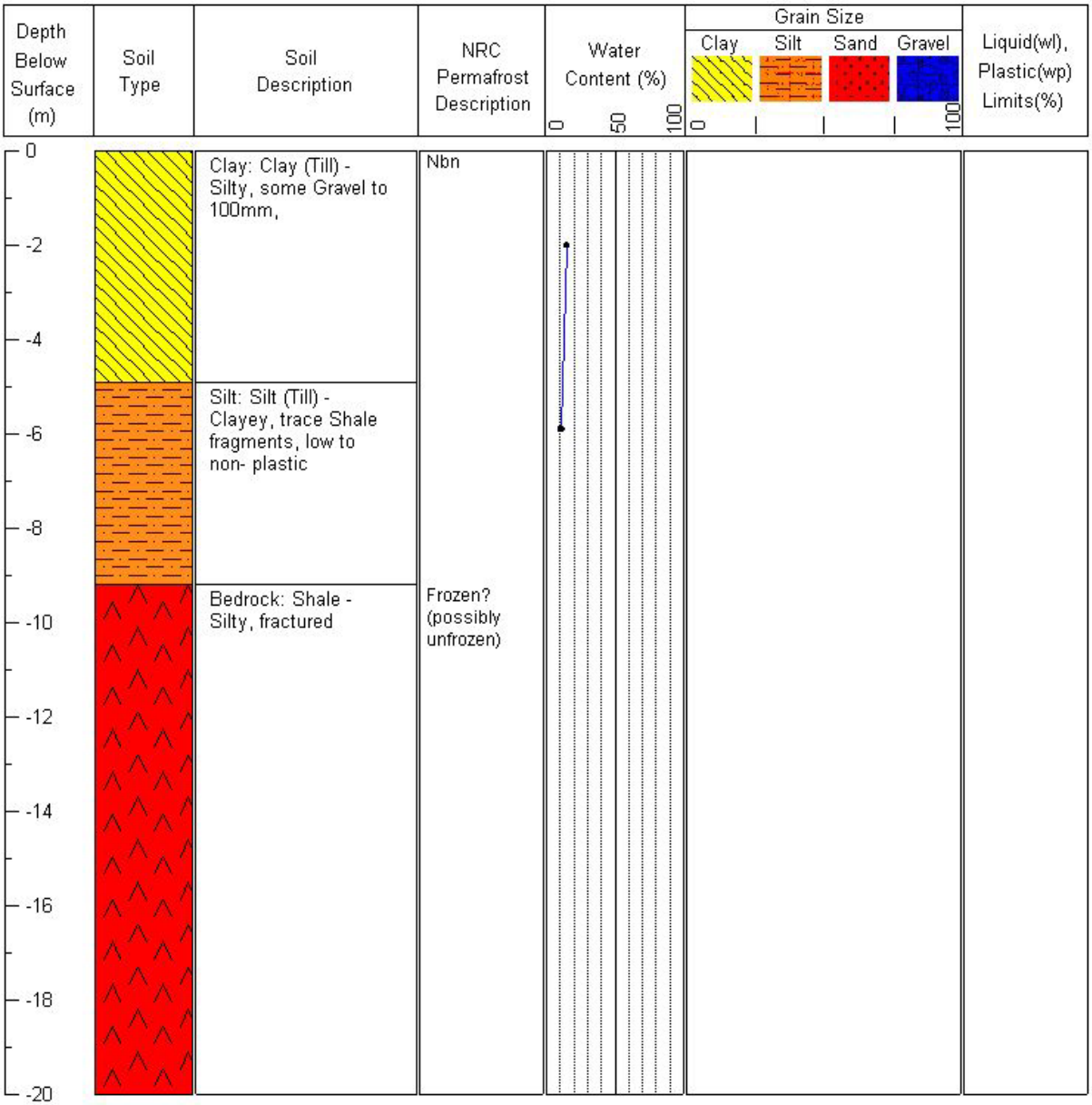
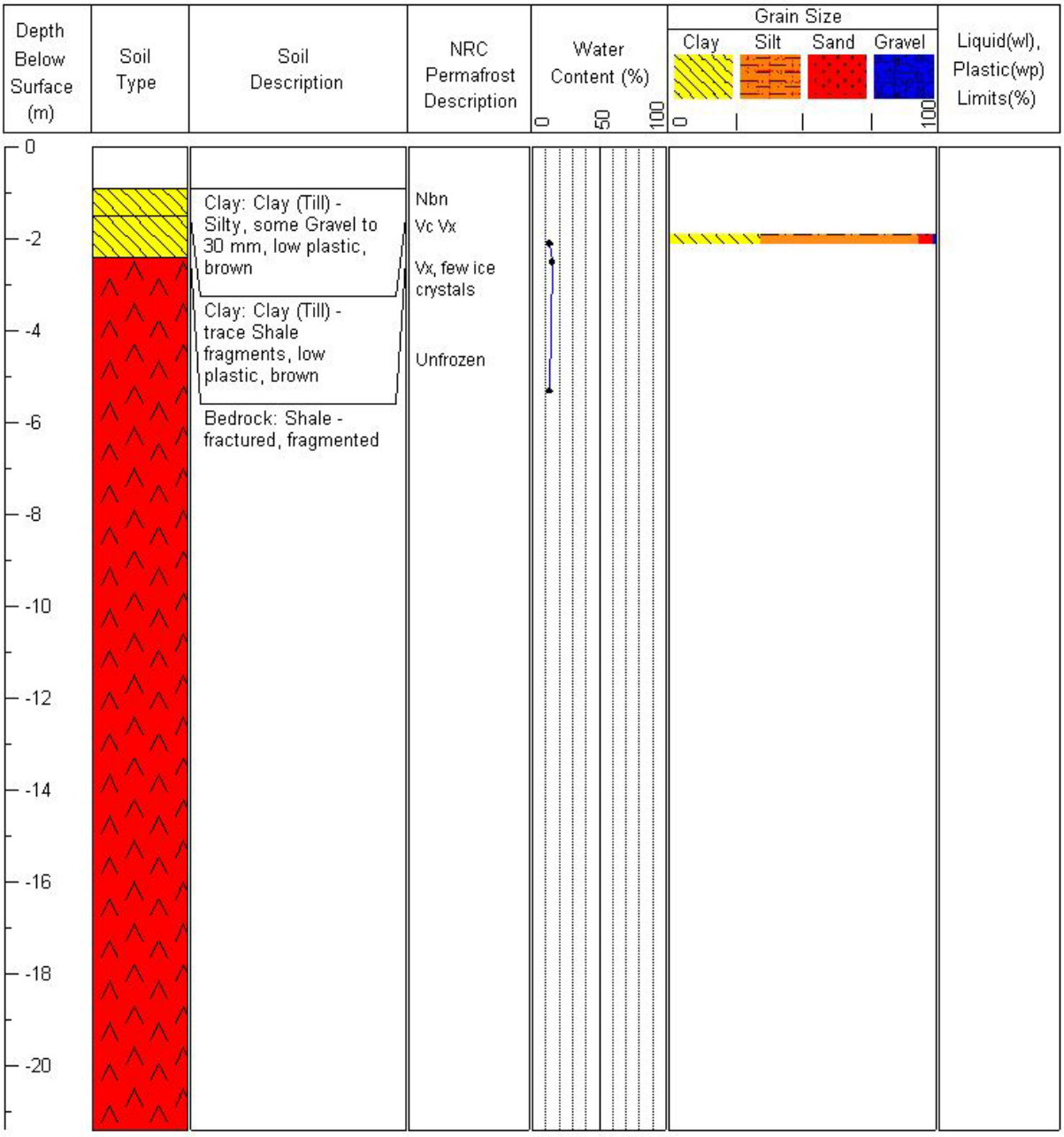
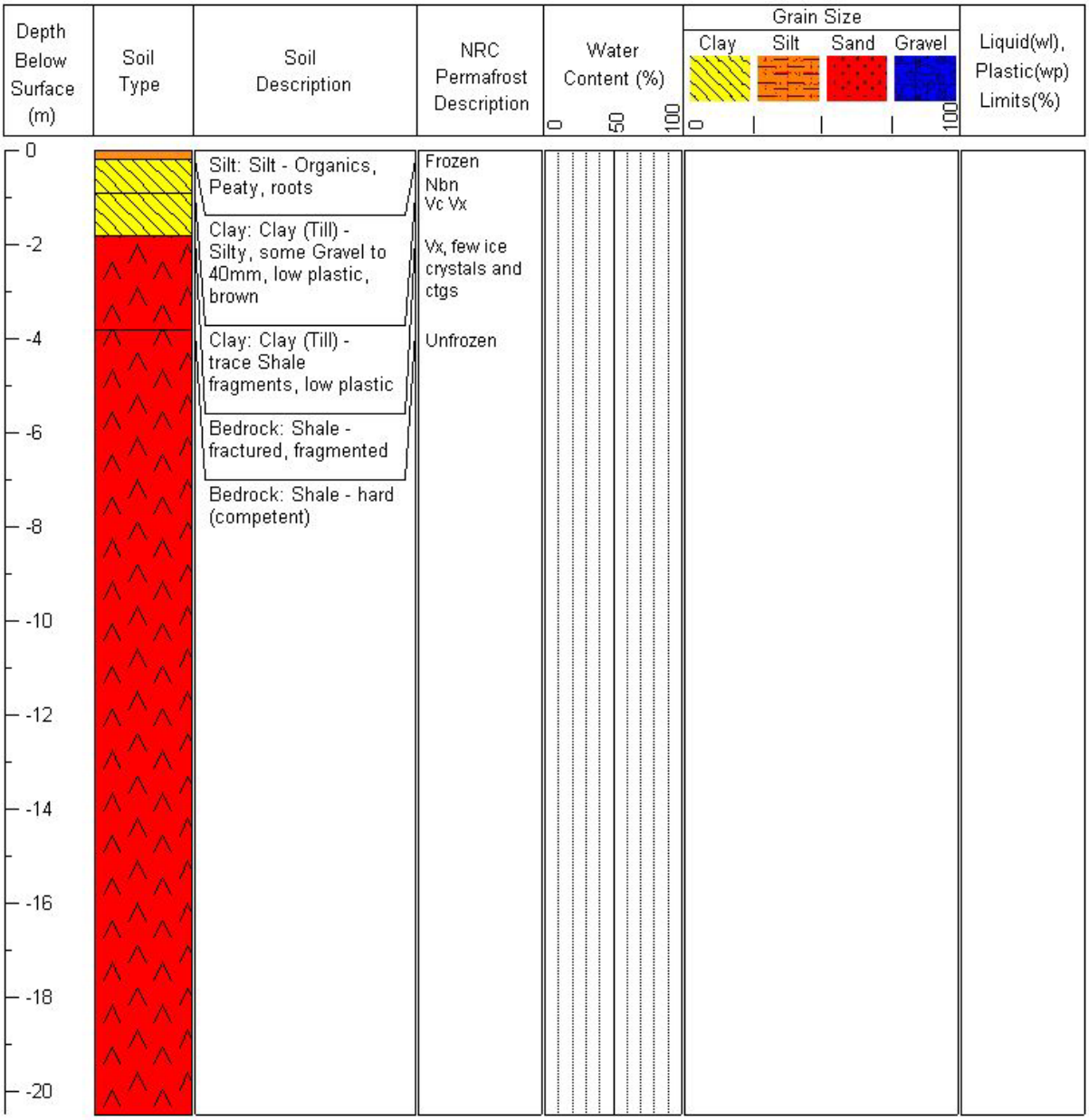
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7236549
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 615736
Original Borehole # : EMR-84-2A-G-1	Zone: 9
Report# : HAL84NWZM	Elevation(m): 123
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/silt/shale, glacial till/bedrock



Borehole # : EMR84-2B-T3	Date: 11-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7236436
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 616013
Original Borehole # : EMR-84-2B-T-3	Zone: 9
Report# : HAL84NWZM	Elevation(m): 110
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/shale, glacial till/bedrock



Borehole # : EMR84-2B-T4	Date: 12-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7236436
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 616013
Original Borehole # : EMR-84-2B-T-4	Zone: 9
Report# : HAL84NWZM	Elevation(m): 110
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/shale, glacial till/bedrock



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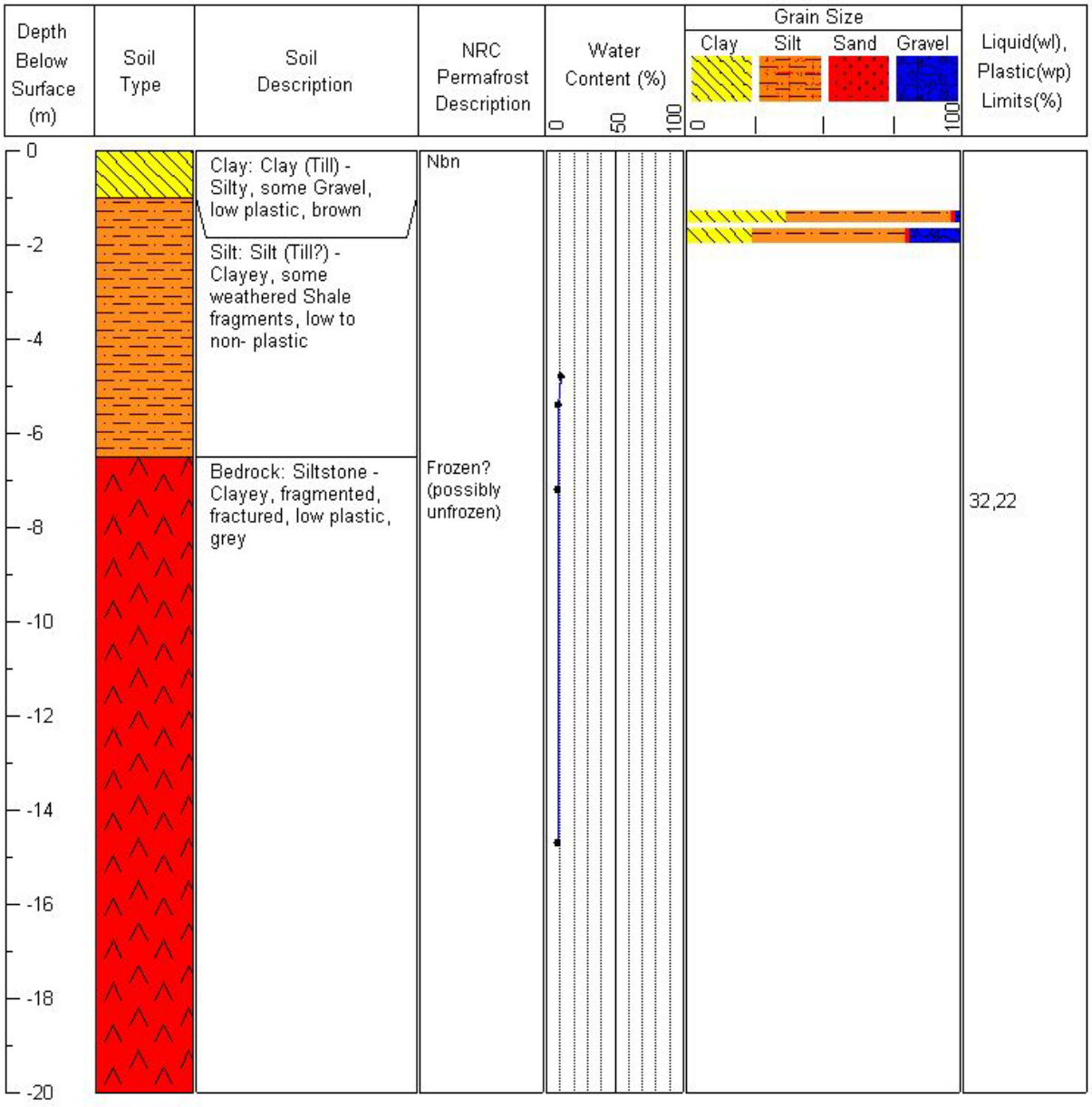
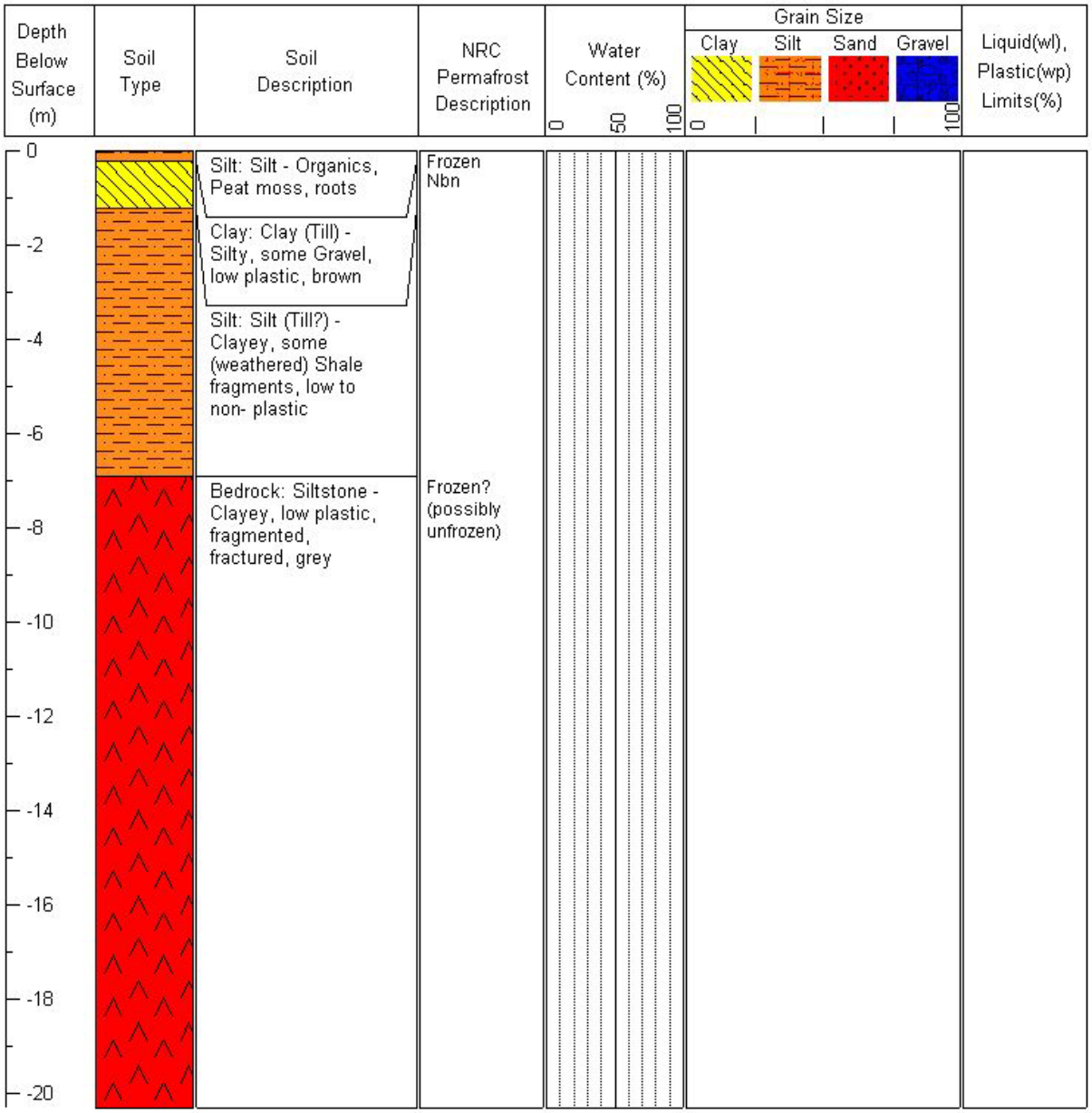
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 616290
Original Borehole # : EMR-84-2C-T-3	Zone: 9
Report# : HAL84NWZM	Elevation(m): 119
Permafrost Conditions: Frozen	Landform: ground moraine
	Surface Material: clay/silt/siltstone, glacial till



Borehole # : EMR84-2C-T4	Date: 09-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7236323
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 616290
Original Borehole # : EMR-84-2C-T-4	Zone: 9
Report# : HAL84NWZM	Elevation(m): 119
Permafrost Conditions: Frozen	Landform: ground moraine
	Surface Material: clay/silt/siltstone, glacial till



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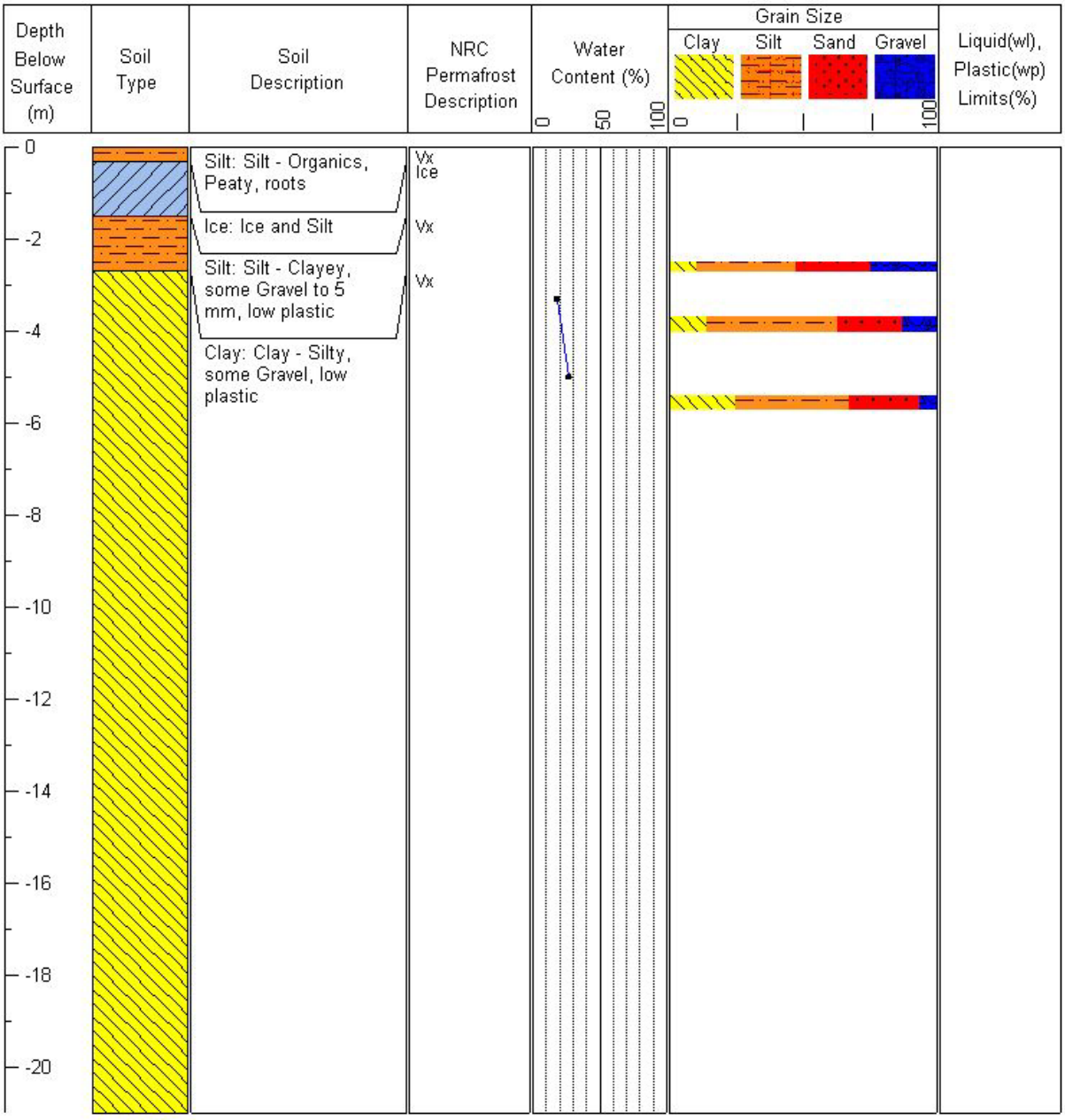
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 377932
Original Borehole # : EMR-84-3A-G-1	Zone: 10
Report# : HAL84NWZM	Elevation(m): 70
Permafrost Conditions: Frozen Landform: alluvial terrace	Surface Material: silt/clay, alluvial



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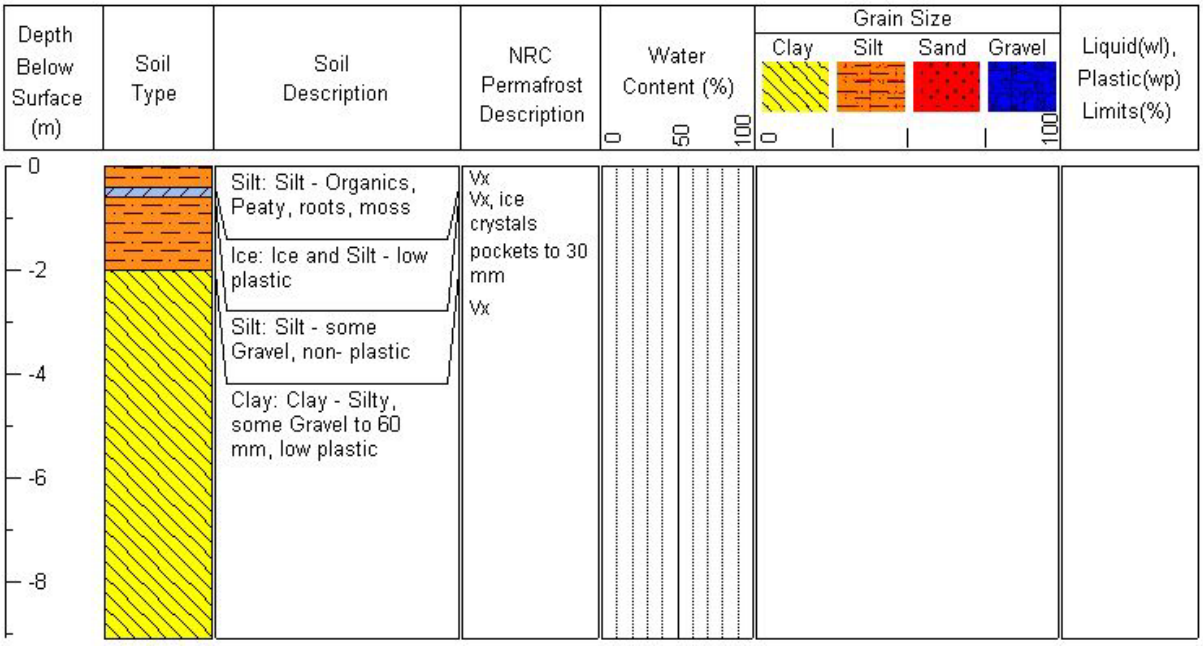
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7201007
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 377932
Original Borehole # : EMR-84-3A-G-1	Zone: 10
Report# : HAL84NWZM	Elevation(m): 70
Permafrost Conditions: Frozen Landform: alluvial terrace	Surface Material: silt/clay, alluvial



Borehole # : EMR84-3B-G1	Date: 19-Mar-84
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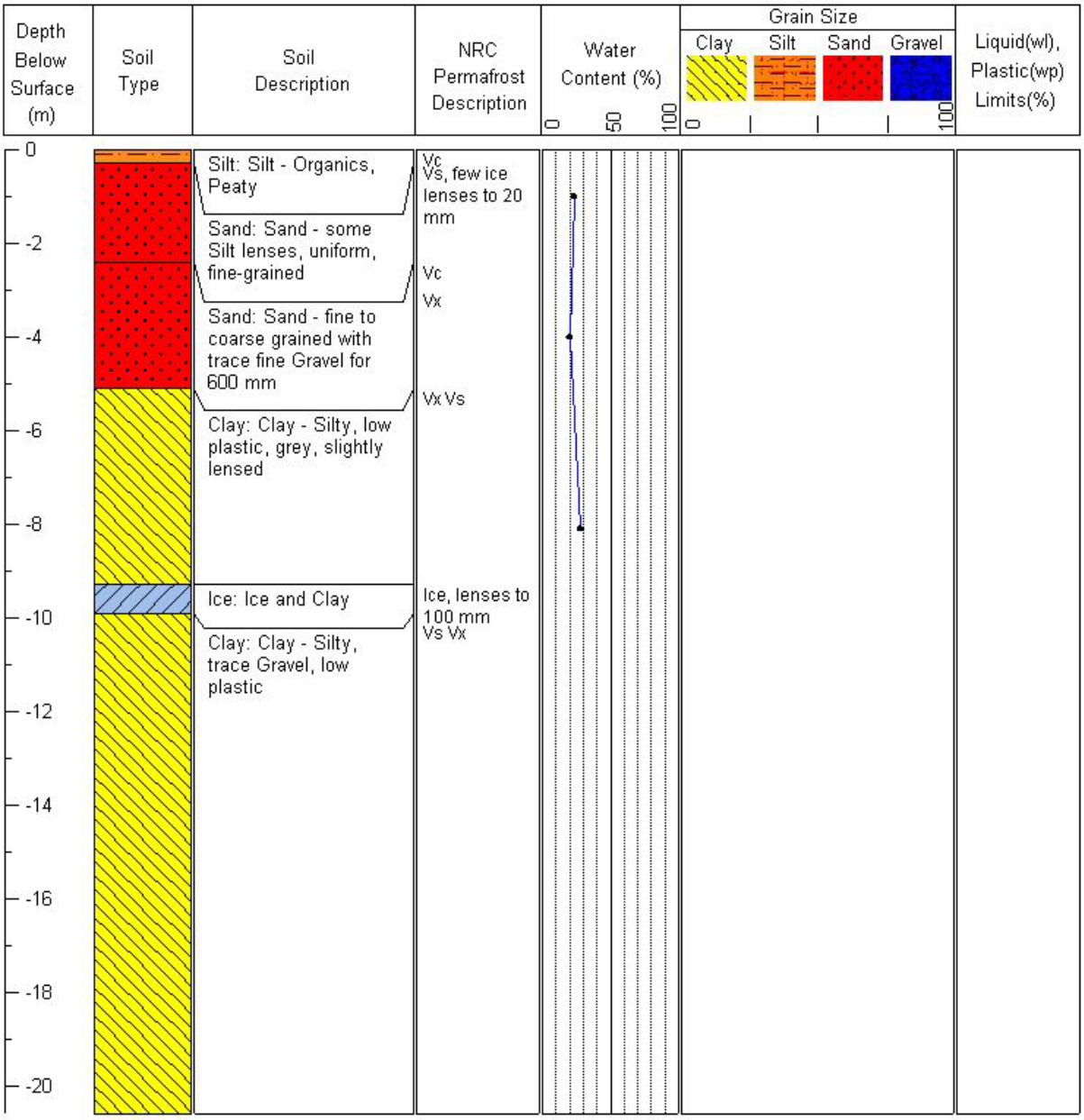
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 378109
Original Borehole # : EMR-84-3B-G-1	Zone: 10
Report# : HAL84NWZM	Elevation(m): 93
Permafrost Conditions: Frozen Landform:	Surface Material: sand/clay



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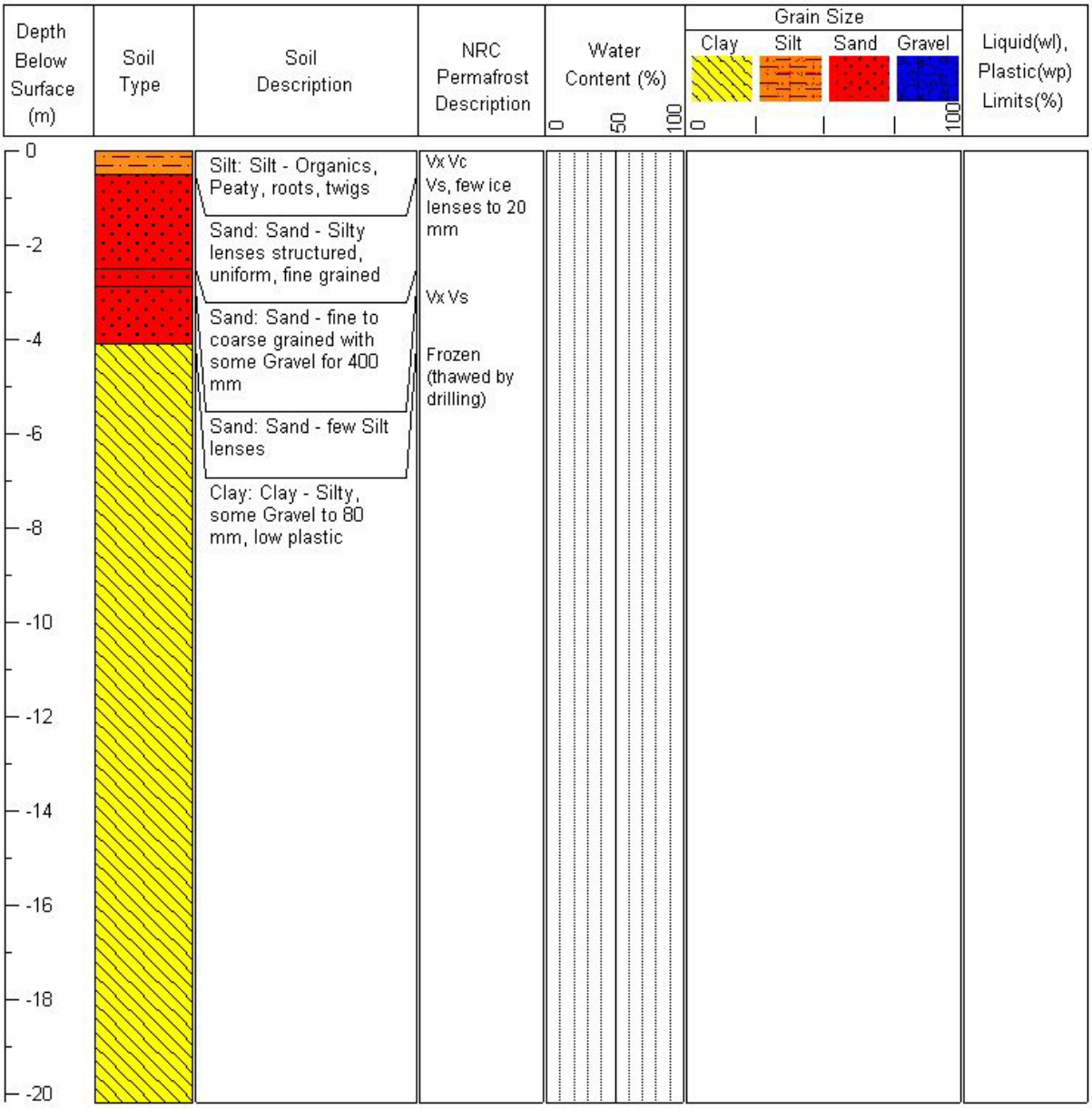
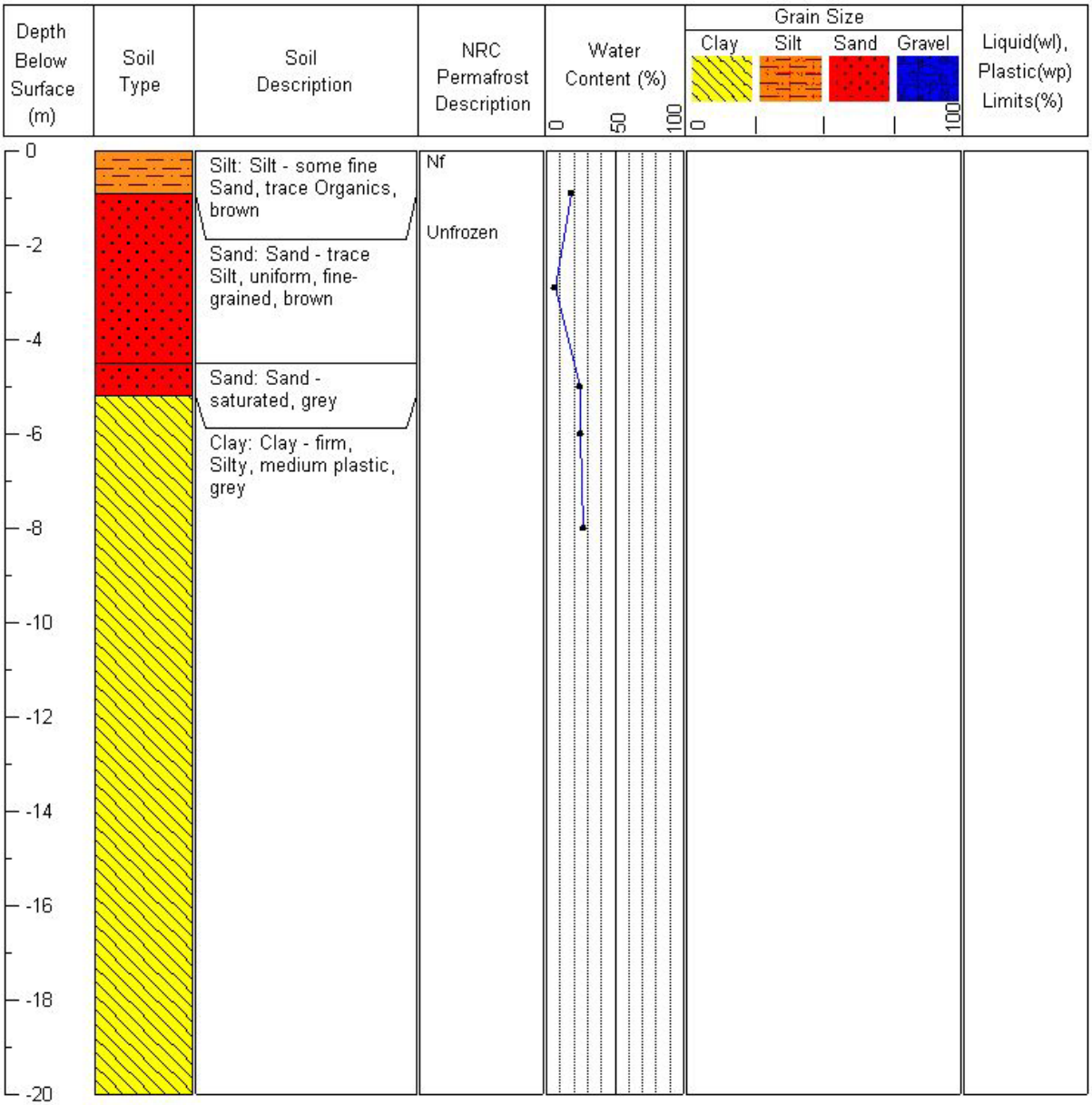
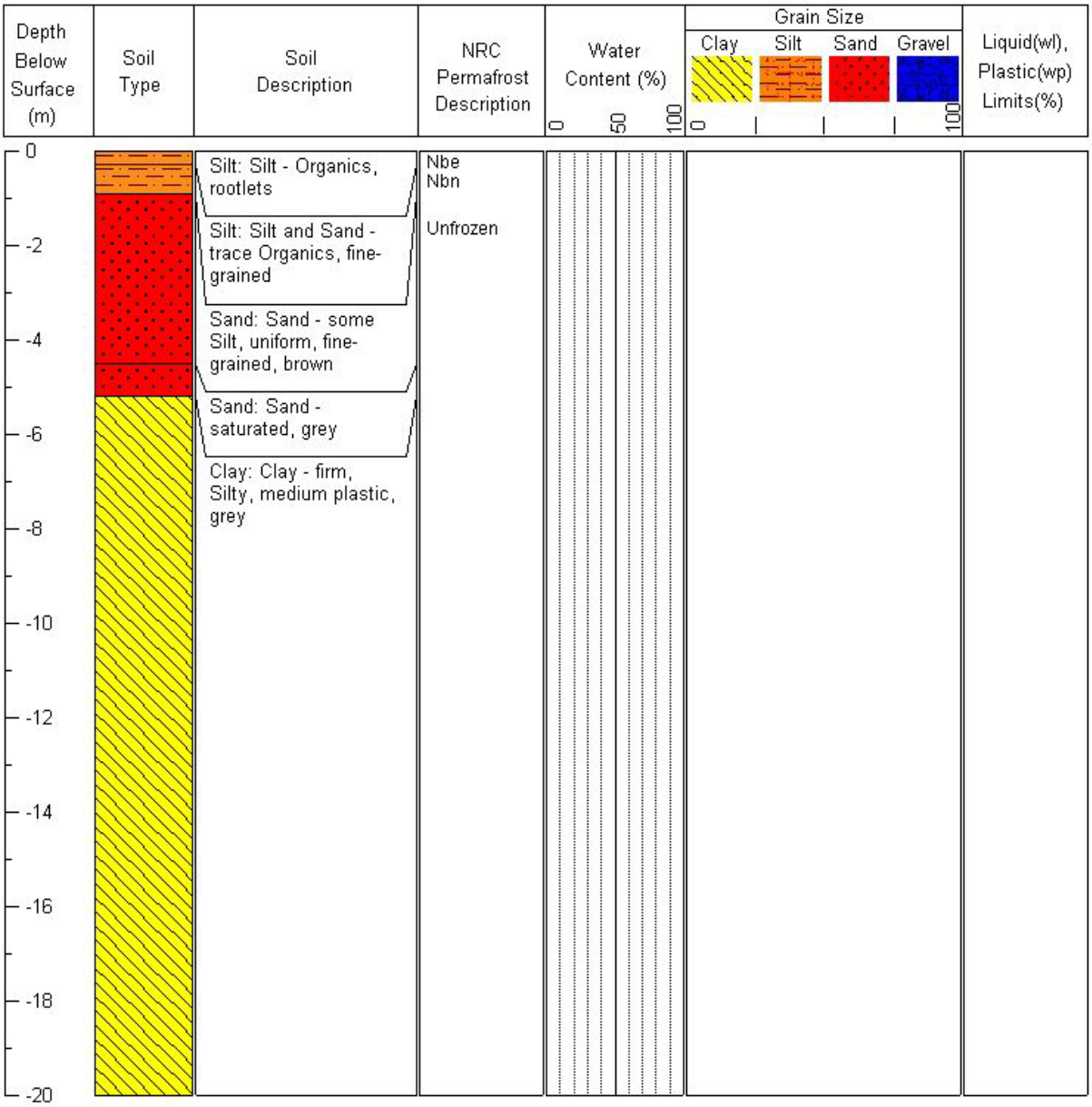
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7200917
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 378109
Original Borehole # : EMR-84-3B-T-4	Zone: 10
Report# : HAL84NWZM	Elevation(m): 93
Permafrost Conditions: Frozen Landform:	Surface Material: sand/clay



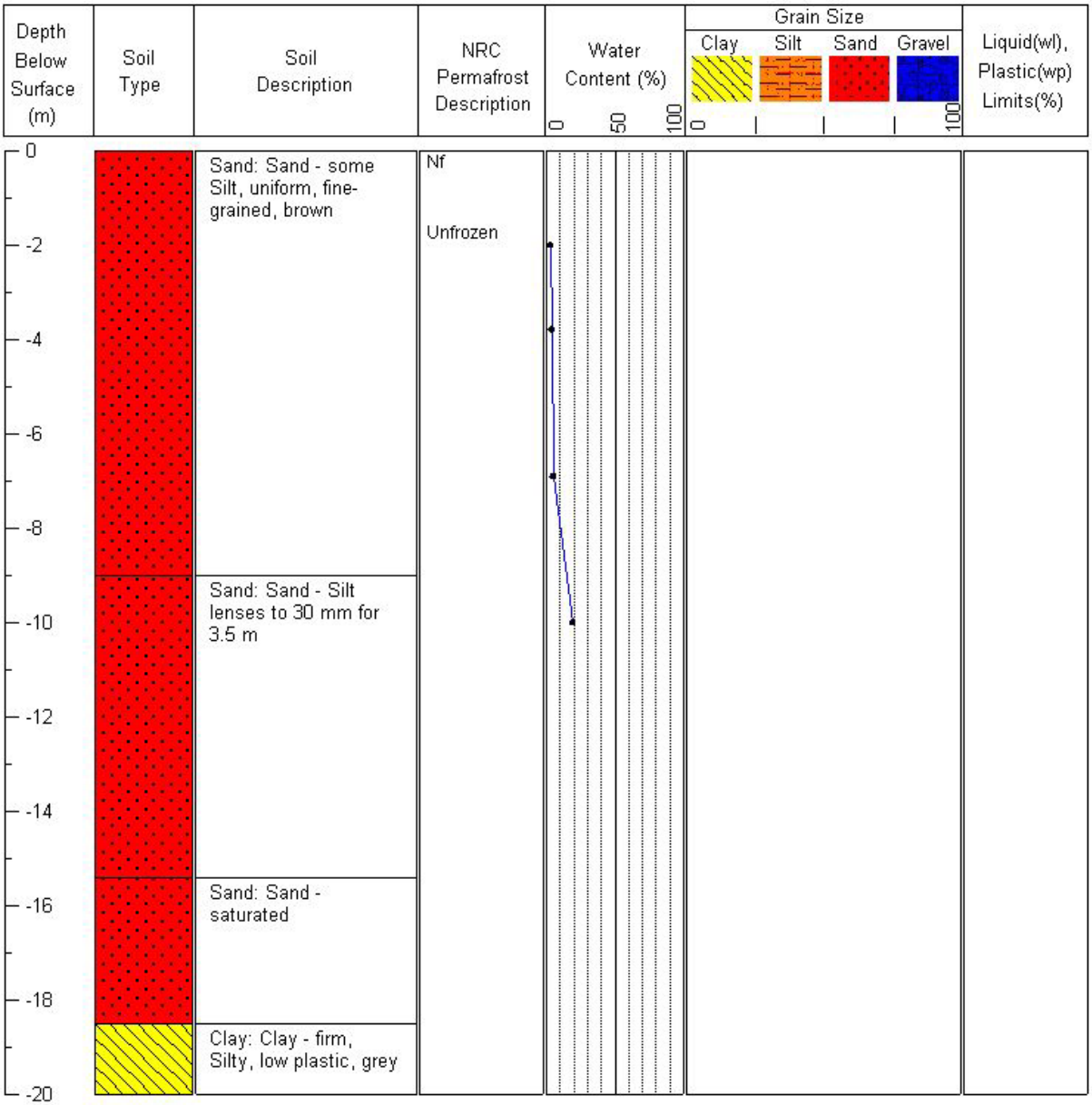
Borehole # : EMR84-4A-T1	Date: 29-Feb-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6882199
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 552975
Original Borehole # : EMR-84-4B-T-1	Zone: 10
Report# : HAL84NWZM	Elevation(m): 153
Permafrost Conditions: Frozen Landform:	Surface Material: silt/sand/clay



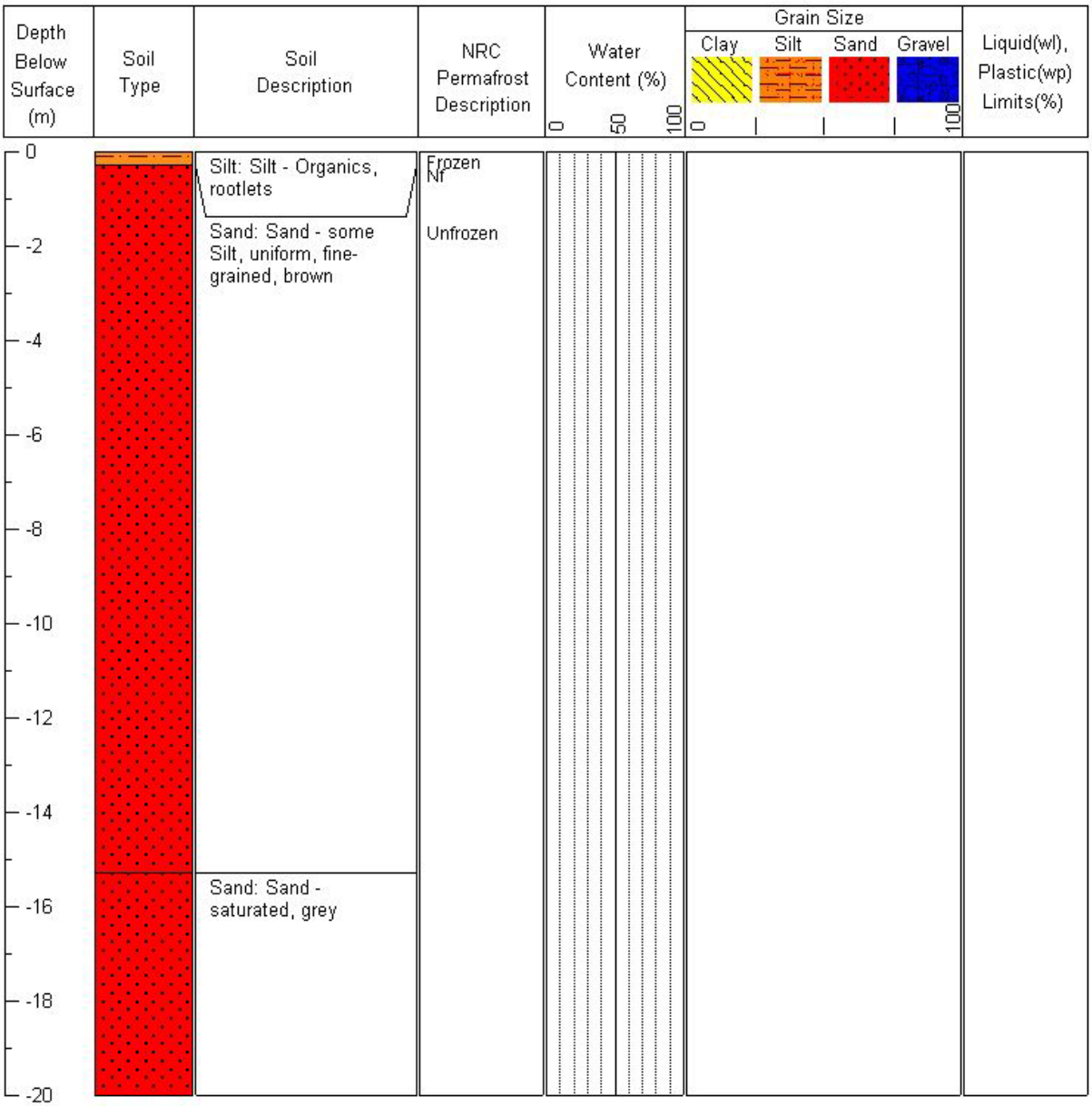
Borehole # : EMR84-4A-T2	Date: 29-Feb-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6882199
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 552975
Original Borehole # : EMR-84-4A-T-2	Zone: 10
Report# : HAL84NWZM	Elevation(m): 153
Permafrost Conditions: Frozen Landform:	Surface Material: silt/sand/clay



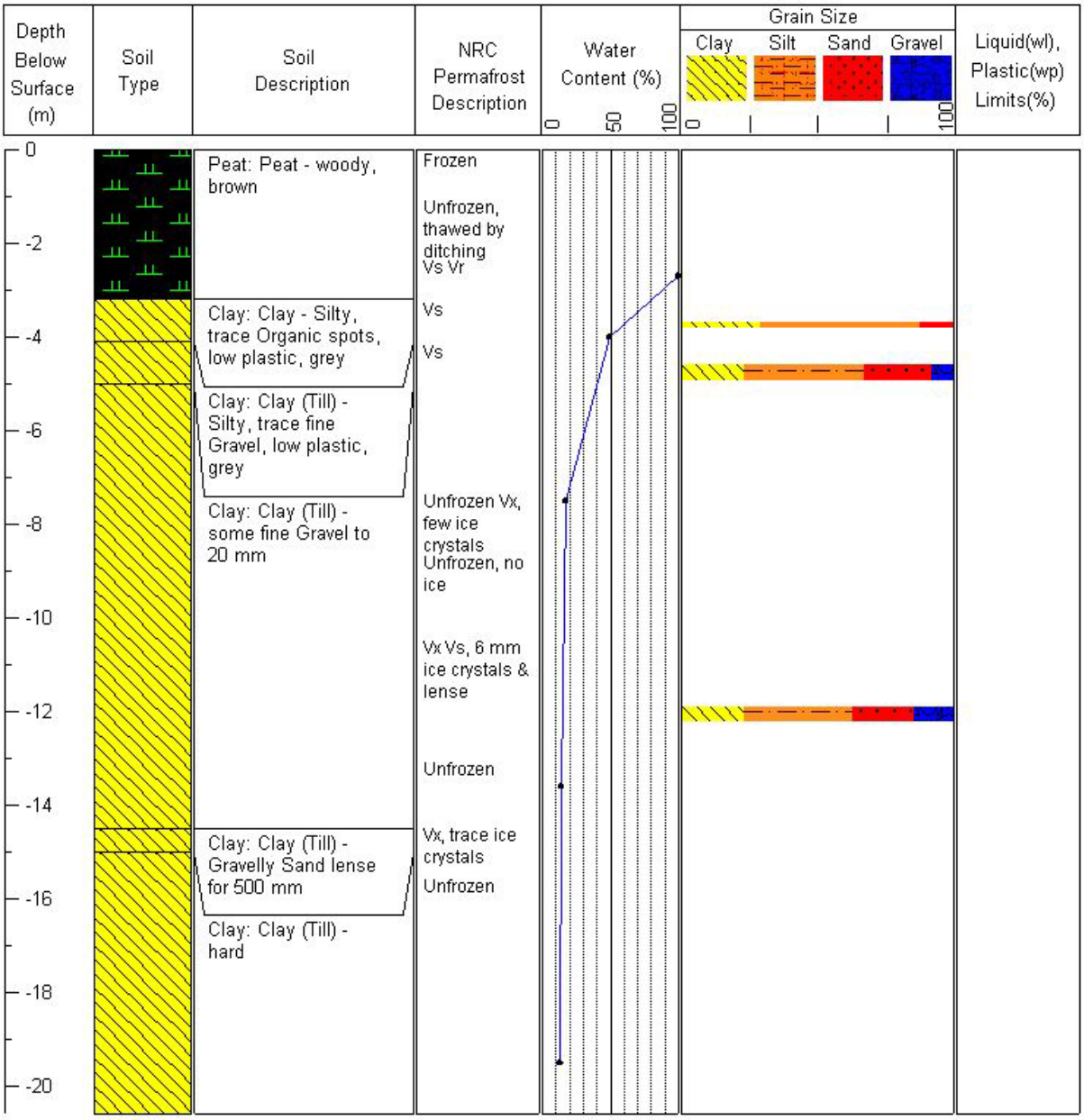
Borehole # : EMR84-4B-T1	Date: 01-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6882153
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 553063
Original Borehole # : EMR-84-4B-T-1	Zone: 10
Report# : HAL84NWZM	Elevation(m): 165
Permafrost Conditions: Unfrozen Landform:	Surface Material: sand/clay



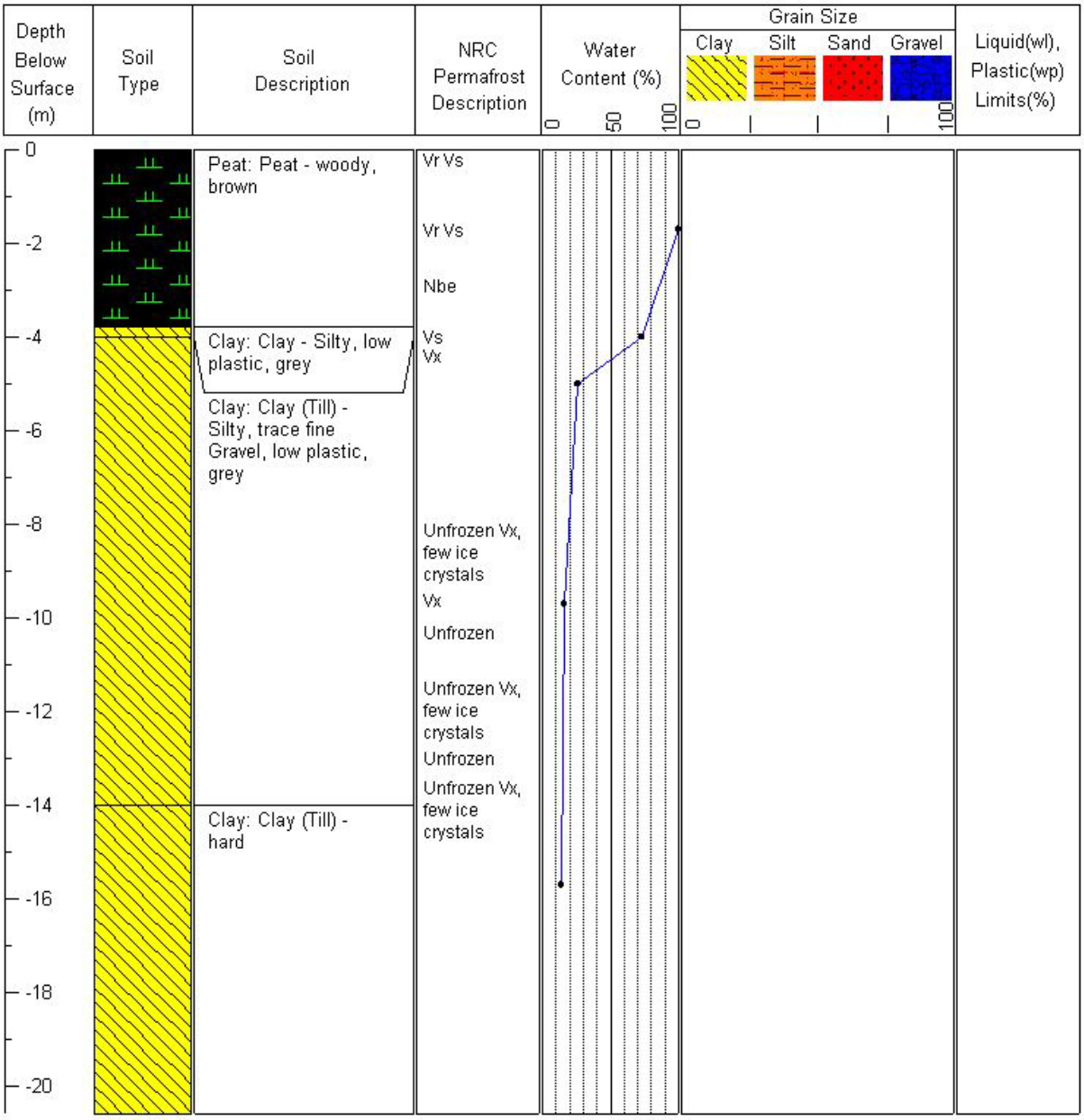
Borehole # : EMR84-4B-T4	Date: 01-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6882153
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 553063
Original Borehole # : EMR-84-4B-T-4	Zone: 10
Report# : HAL84NWZM	Elevation(m): 165
Permafrost Conditions: Frozen Landform:	Surface Material: sand



Borehole # : EMR84-5A-T3	Date: 18-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6626963
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 358560
Original Borehole # : EMR-84-5A-T3	Zone: 11
Report# : HAL84NWZM	Elevation(m): 552
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



Borehole # : EMR84-5A-T4	Date: 18-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6626963
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 358560
Original Borehole # : EMR-84-5A-T4	Zone: 11
Report# : HAL84NWZM	Elevation(m): 552
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



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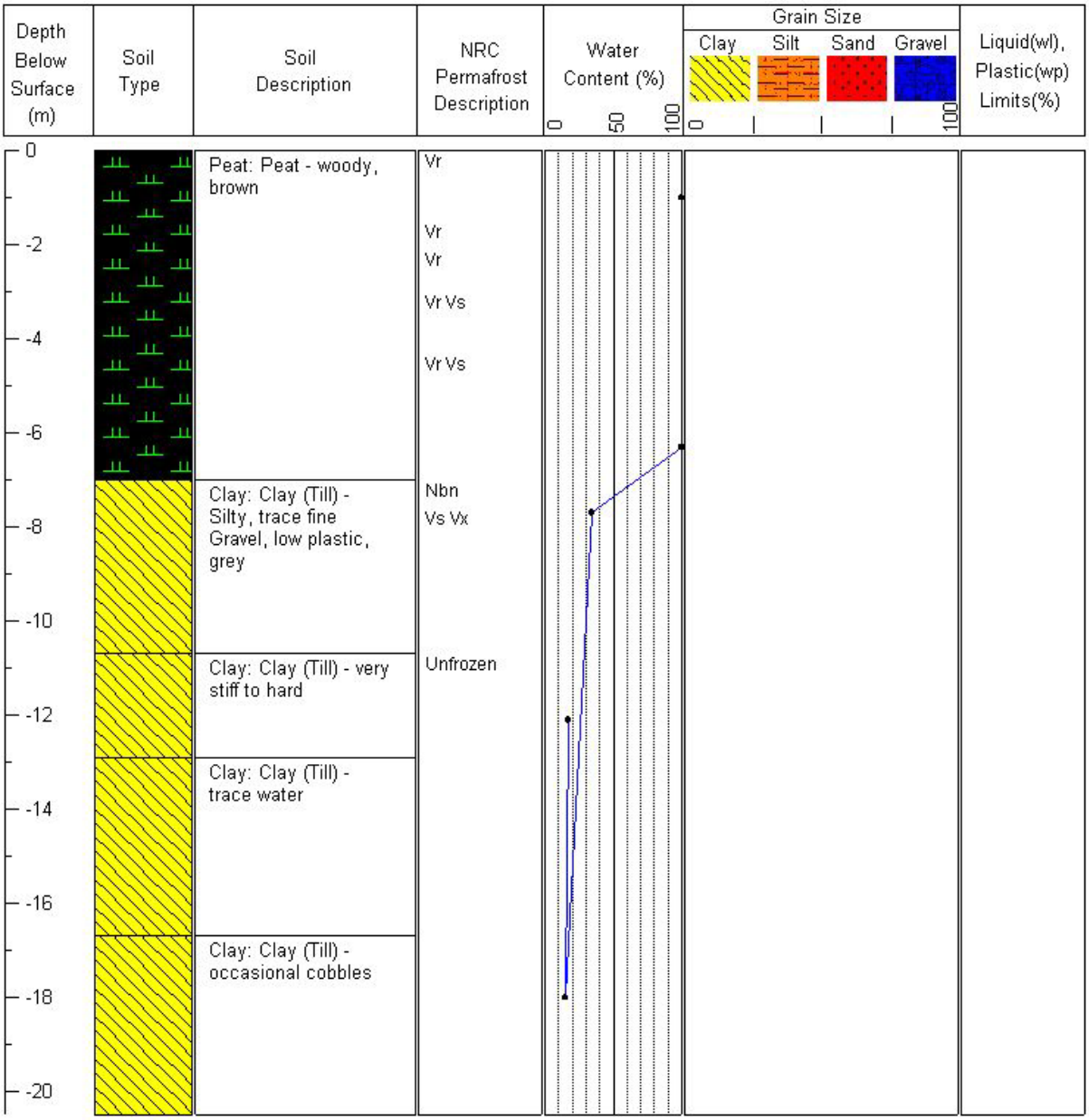
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 358686
Original Borehole # : EMR-84-5B-T3	Zone: 11
Report# : HAL84NWZM	Elevation(m): 552
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



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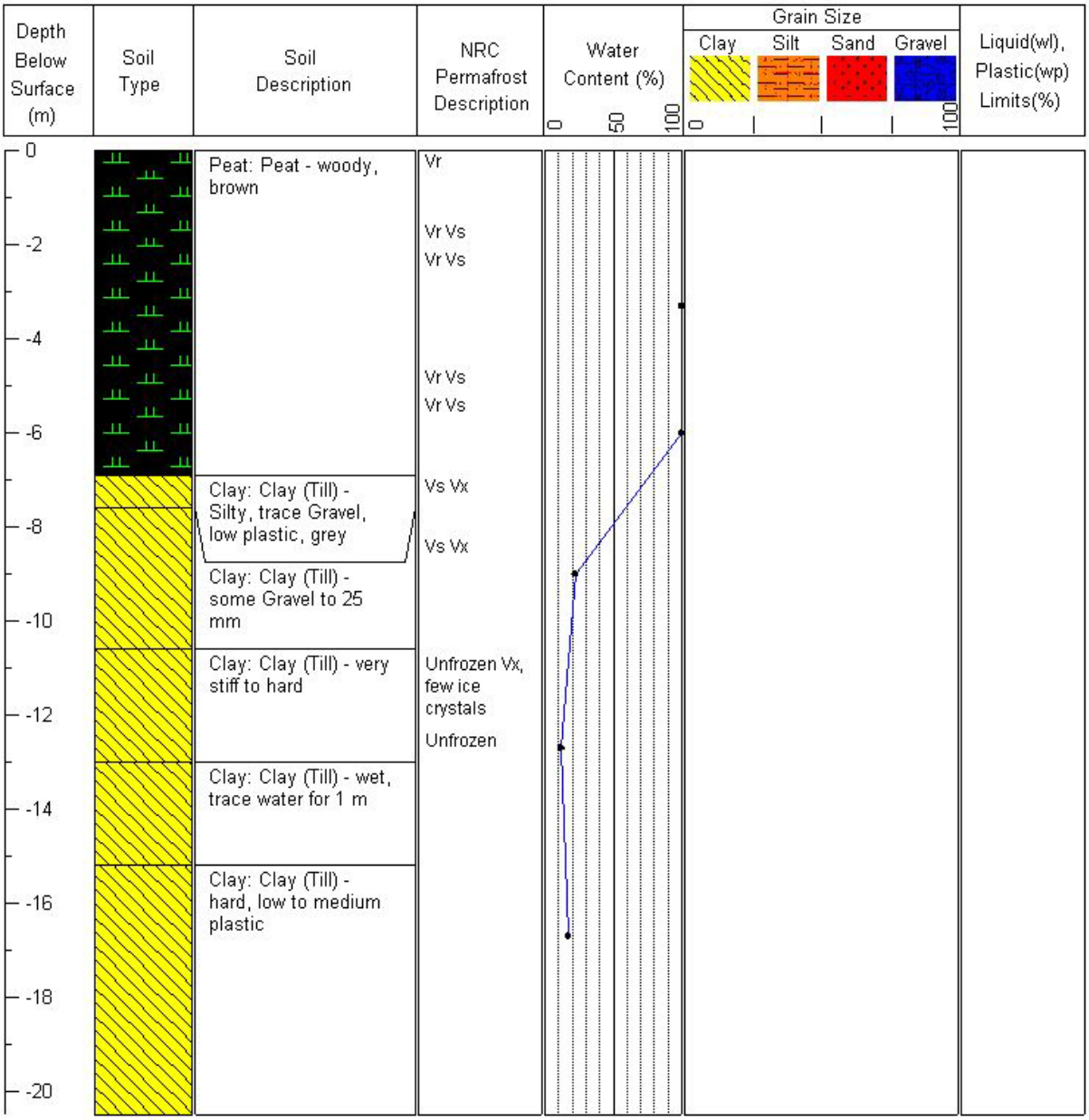
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 358686
Original Borehole # : EMR-84-5B-T4	Zone: 11
Report# : HAL84NWZM	Elevation(m): 552
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



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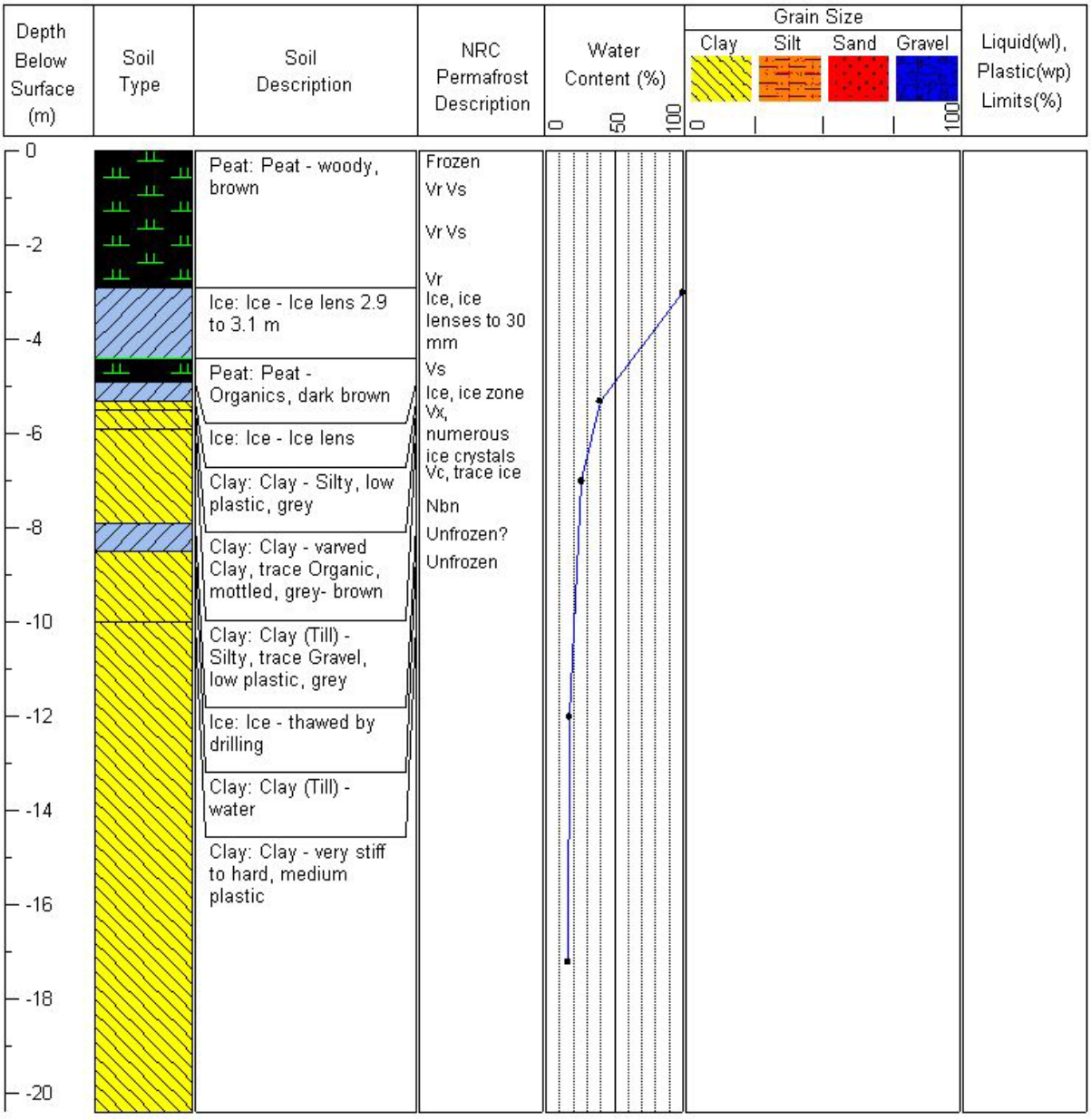
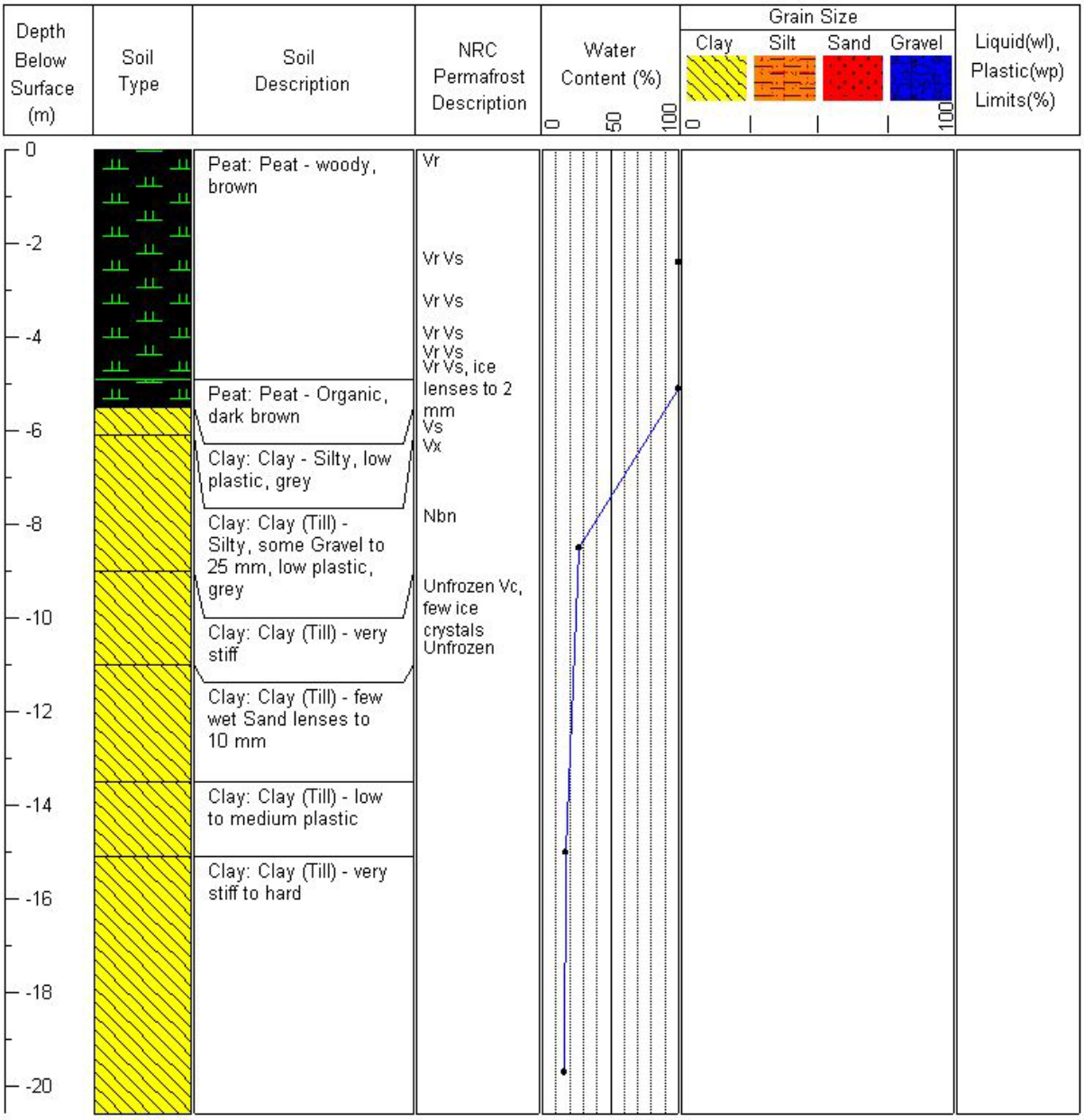
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6593337
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 372576
Original Borehole # : EMR-84-6-G-1	Zone: 11
Report# : HAL84NWZM	Elevation(m): 575
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



Borehole # : EMR84-6-T3	Date: 19-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6593337
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 372576
Original Borehole # : EMR-84-6-T3	Zone: 11
Report# : HAL84NWZM	Elevation(m): 575
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



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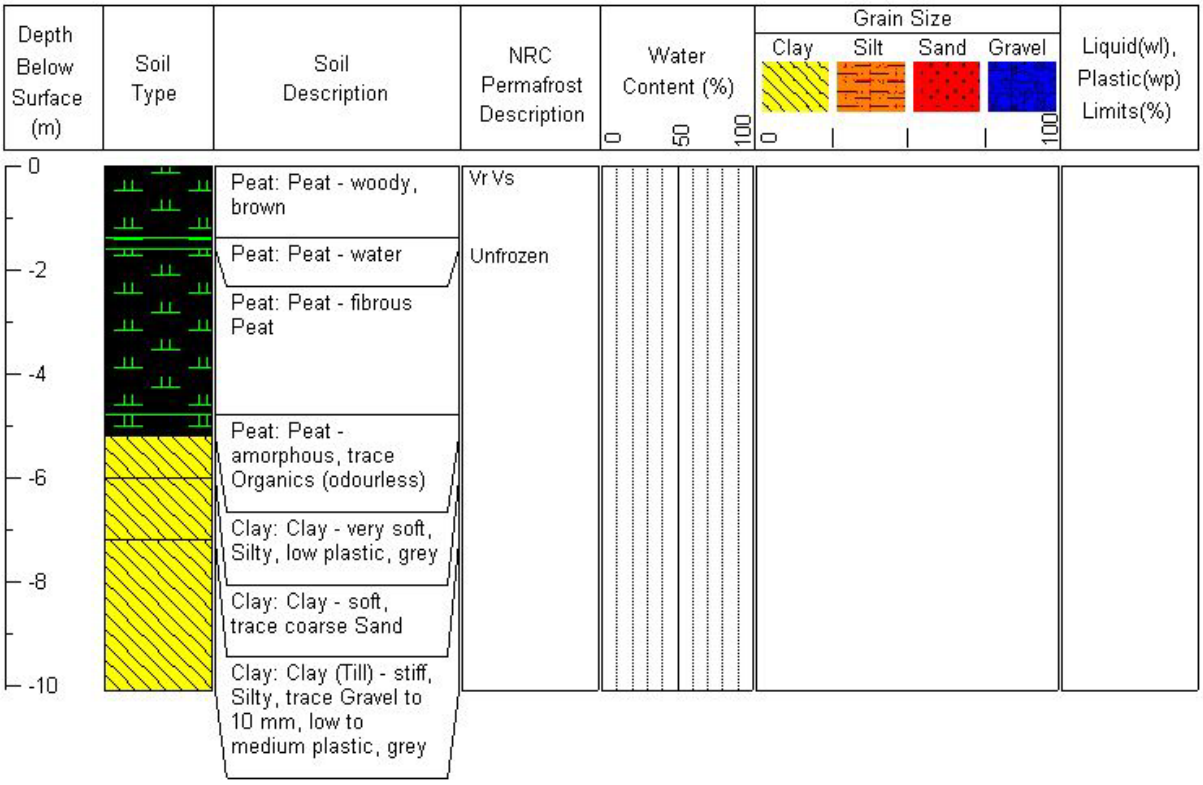
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6593337
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 372576
Original Borehole # : EMR-84-6-T-5	Zone: 11
Report# : HAL84NWZM	Elevation(m): 575
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



Borehole # : EMR85-7A-G1	Date: 18-Feb-85
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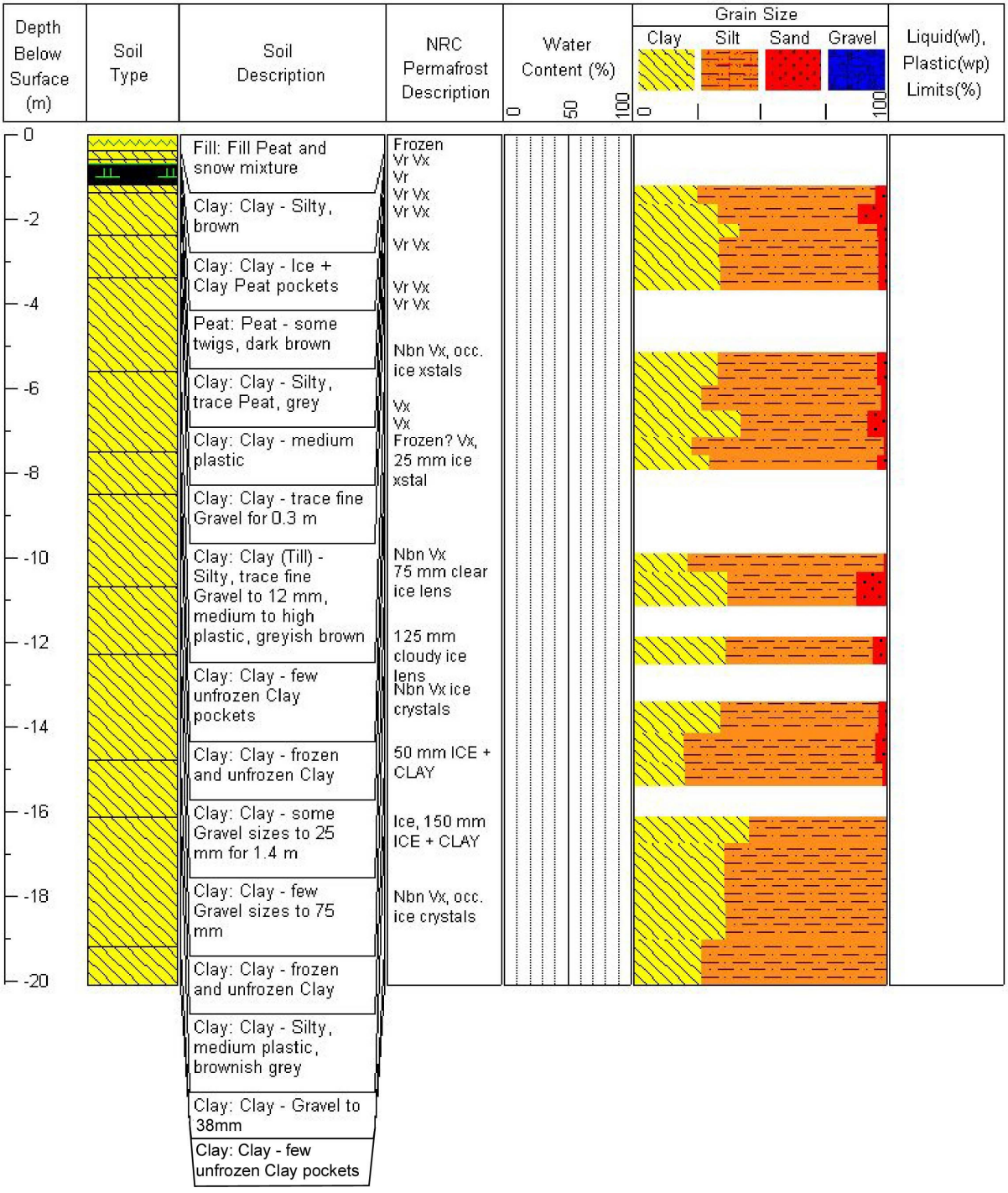
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 468110
Original Borehole # : EMR-85-7A-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 255
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



Borehole # : EMR85-7A-T4	Date: 27-Feb-85
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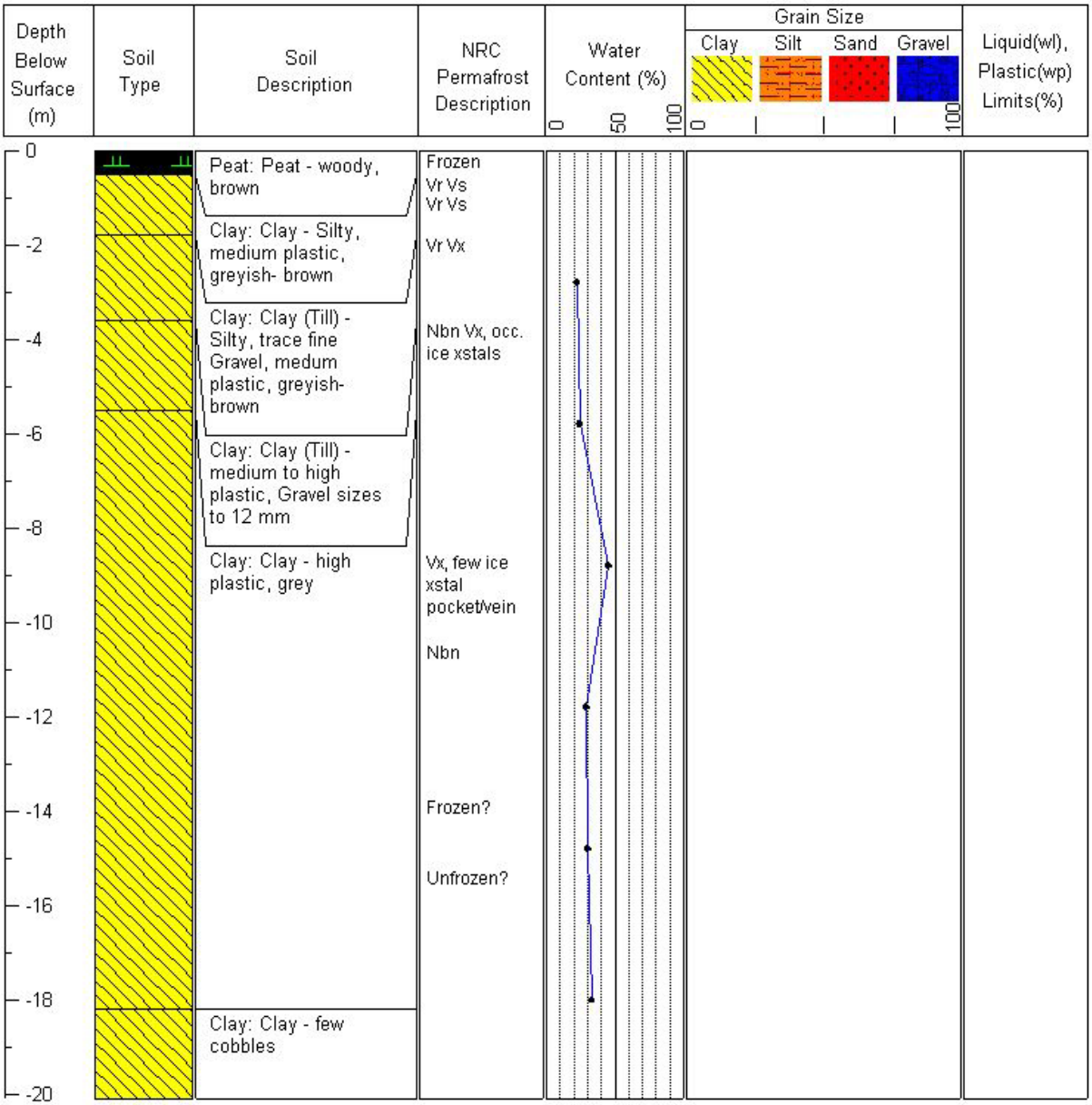
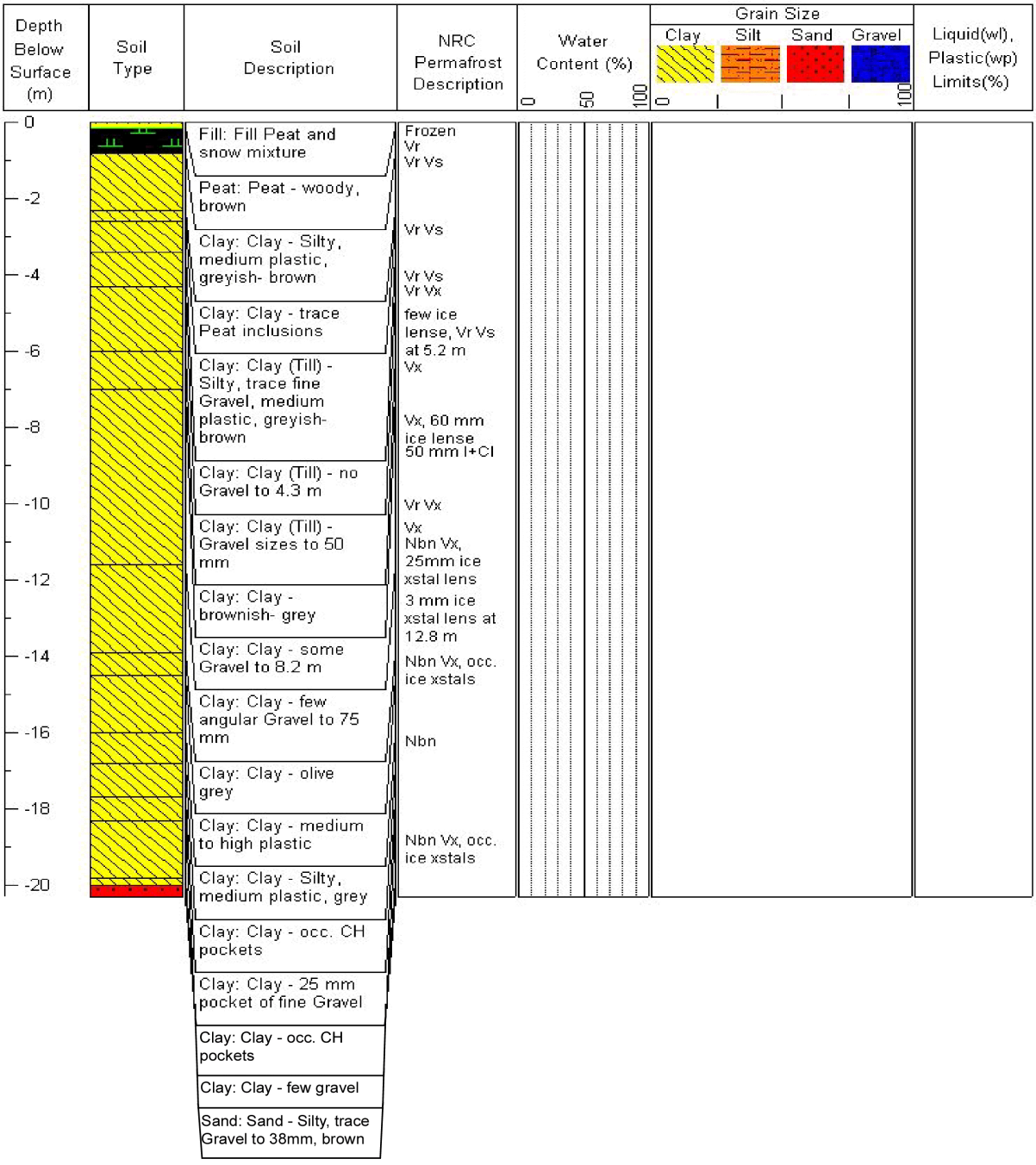
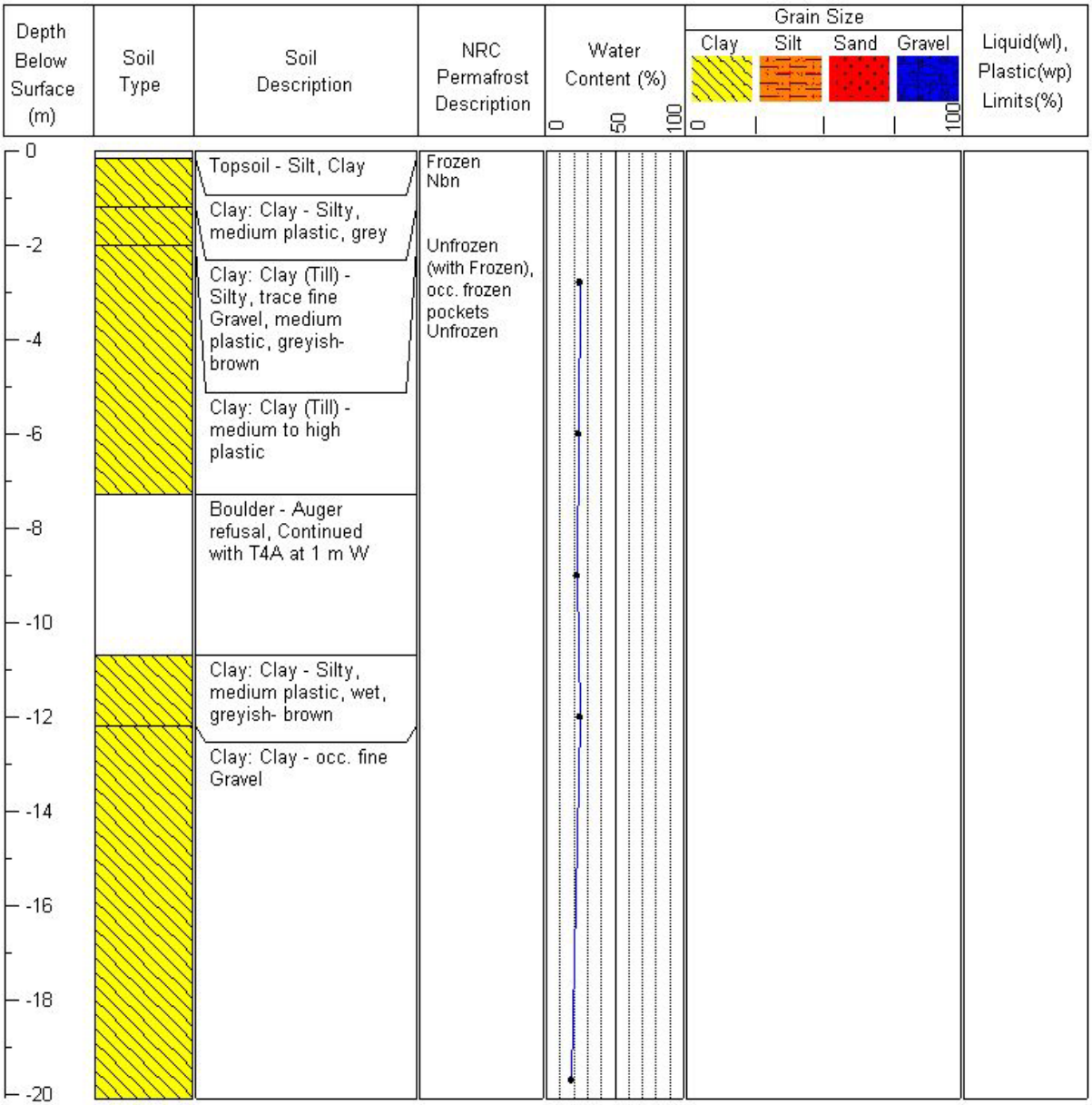
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 468110
Original Borehole # : EMR-85-7A-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 255
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



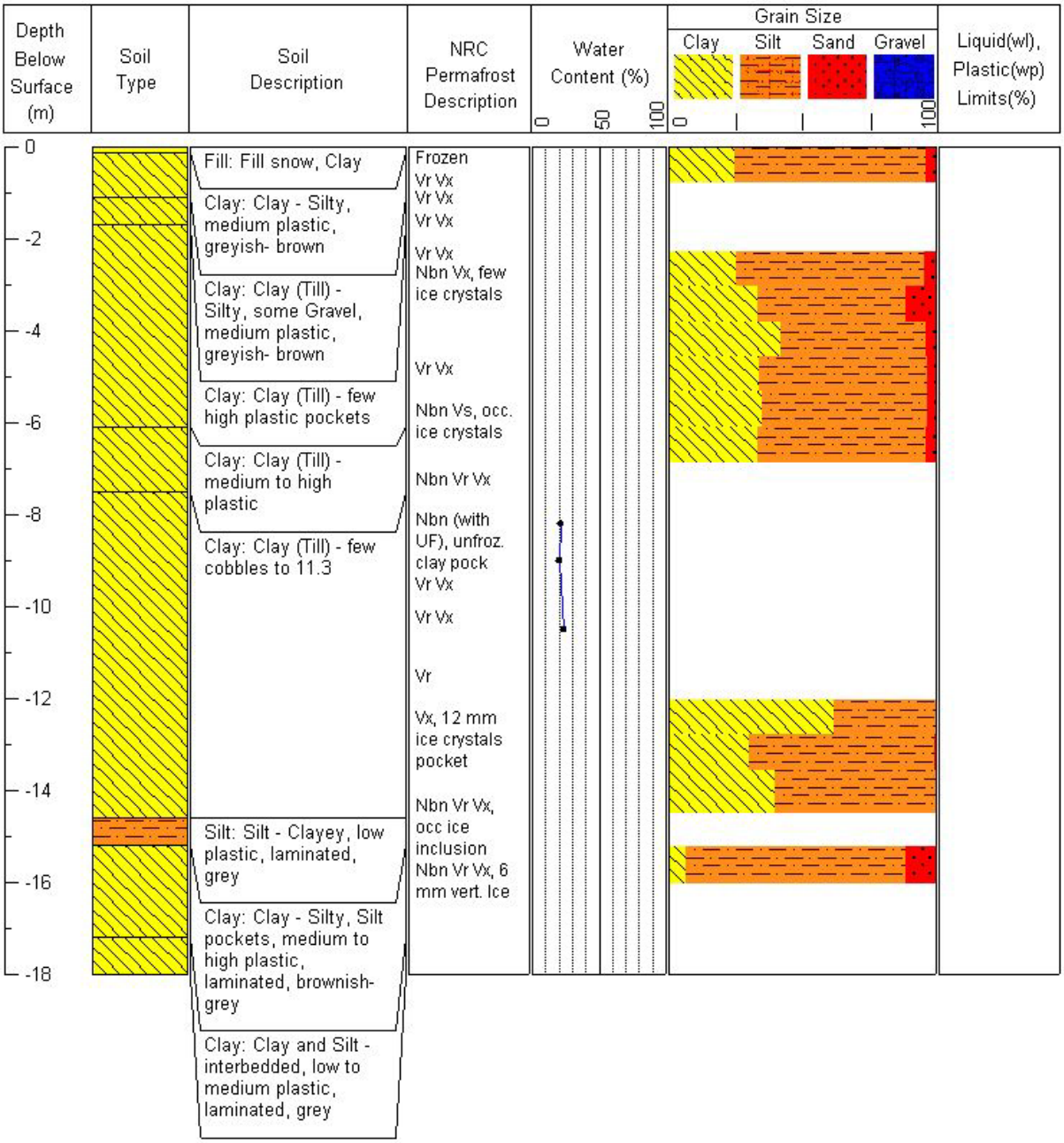
Borehole #: EMR85-7B-G1	Date: 16-Feb-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7053462
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 468671
Original Borehole #: EMR-85-7B-G-1	Zone: 10
Report#: HAL85NWZM	Elevation(m): 265
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/sand, glacial till



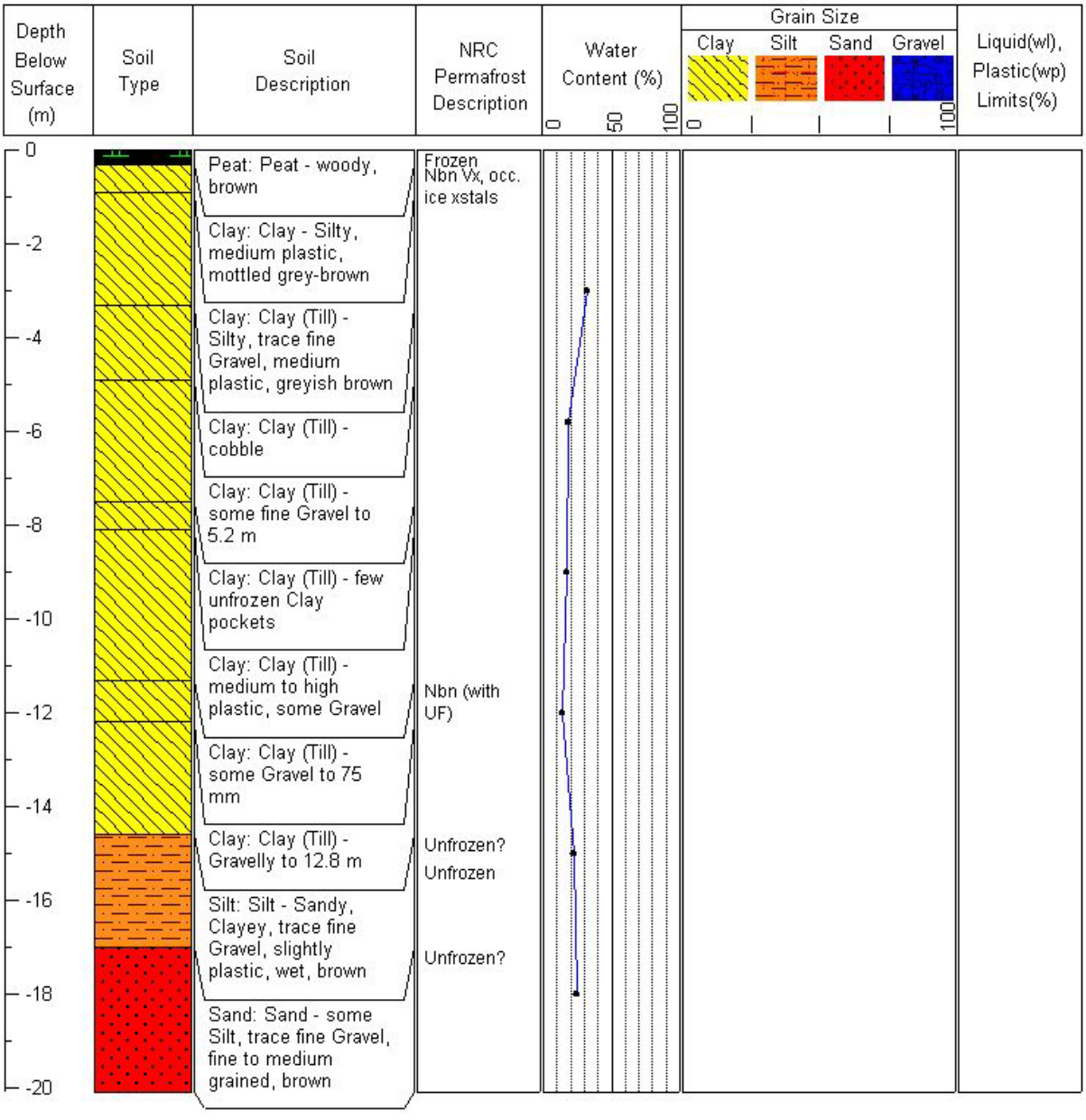
Borehole # : EMR85-7B-T4	Date: 17-Feb-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7053462
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 468671
Original Borehole # : EMR-85-7B-T-4/T-4A	Zone: 10
Report# : HAL85NWZM	Elevation(m): 265
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



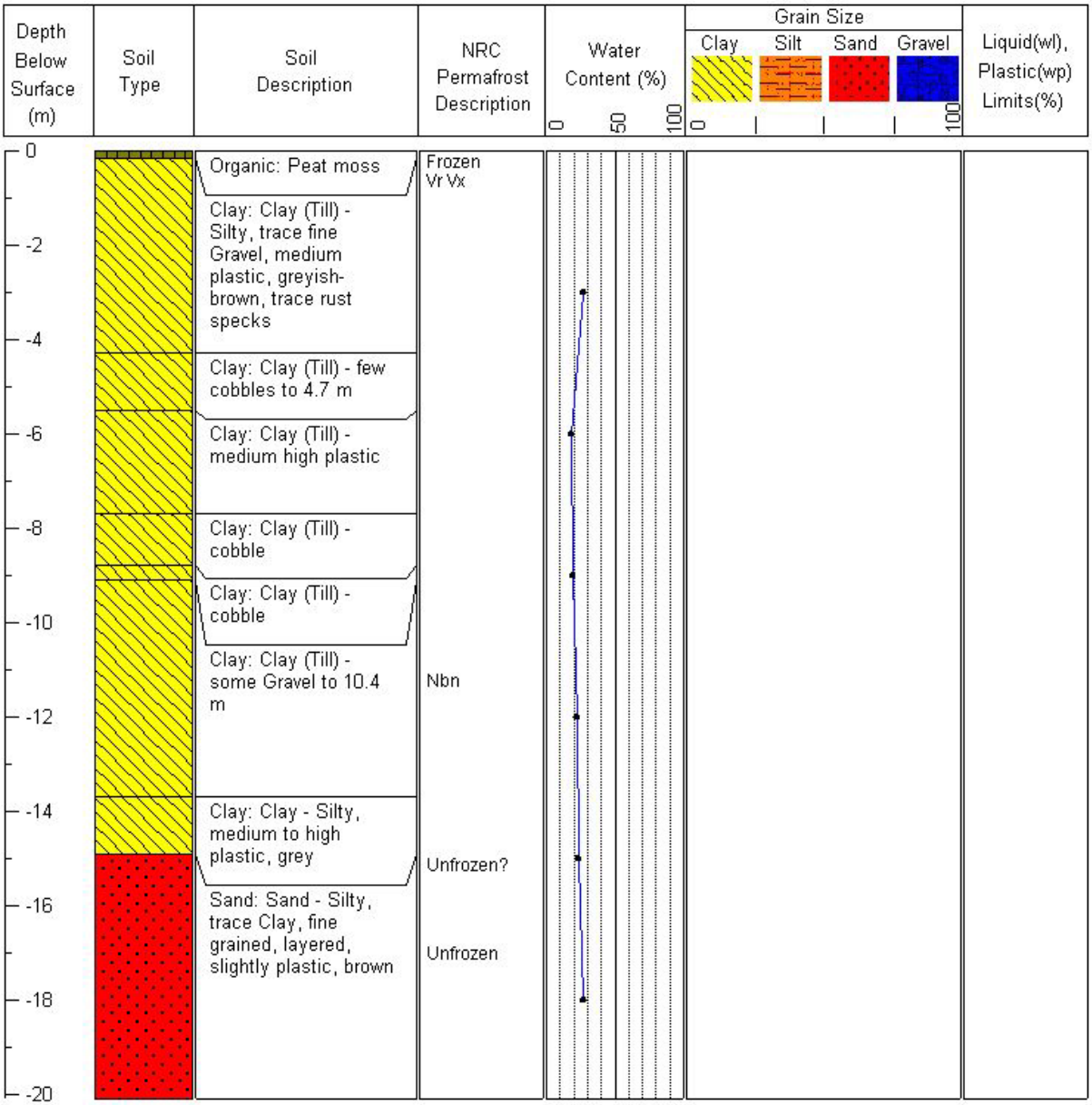
Borehole # : EMR85-7C-G1	Date: 26-Feb-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7053076
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 468755
Original Borehole # : EMR-85-7C-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 259
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/silt, glacial till



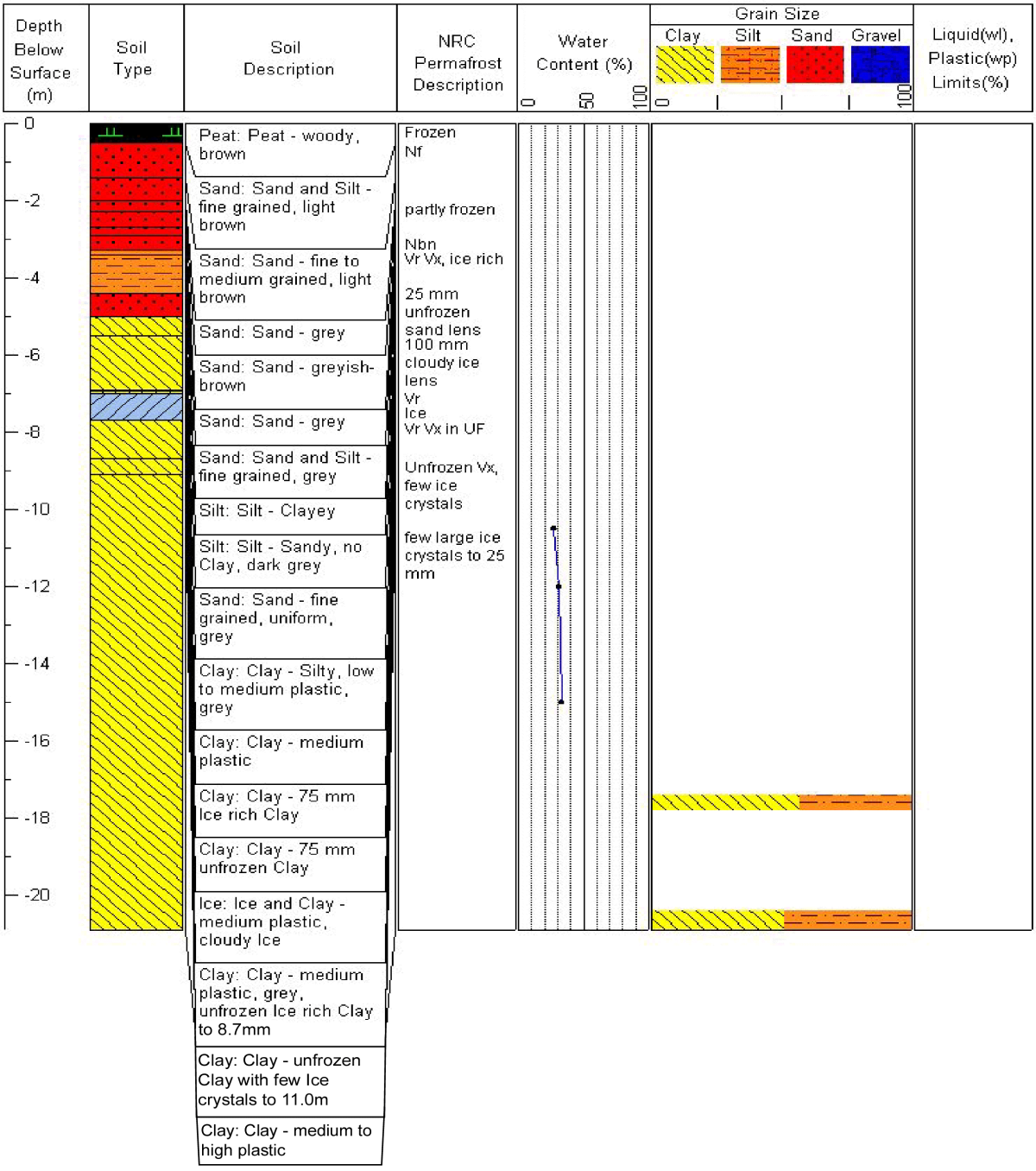
Borehole # : EMR85-7C-T3	Date: 27-Feb-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7053076
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 468755
Original Borehole # : EMR-85-7C-T-3	Zone: 10
Report# : HAL85NWZM	Elevation(m): 259
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/silt, glacial till



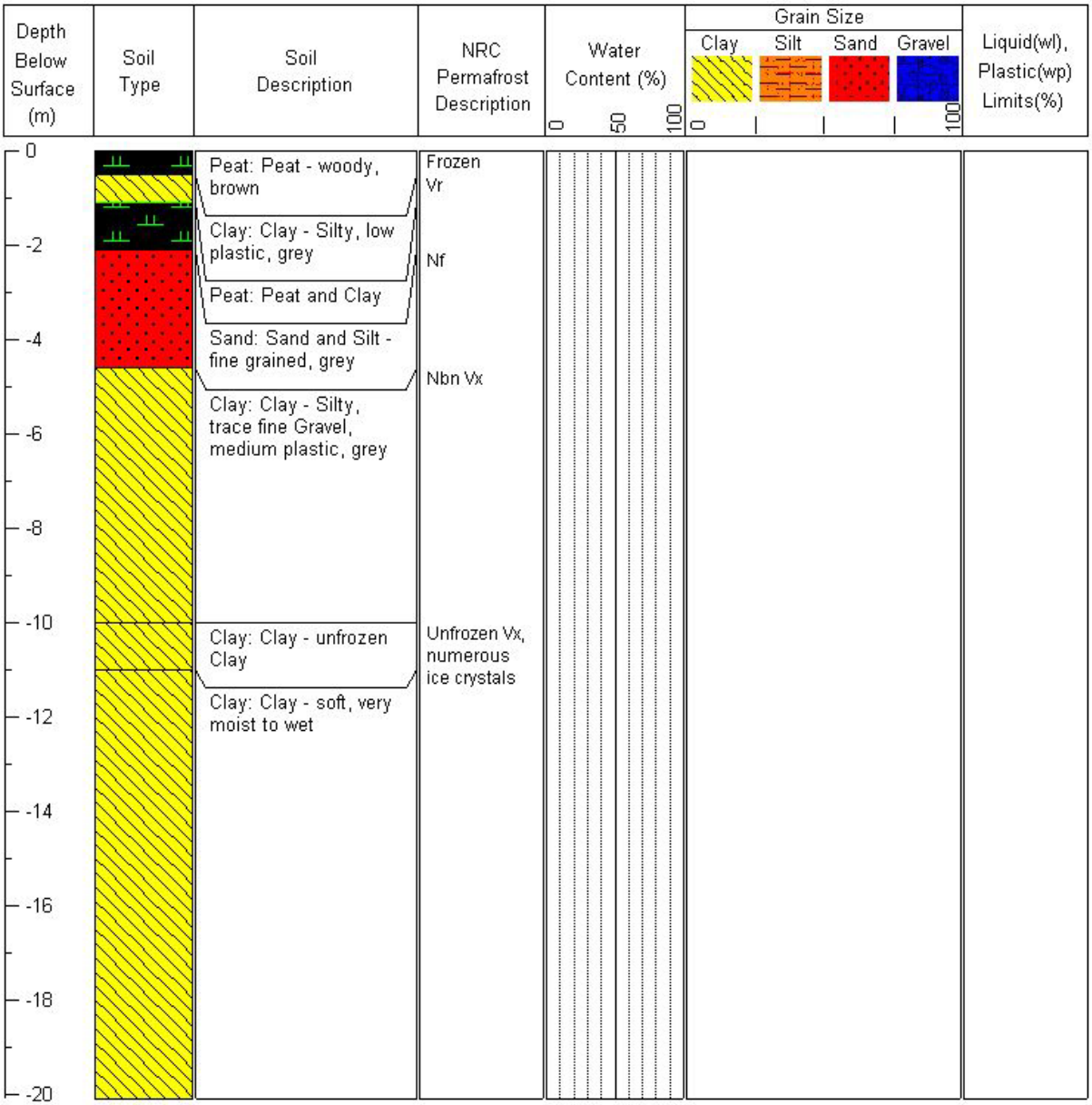
Borehole # : EMR85-7C-T4	Date: 27-Feb-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7053076
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 468755
Original Borehole # : EMR-85-7C-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 259
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/silt/sand, glacial till



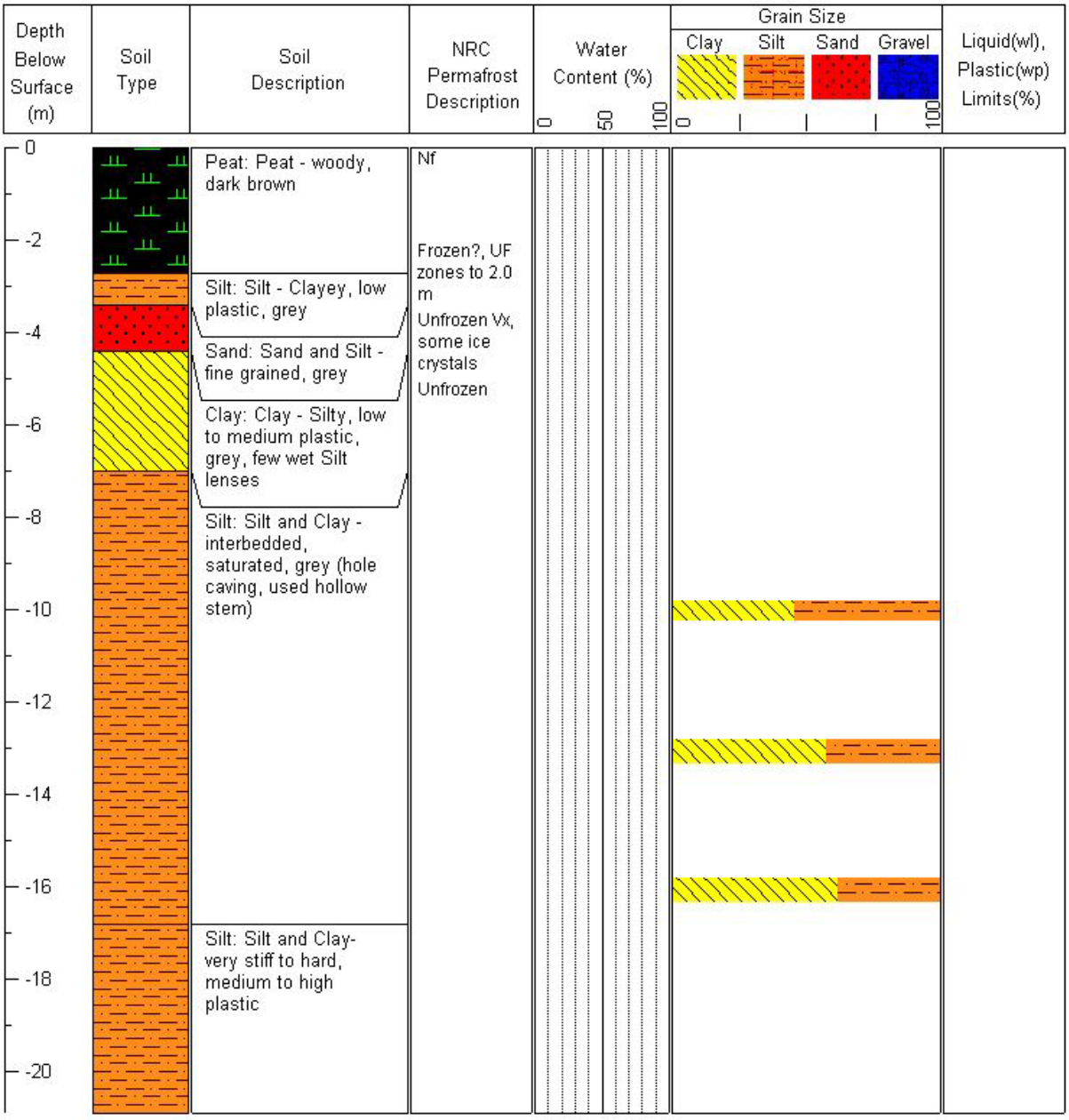
Borehole # : EMR85-8A-G1	Date: 05-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6831378
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 601248
Original Borehole # : EMR-85-8A-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 191
Permafrost Conditions: Frozen Landform:	Surface Material: clay/silt/sand



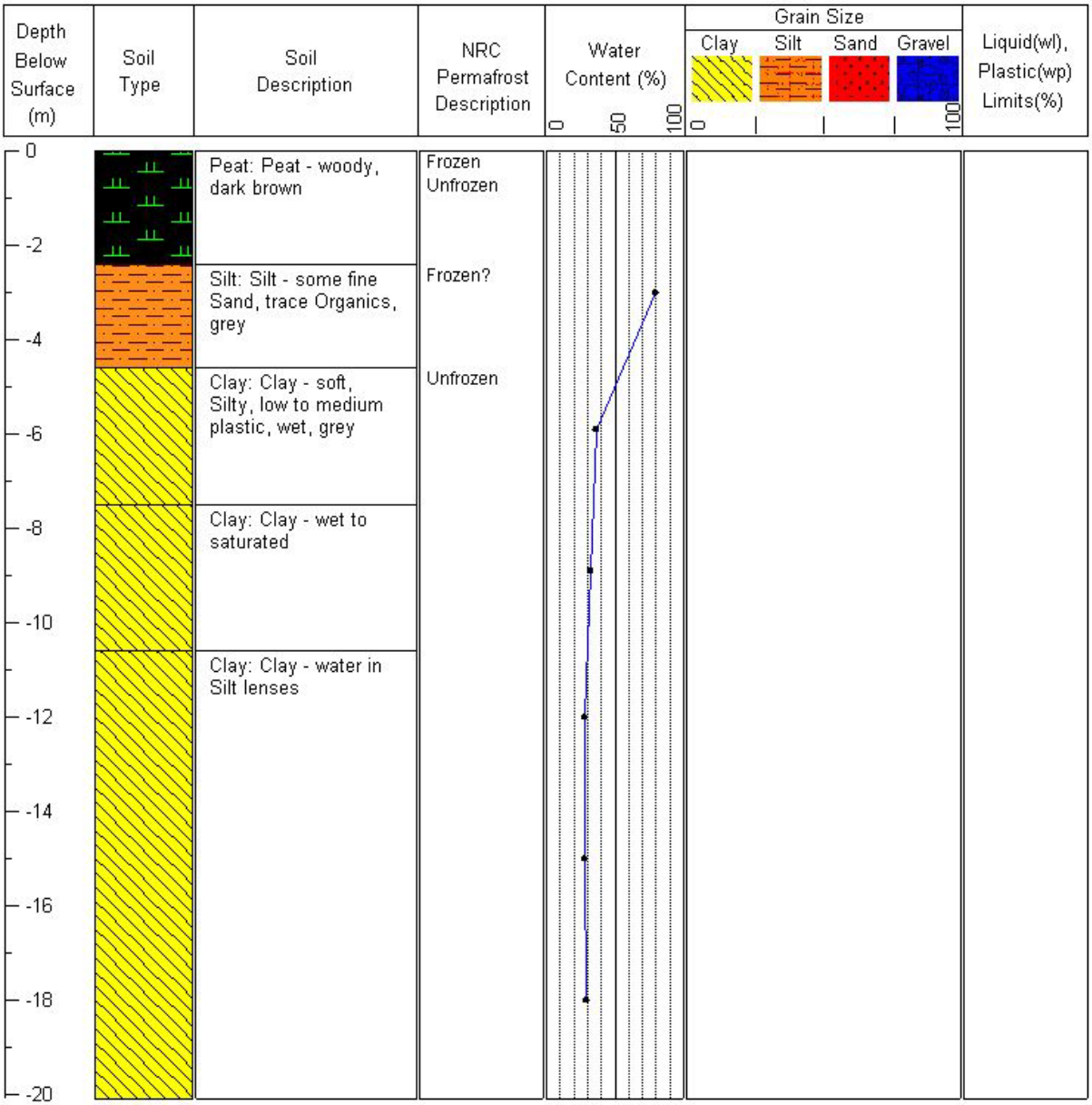
Borehole # : EMR85-8A-T4	Date: 03-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6831378
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 601248
Original Borehole # : EMR-85-8A-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 191
Permafrost Conditions: Frozen Landform:	Surface Material: sand/clay



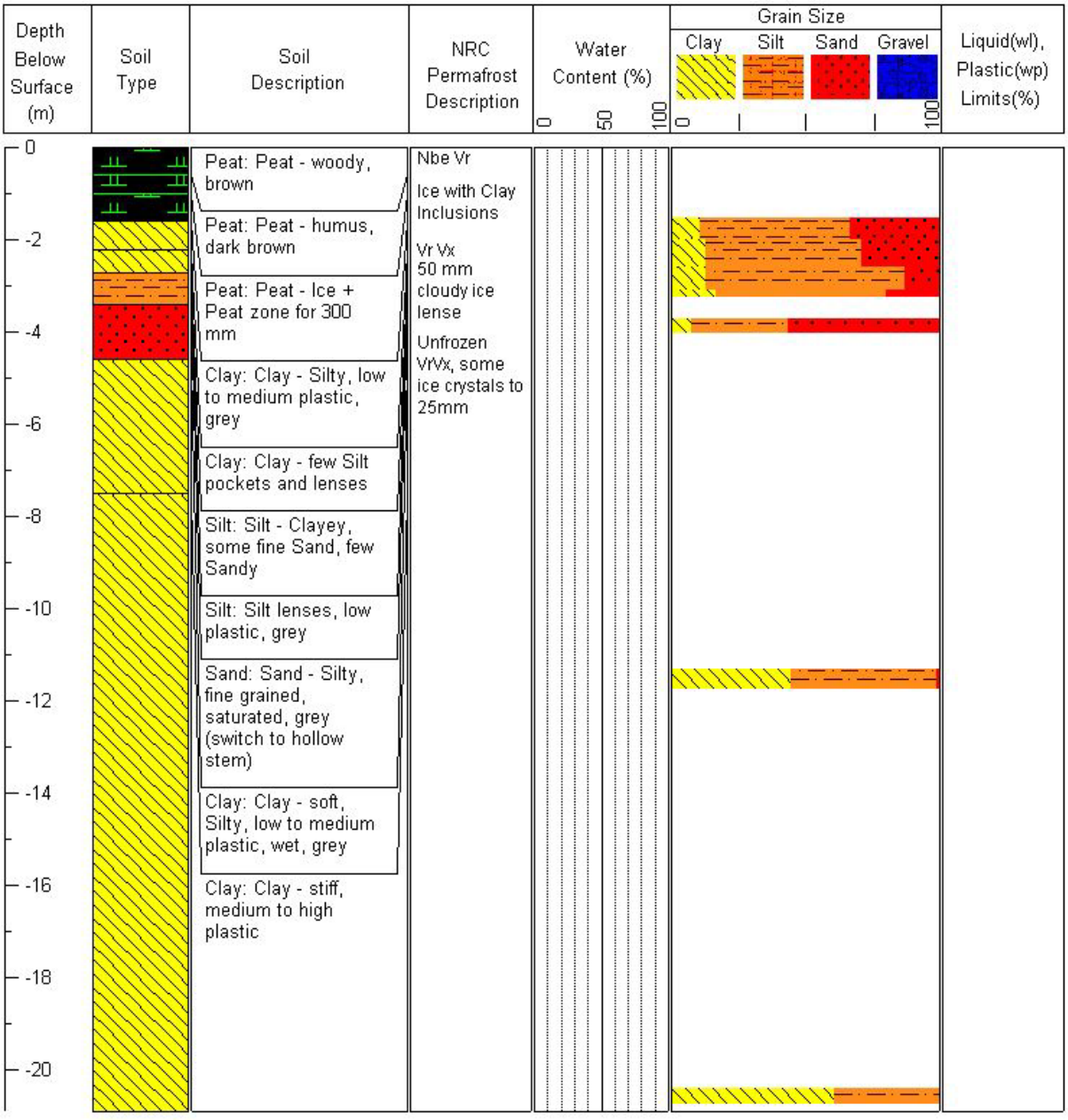
Borehole # : EMR85-8B-G1	Date: 06-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6831139
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 601429
Original Borehole # : EMR-85-8B-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 190
Permafrost Conditions: Frozen Landform:	Surface Material: sand/silt/clay



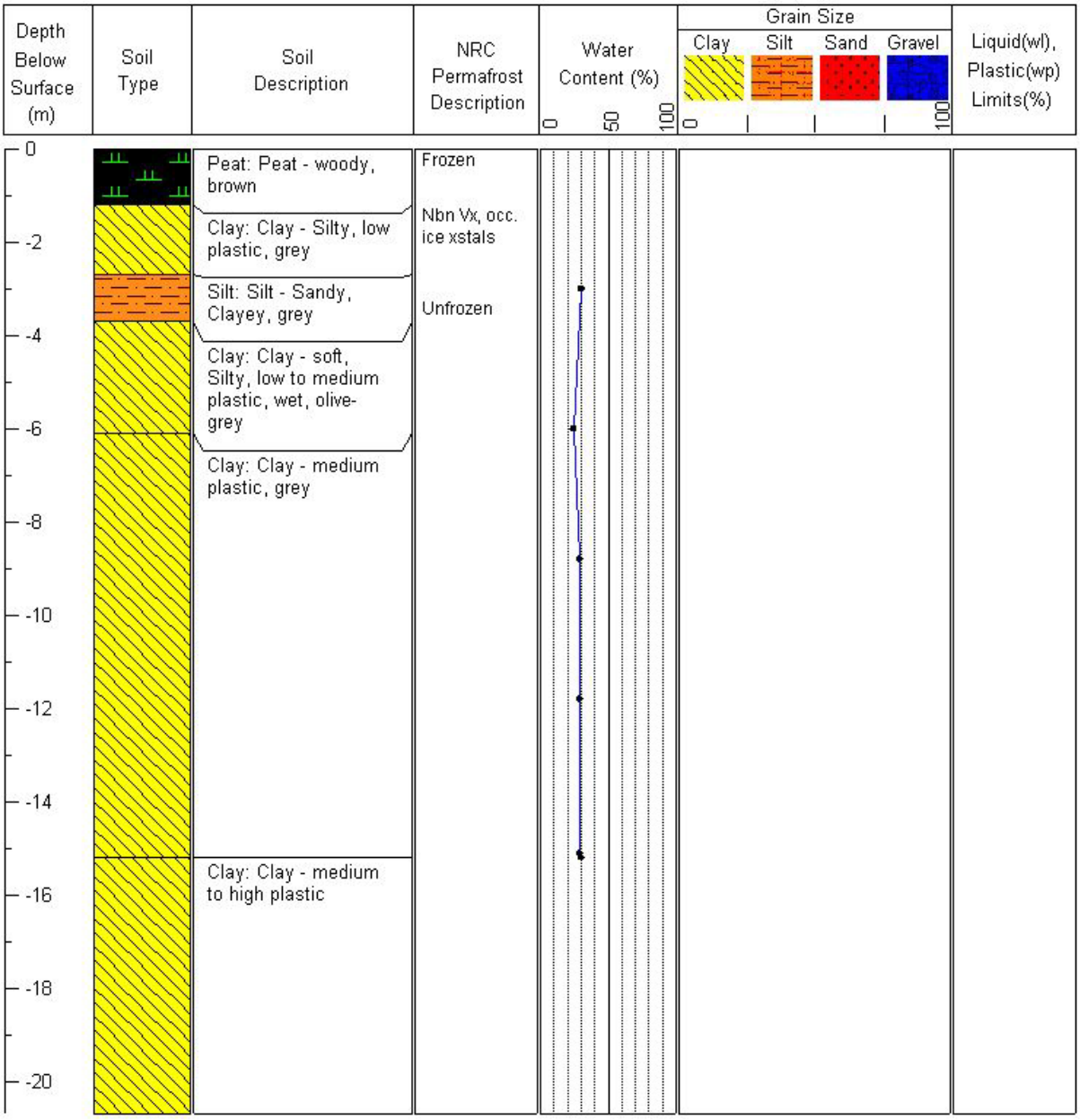
Borehole # : EMR85-8B-T4	Date: 05-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6831139
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 601429
Original Borehole # : EMR-85-8B-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 190
Permafrost Conditions: Frozen Landform:	Surface Material: silt/clay



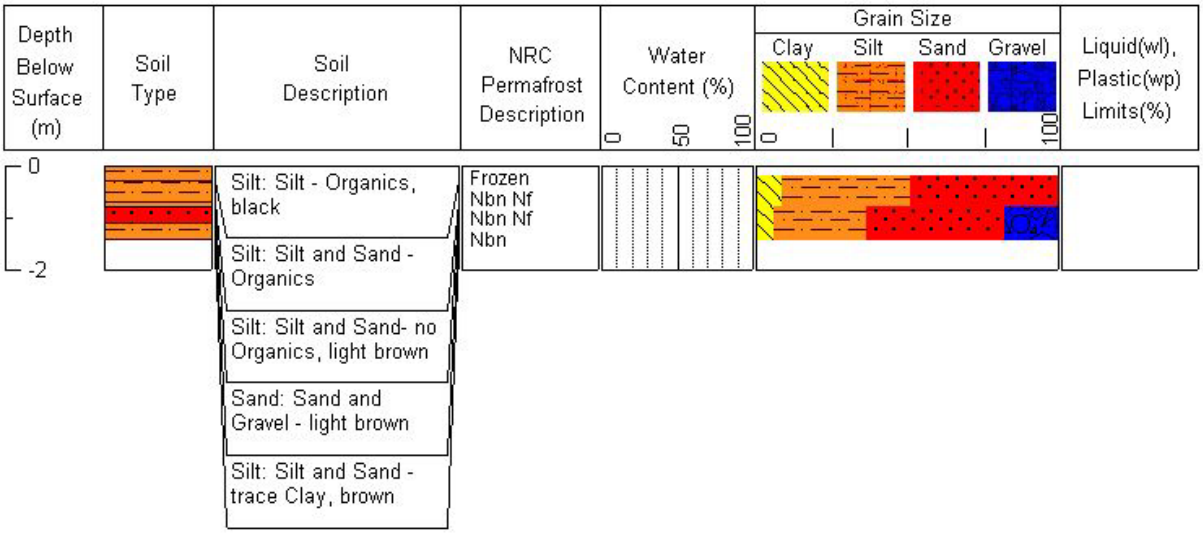
Borehole # : EMR85-8C-G1	Date: 06-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6830985
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 601557
Original Borehole # : EMR-85-8C-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 190
Permafrost Conditions: Frozen Landform:	Surface Material: silt/sand/clay



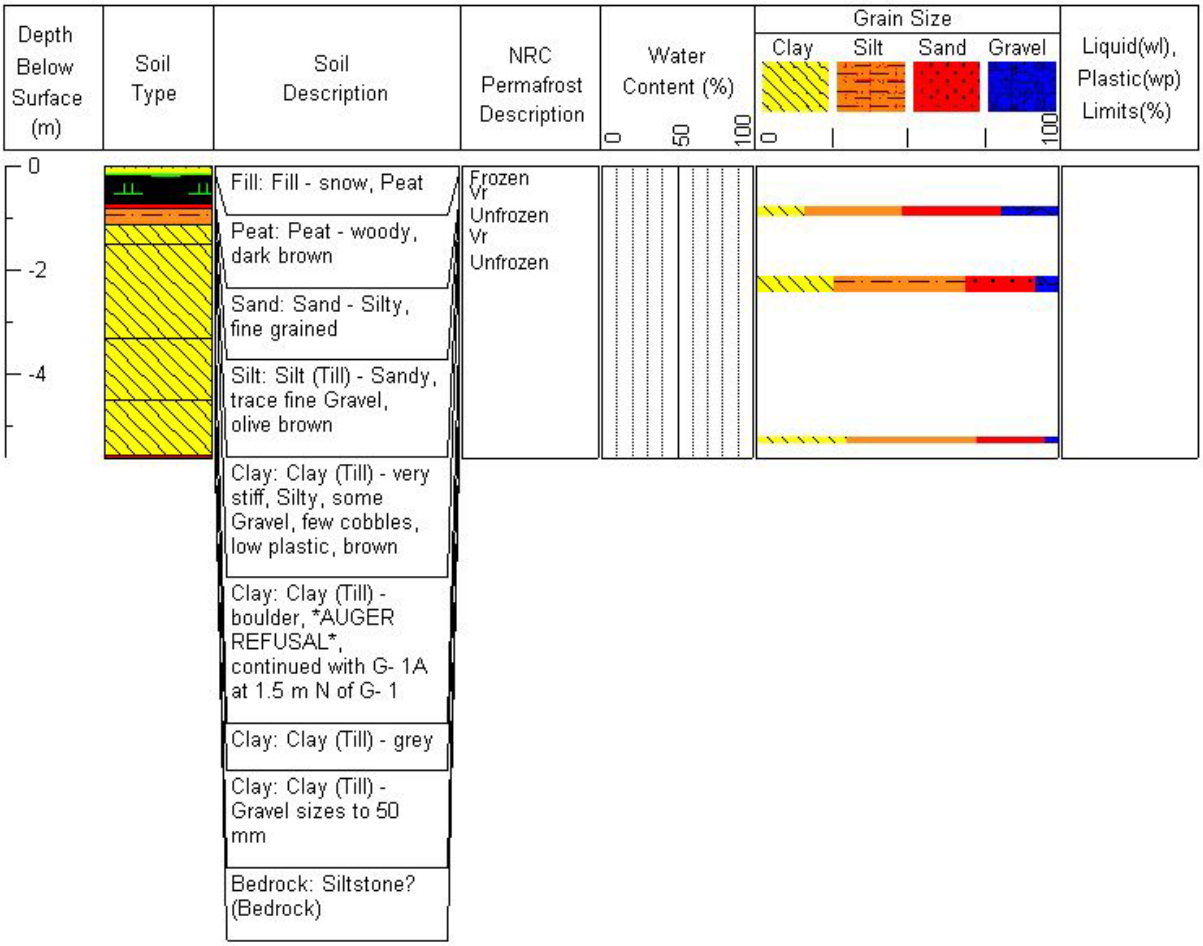
Borehole # : EMR85-8C-T4	Date: 06-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6830985
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 601557
Original Borehole # : EMR-85-8C-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 190
Permafrost Conditions: Frozen Landform:	Surface Material: silt/clay



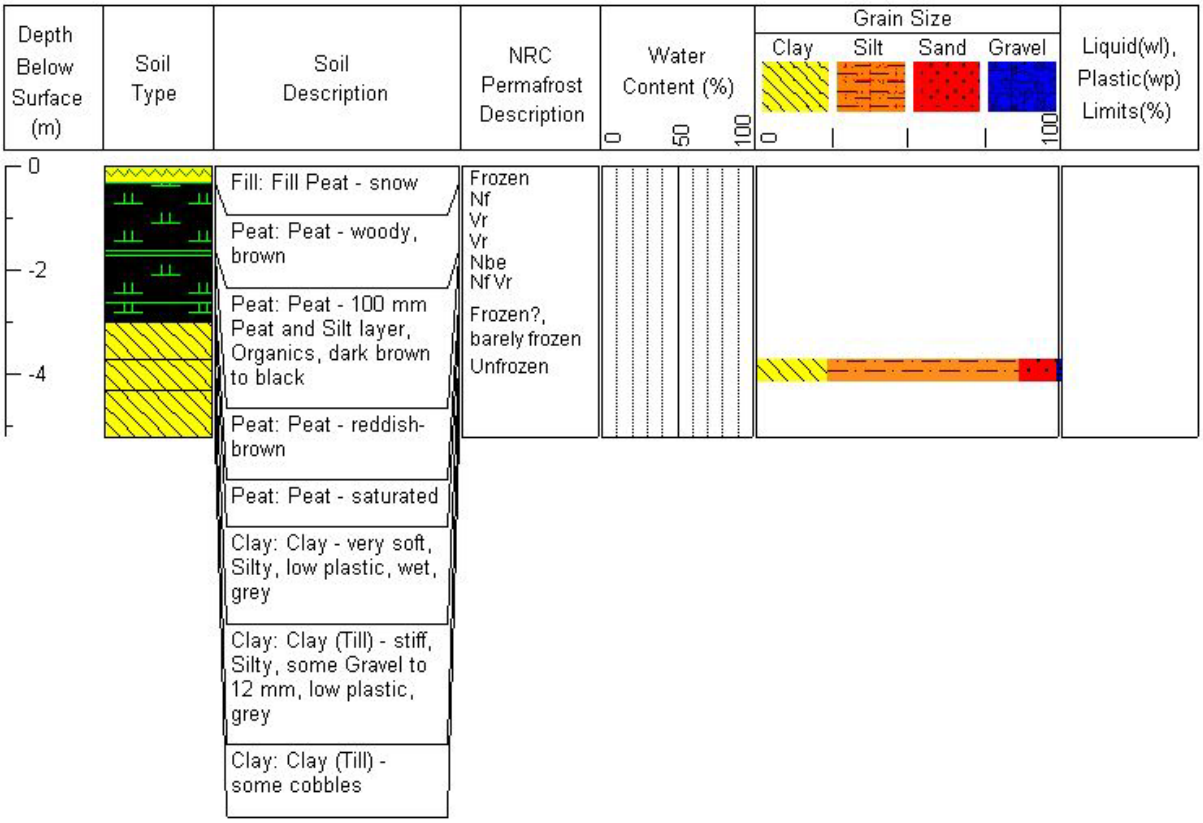
Borehole # : EMR85-9-G1	Date: 07-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6808564
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 612030
Original Borehole # : EMR-85-9-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 223
Permafrost Conditions: Frozen Landform:	Surface Material: silt/sand/gravel



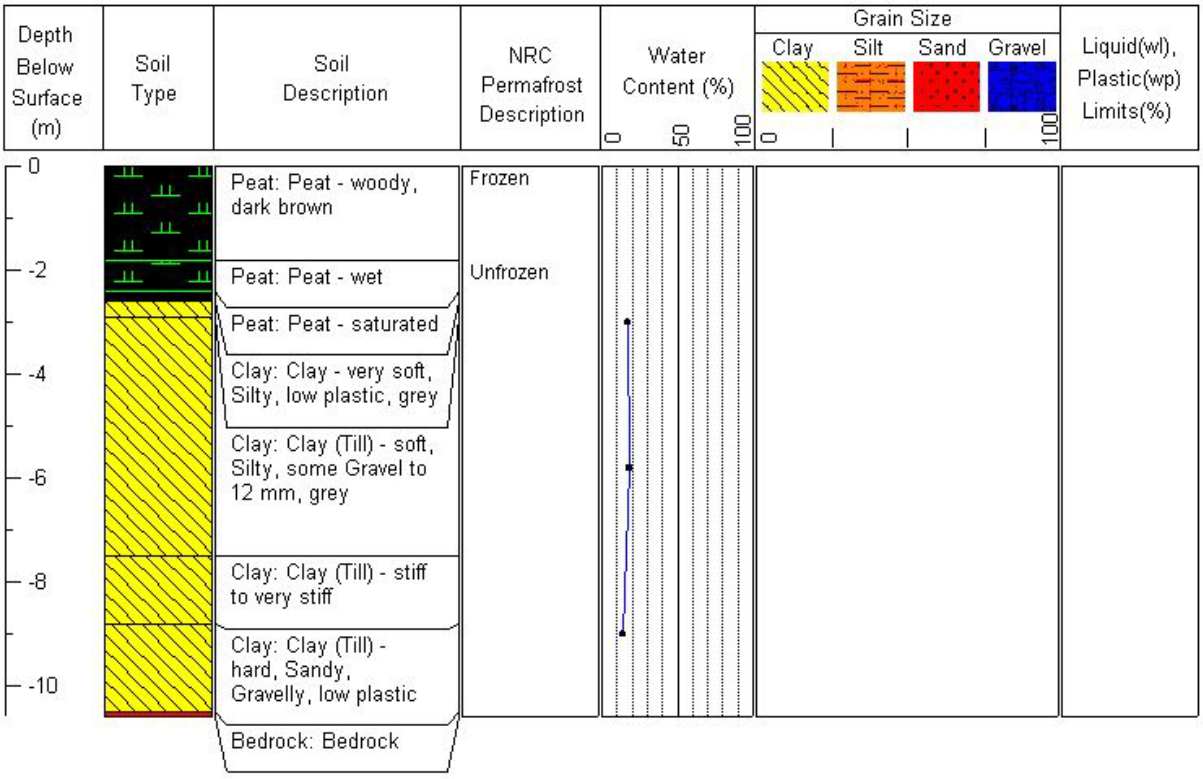
Borehole # : EMR85-10A-G1	Date: 09-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6804155
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 614129
Original Borehole # : EMR-85-10A-G-1/1A	Zone: 10
Report# : HAL85NWZM	Elevation(m):
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: silt/sand, glacial till



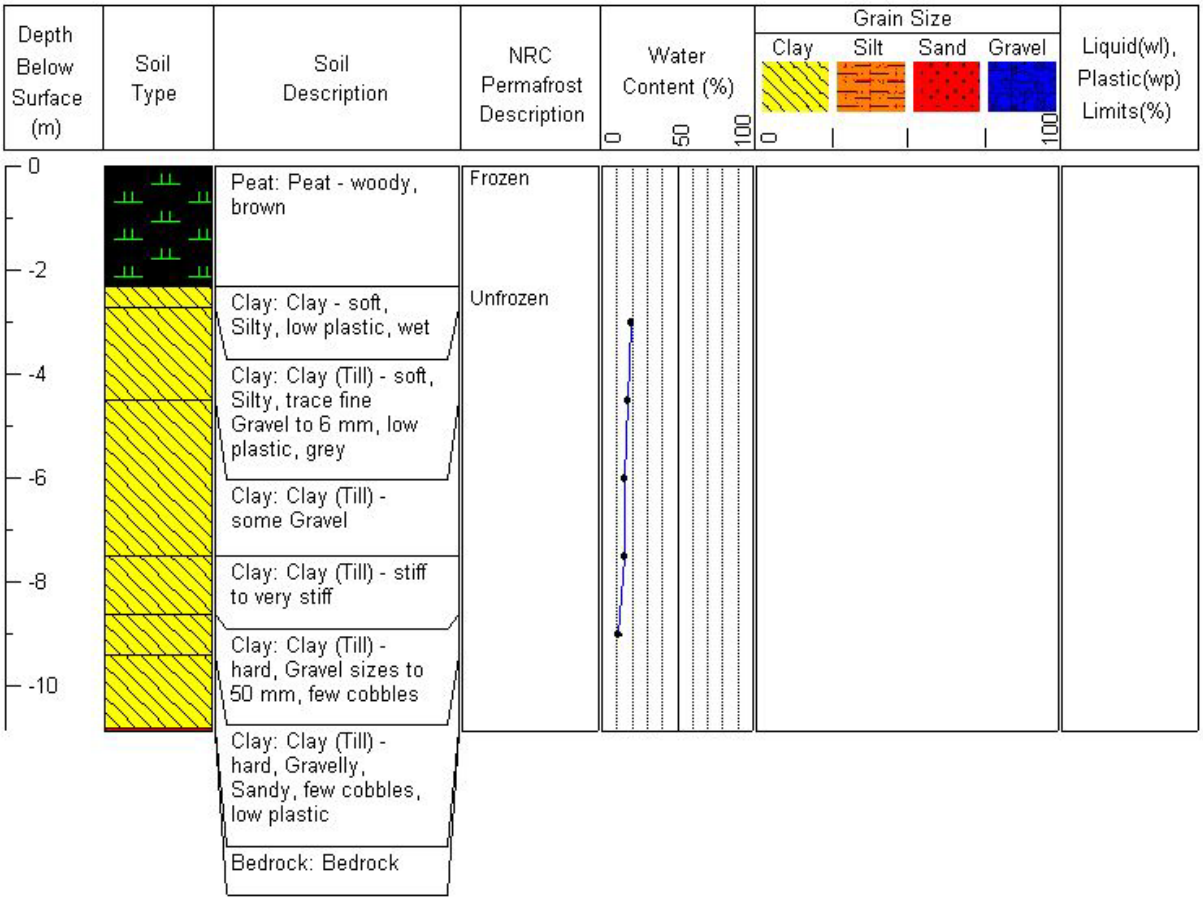
Borehole # : EMR85-10B-G1	Date: 09-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6803790
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 614292
Original Borehole # : EMR-85-10B-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 244
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



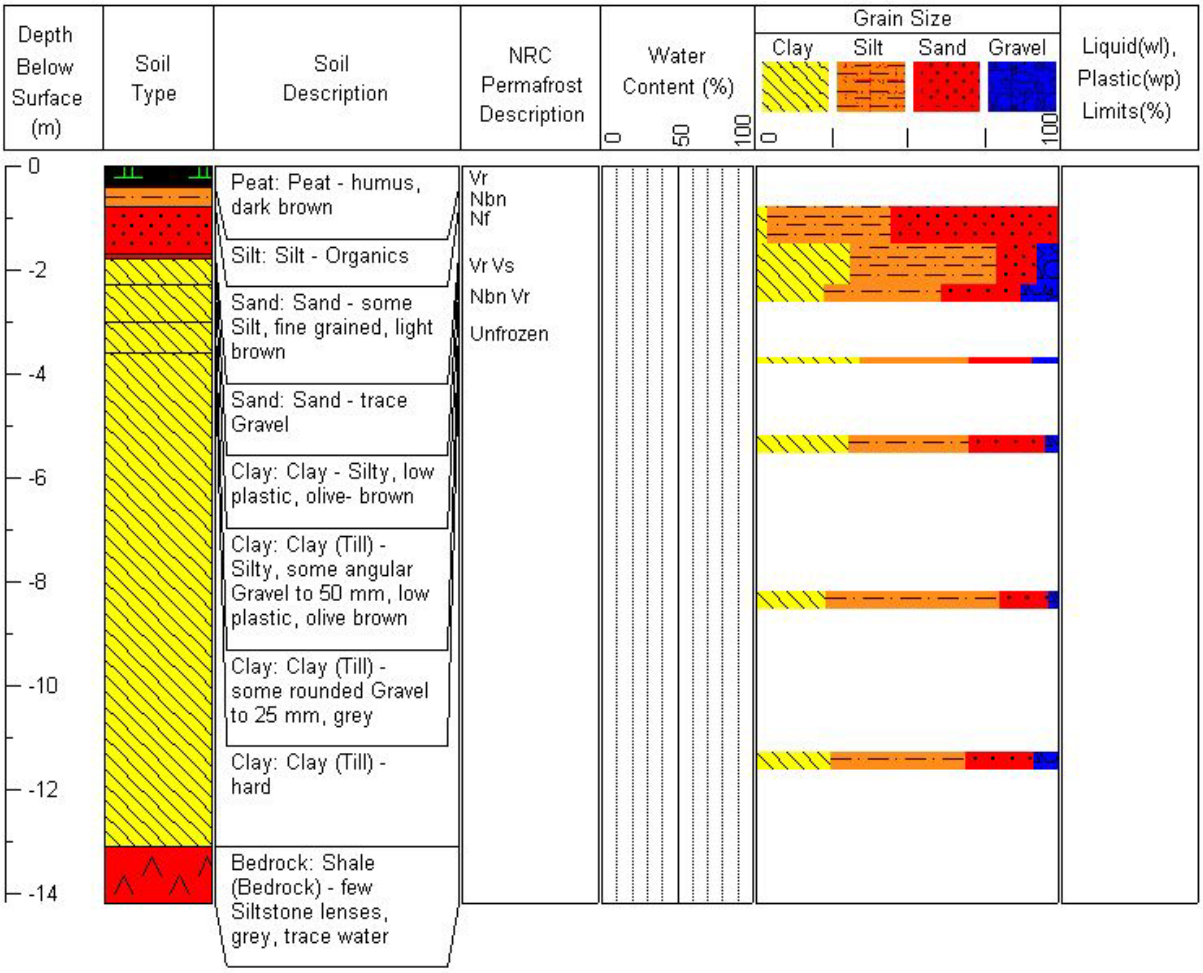
Borehole # : EMR85-10B-T3	Date: 09-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6803790
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 614292
Original Borehole # : EMR-85-10B-T-3	Zone: 10
Report# : HAL85NWZM	Elevation(m): 244
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/bedrock, glacial till



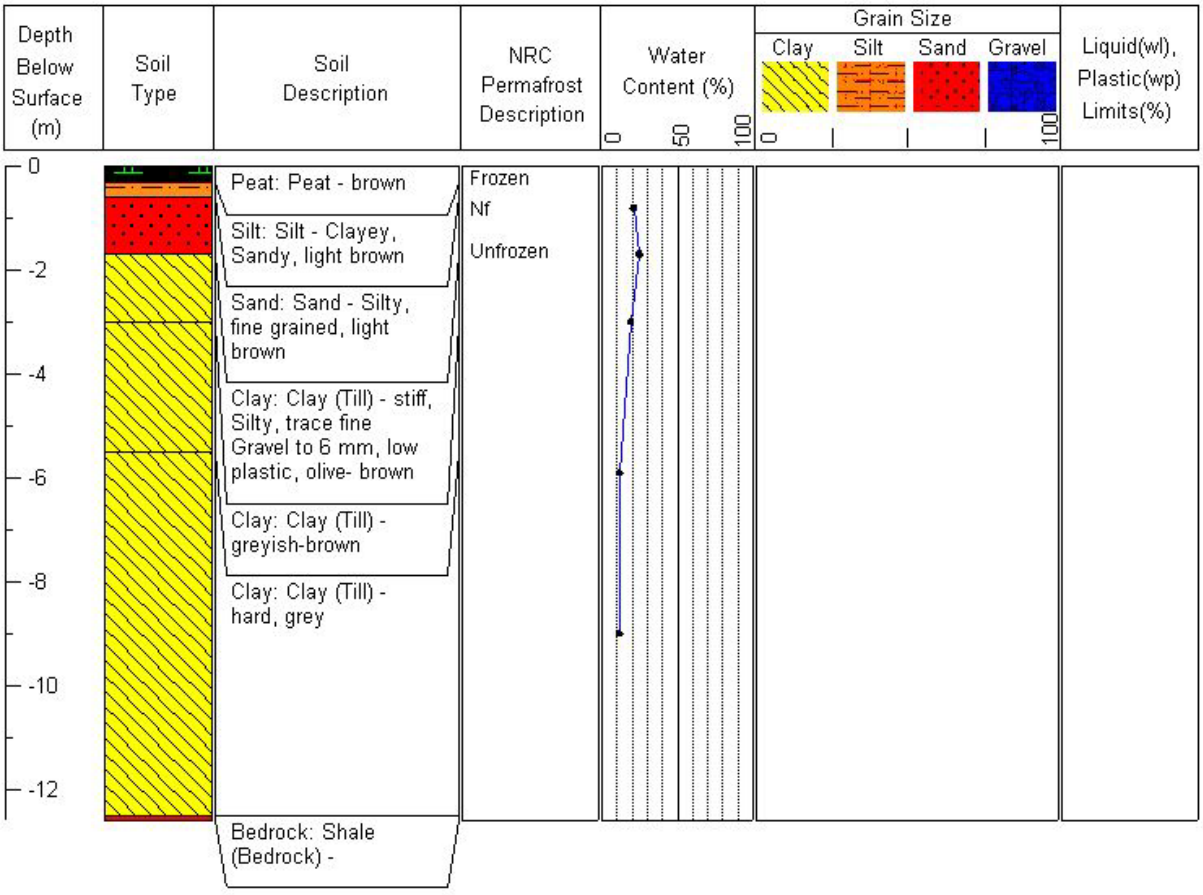
Borehole # : EMR85-10B-T4	Date: 09-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6803790
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 614292
Original Borehole # : EMR-85-10B-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 244
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/bedrock, glacial till



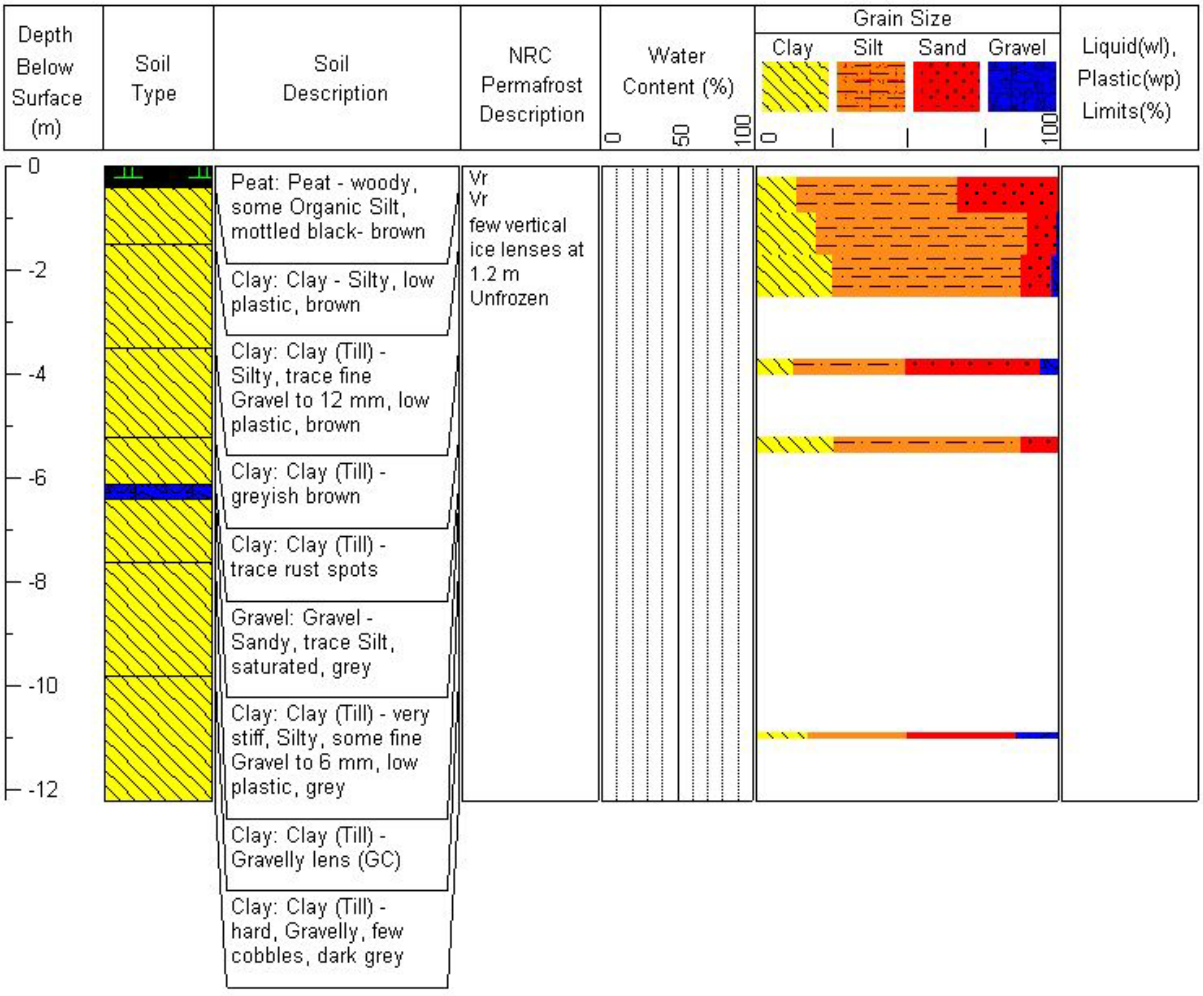
Borehole # : EMR85-11-G1	Date: 08-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6795916
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 617943
Original Borehole # : EMR-85-11-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 251
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: sand/clay/bedrock, glacial till



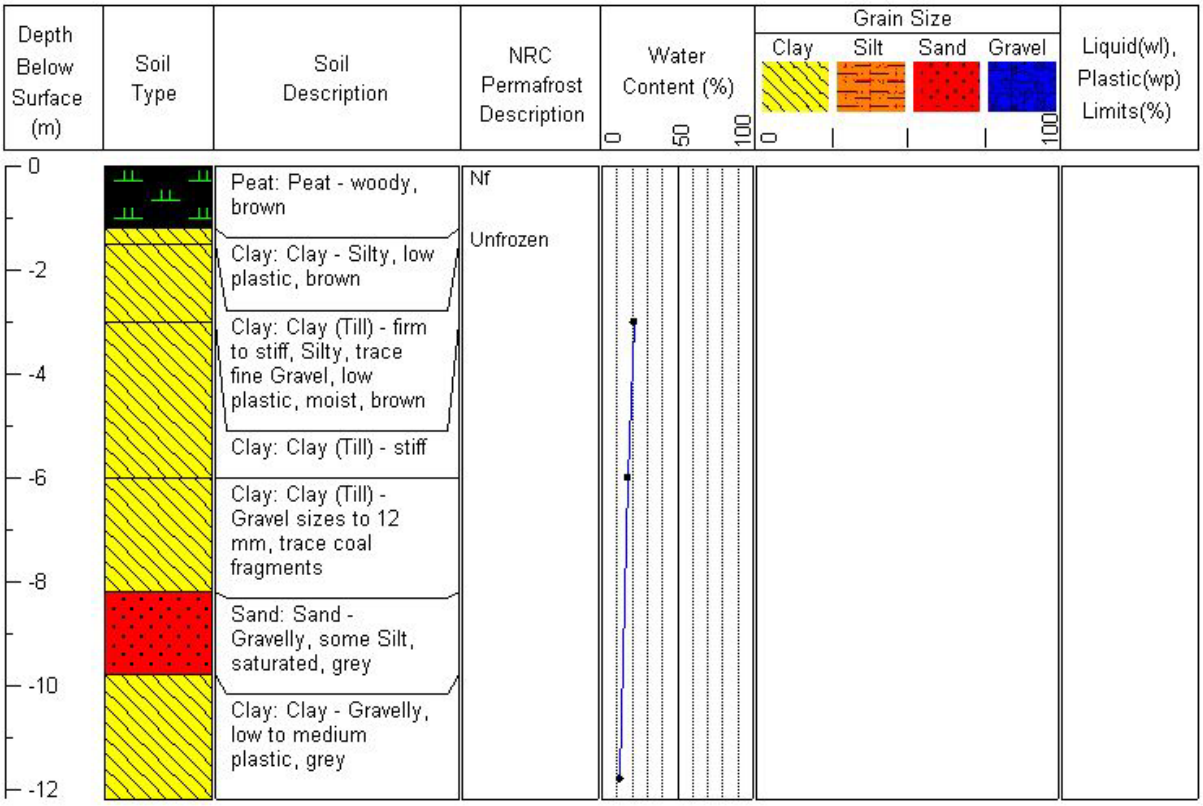
Borehole # : EMR85-11-T4	Date: 08-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6795916
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 617943
Original Borehole # : EMR-85-11-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 251
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: sand/clay/bedrock, glacial till



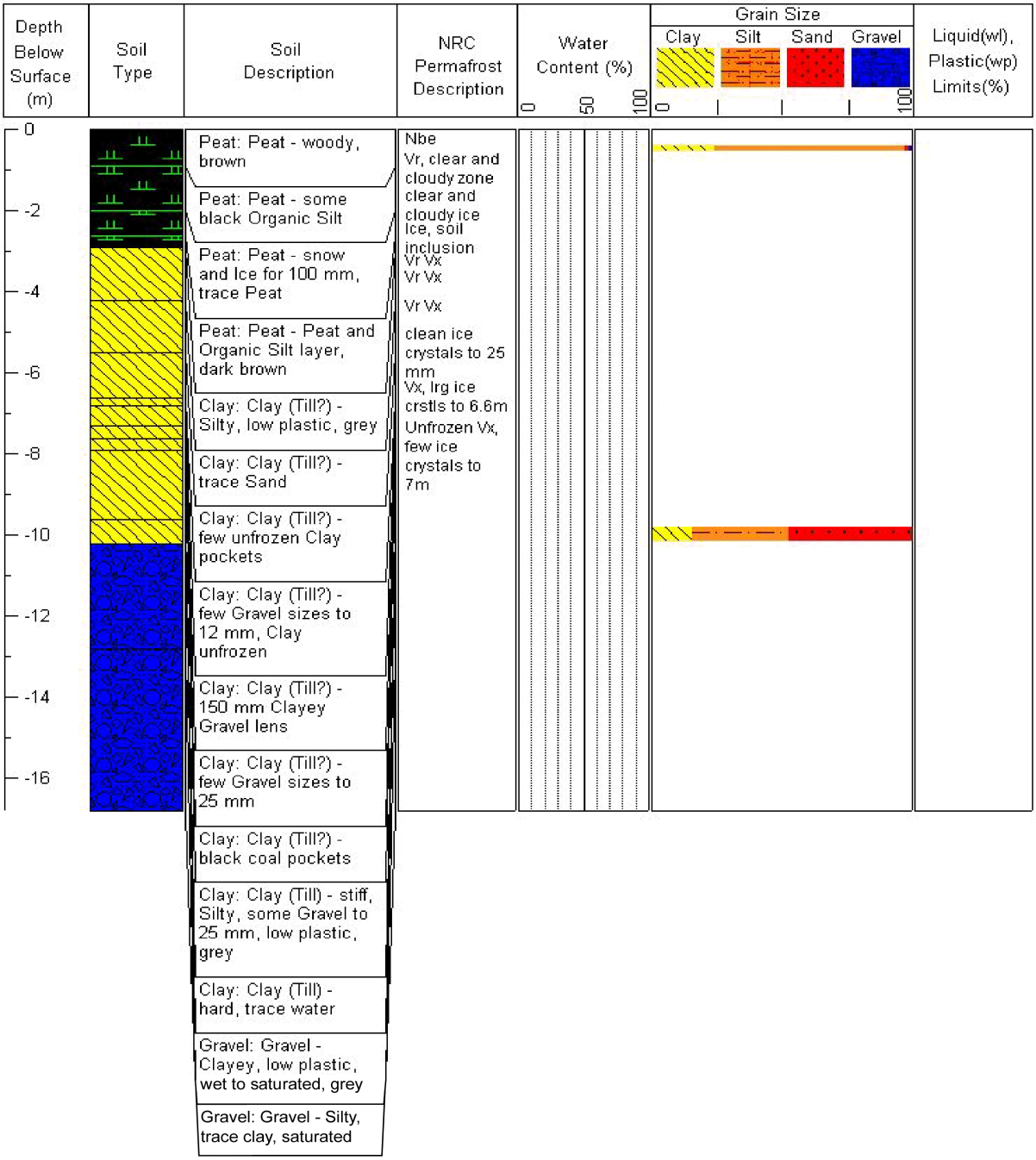
Borehole # : EMR85-12A-G1	Date: 08-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6777939
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 638895
Original Borehole # : EMR-85-12A-G-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 298
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/gravel, glacial till



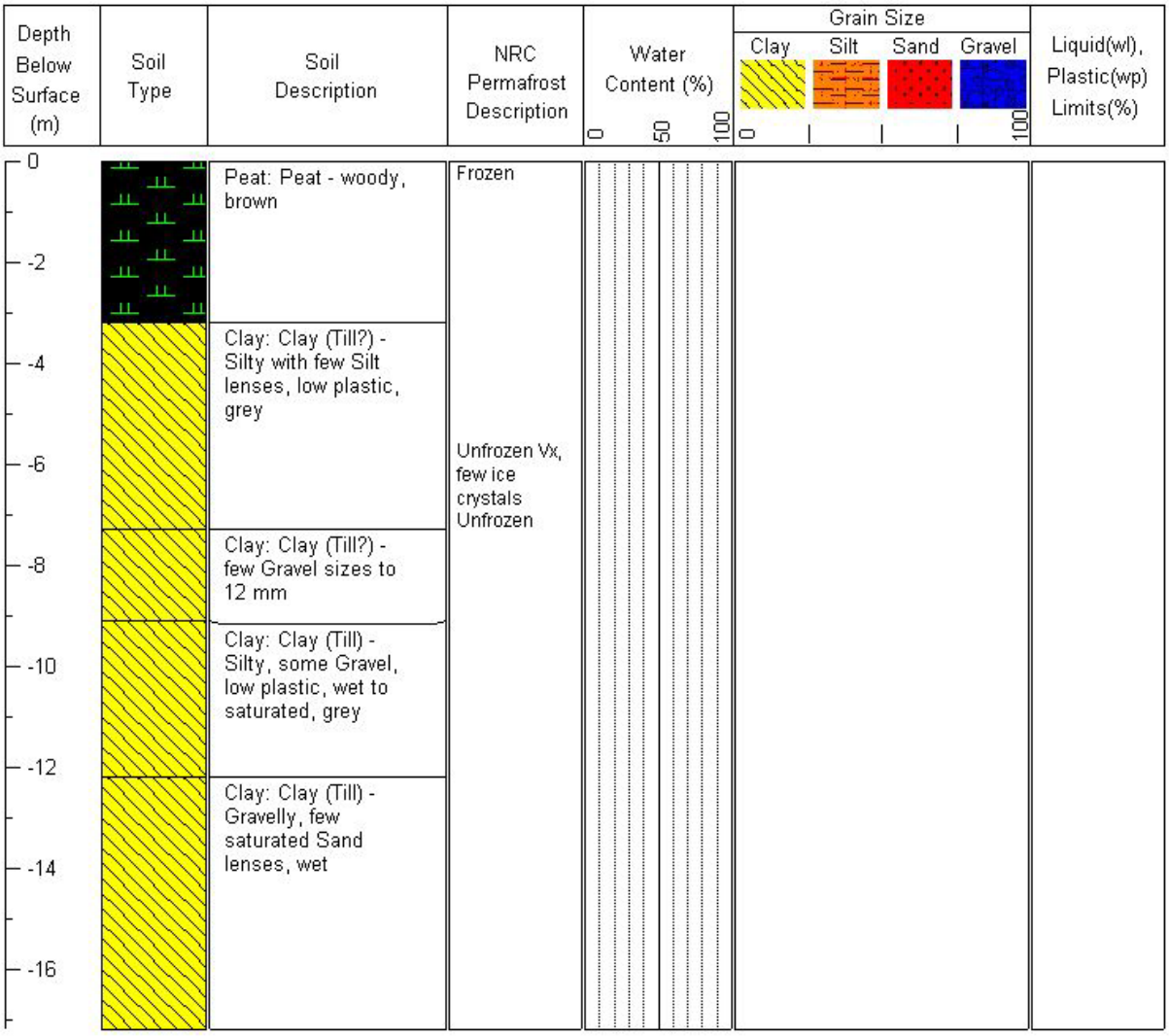
Borehole # : EMR85-12A-T4	Date: 08-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6777939
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 638895
Original Borehole # : EMR-85-12A-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 298
Permafrost Conditions: Unfrozen Landform: ground moraine	Surface Material: clay/sand, glacial till



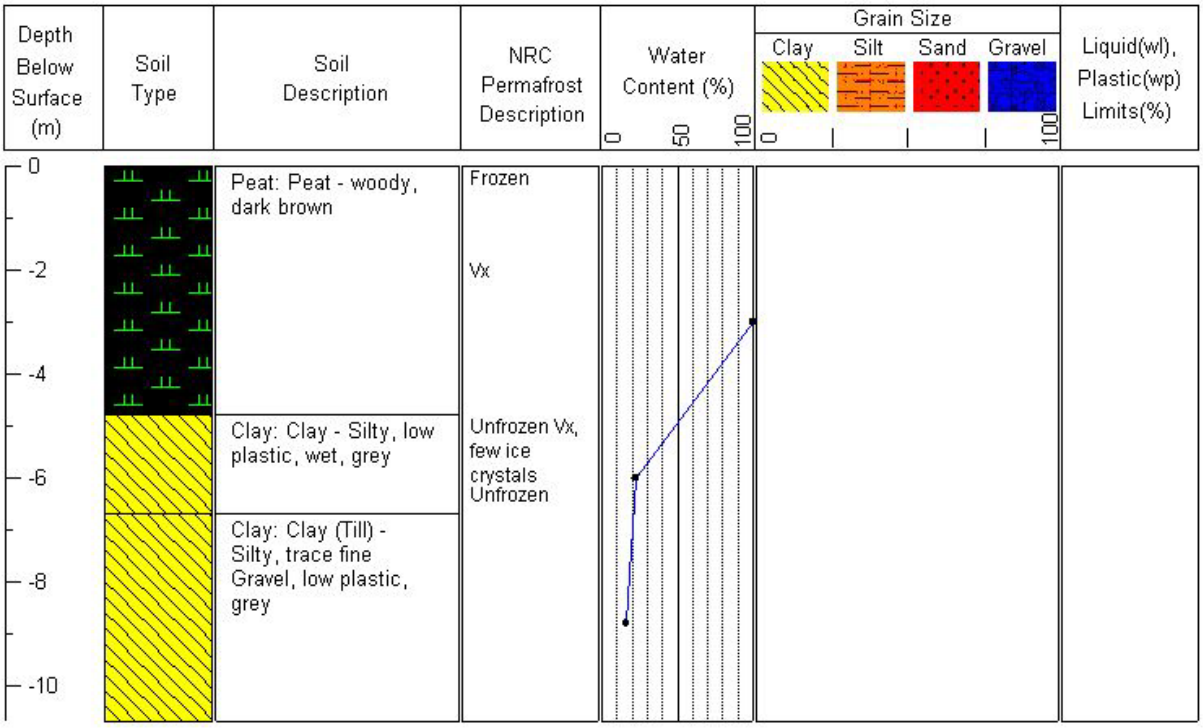
Borehole #: EMR85-12B-G1	Date: 07-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6777895
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 638913
Original Borehole #: EMR-85-12B-G-1	Zone: 10
Report#: HAL85NWZM	Elevation(m): 300
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay/gravel, glacial till



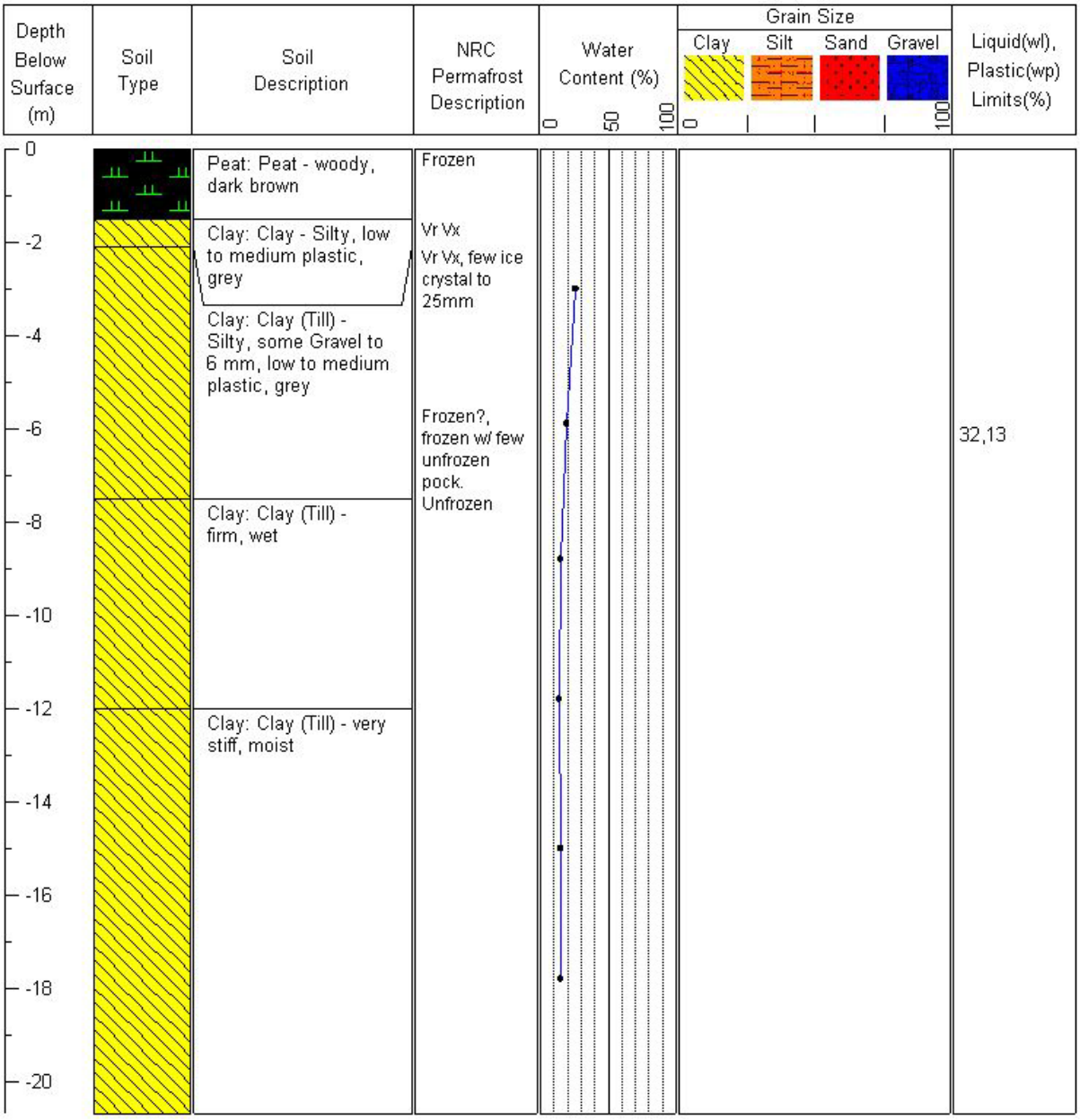
Borehole # : EMR85-12B-T3	Date: 07-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6777895
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 638913
Original Borehole # : EMR-85-12B-T-3	Zone: 10
Report# : HAL85NWZM	Elevation(m): 300
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



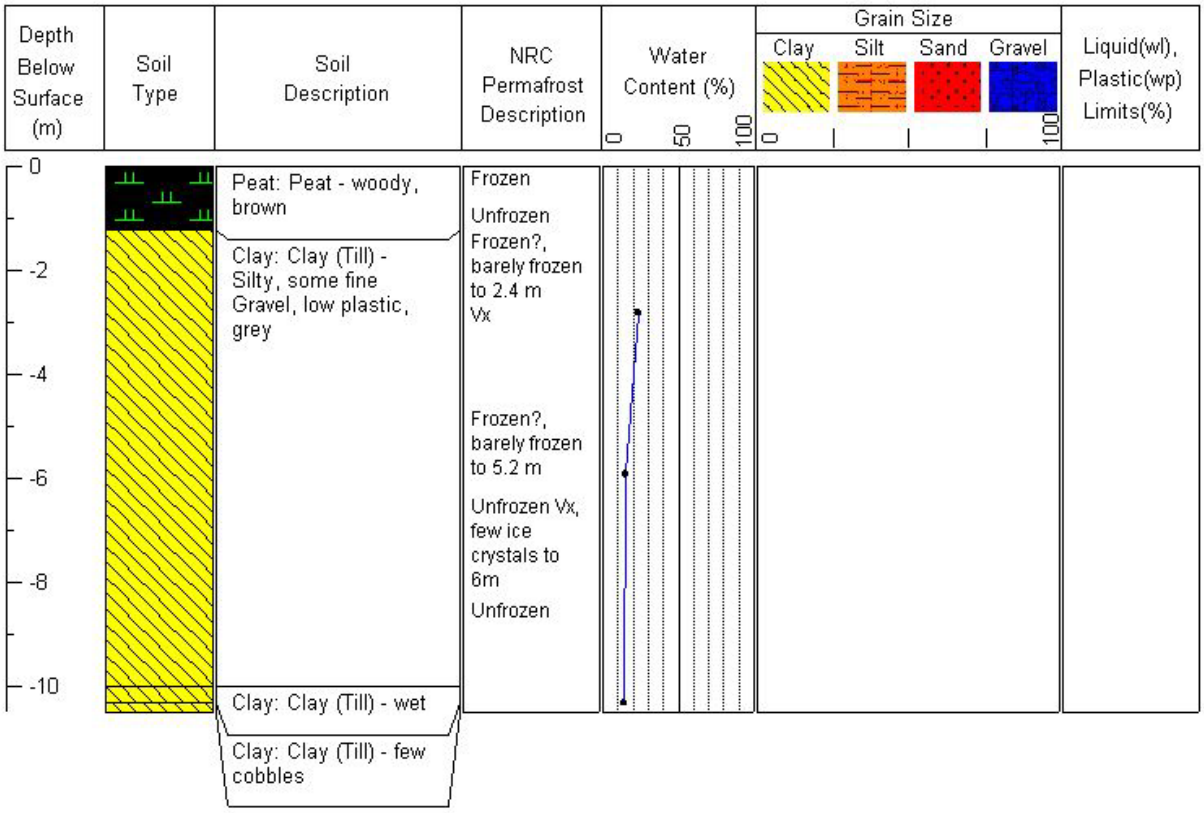
Borehole # : EMR85-12B-T4	Date: 07-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6777895
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 638913
Original Borehole # : EMR-85-12B-T-4	Zone: 10
Report# : HAL85NWZM	Elevation(m): 300
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



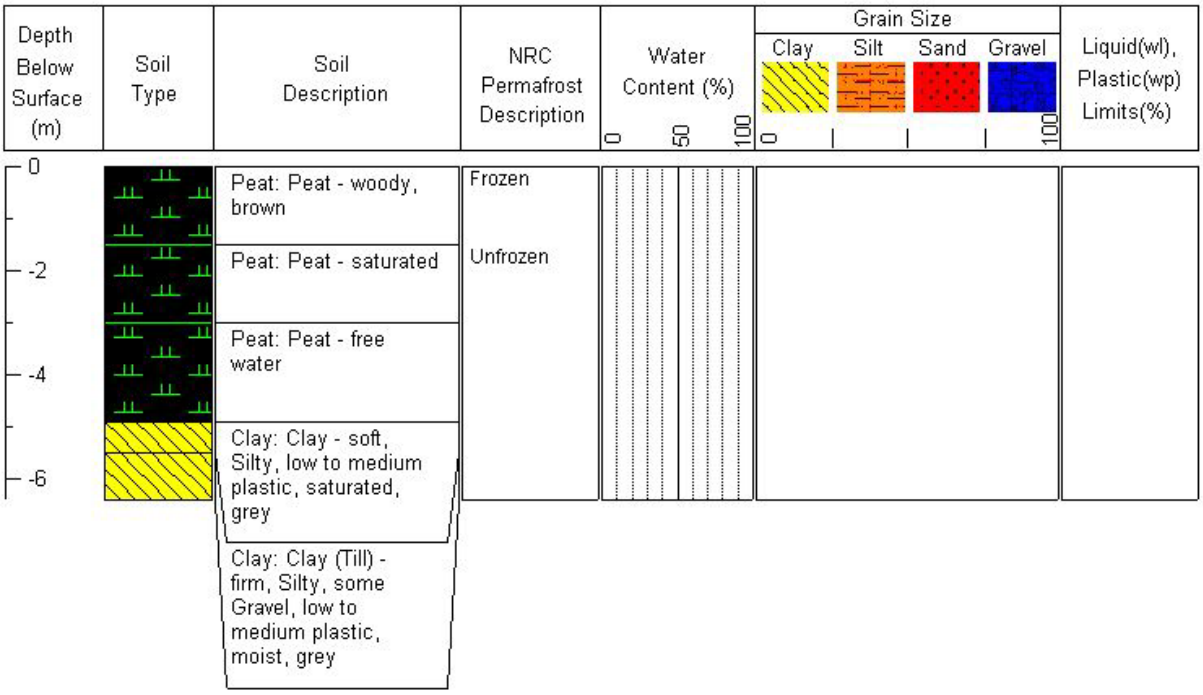
Borehole # : EMR85-13A-T1	Date: 04-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6717511
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 648623
Original Borehole # : EMR-85-13A-T-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 634
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



Borehole # : EMR85-13BT1A	Date: 04-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6717328
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 648705
Original Borehole # : EMR-85-13B-T-1A	Zone: 10
Report# : HAL85NWZM	Elevation(m): 634
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till



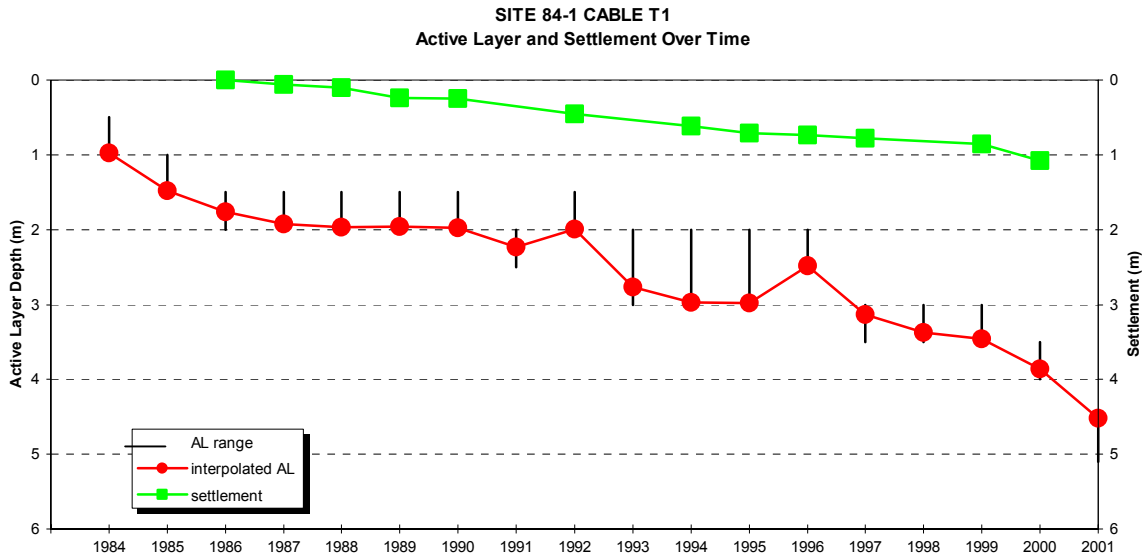
Borehole # : EMR85-13C-T1	Date: 04-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6717146
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 648786
Original Borehole # : EMR-85-13C-T-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 634
Permafrost Conditions: Frozen Landform: ground moraine	Surface Material: clay, glacial till

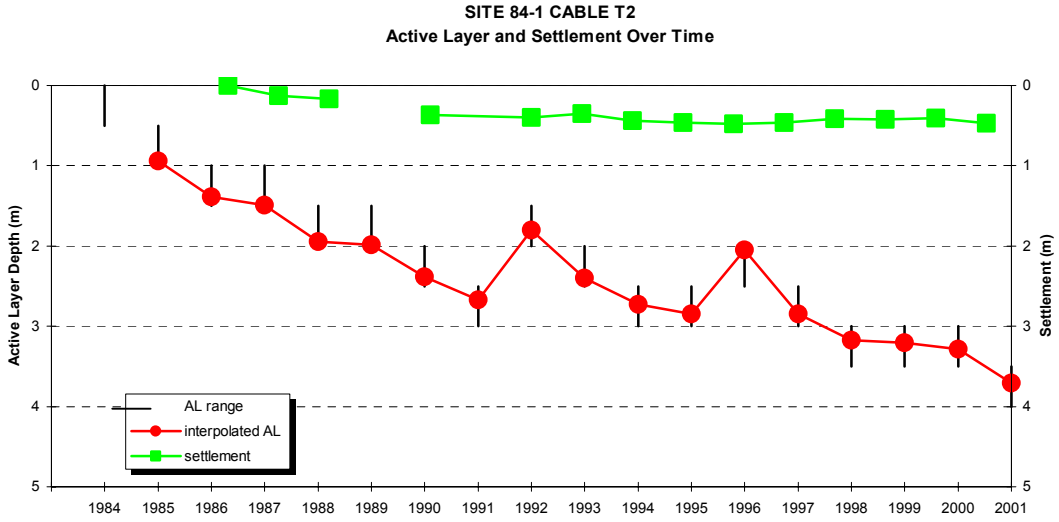


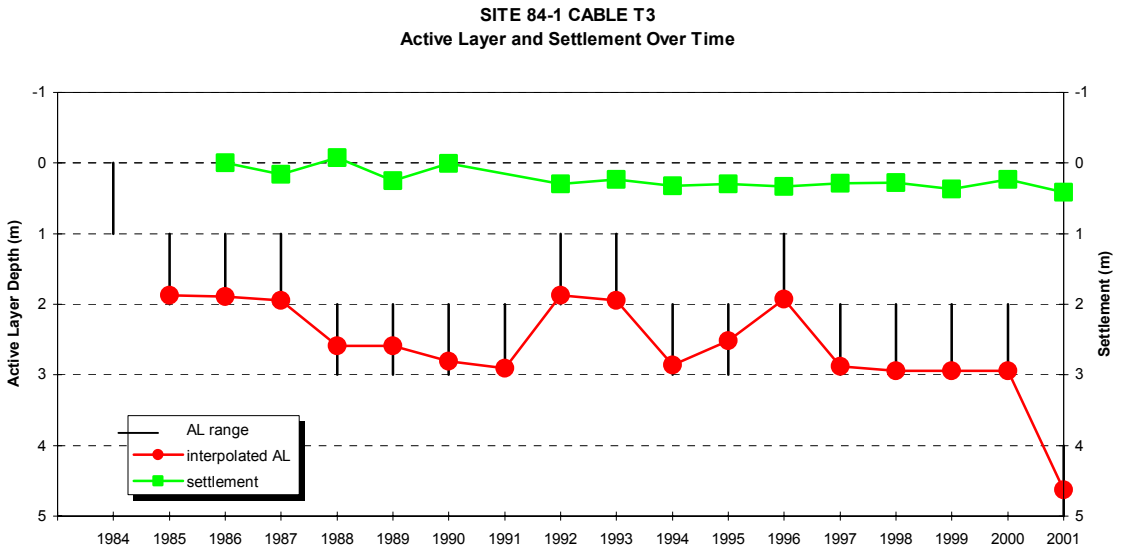
APPENDIX 2

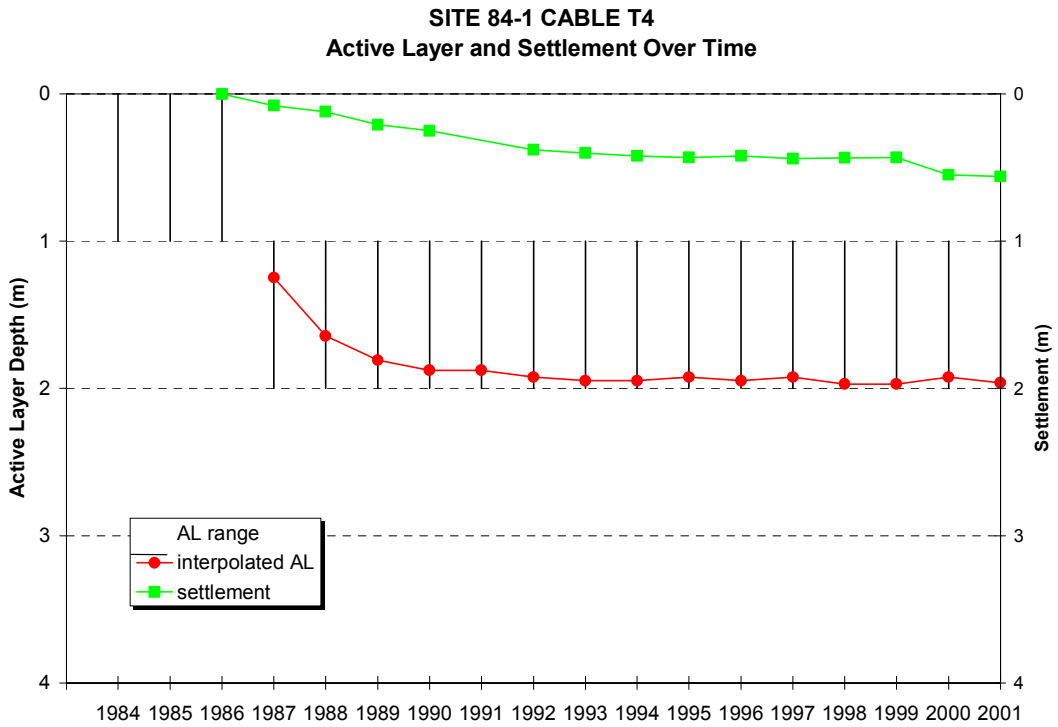
THAW DEPTH AND SETTLEMENT PLOTS

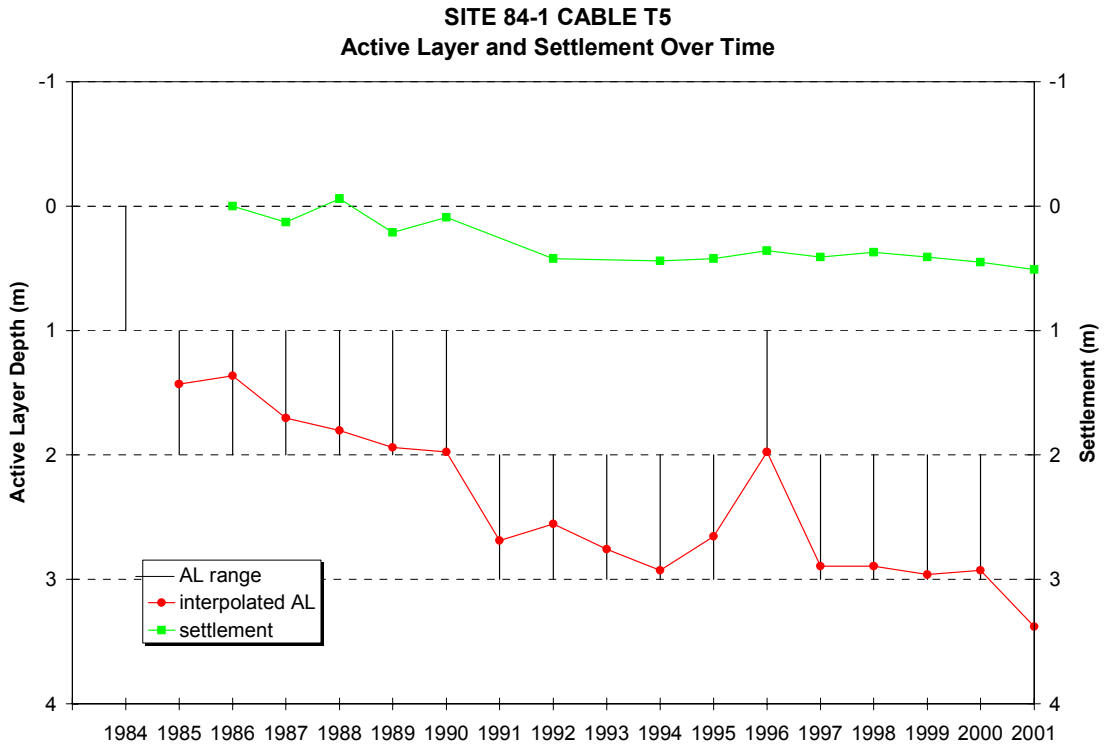
Maximum summer thaw penetration and the position of the ground surface over the monitoring period are shown on the graphs in this section. Active layer depth on the graphs refers to the position of the base of the active layer relative to the fixed reference. AL range refers to the range between the sensor above and below the depth of thaw penetration. Interpolated AL refers to the thaw depth interpolated between sensors assuming a linear temperature gradient. A downward pointing arrow indicates that the thaw penetration is deeper than the value given (i.e. is below the deepest sensor). Settlement refers to the position of the ground surface relative to a fixed reference determined by measuring the height of the top of PVC casing above the ground surface.

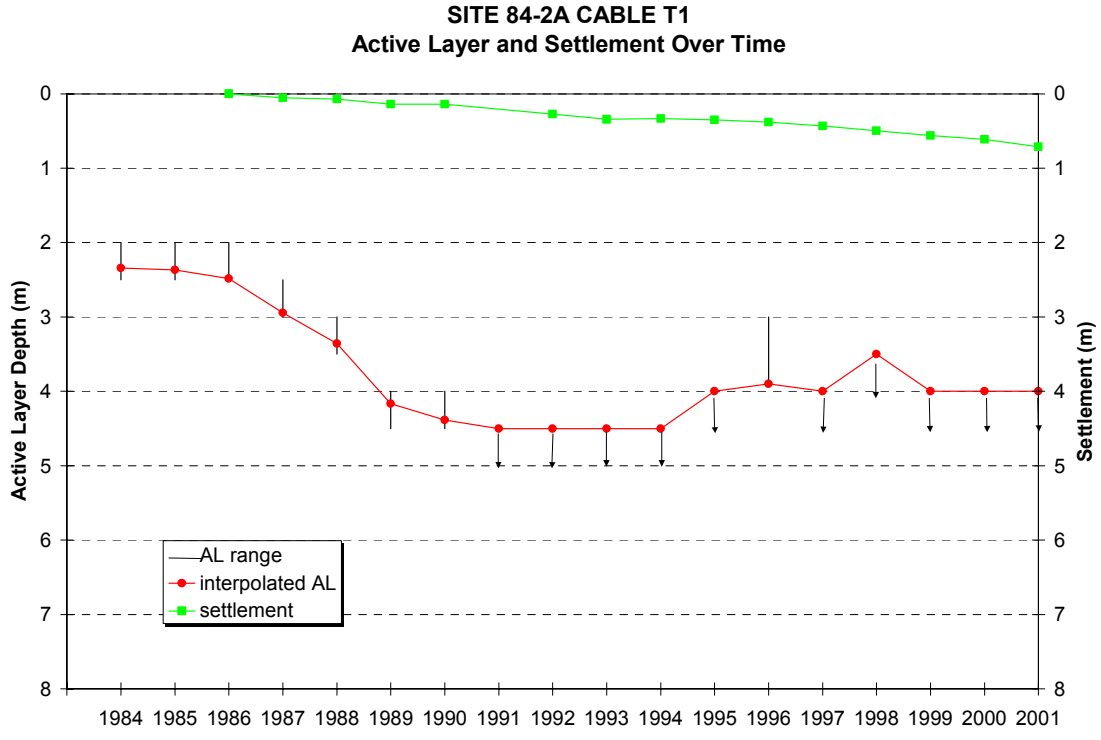

SITE 84-1 CABLE T1
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
AL range
interpolated AL
settlement

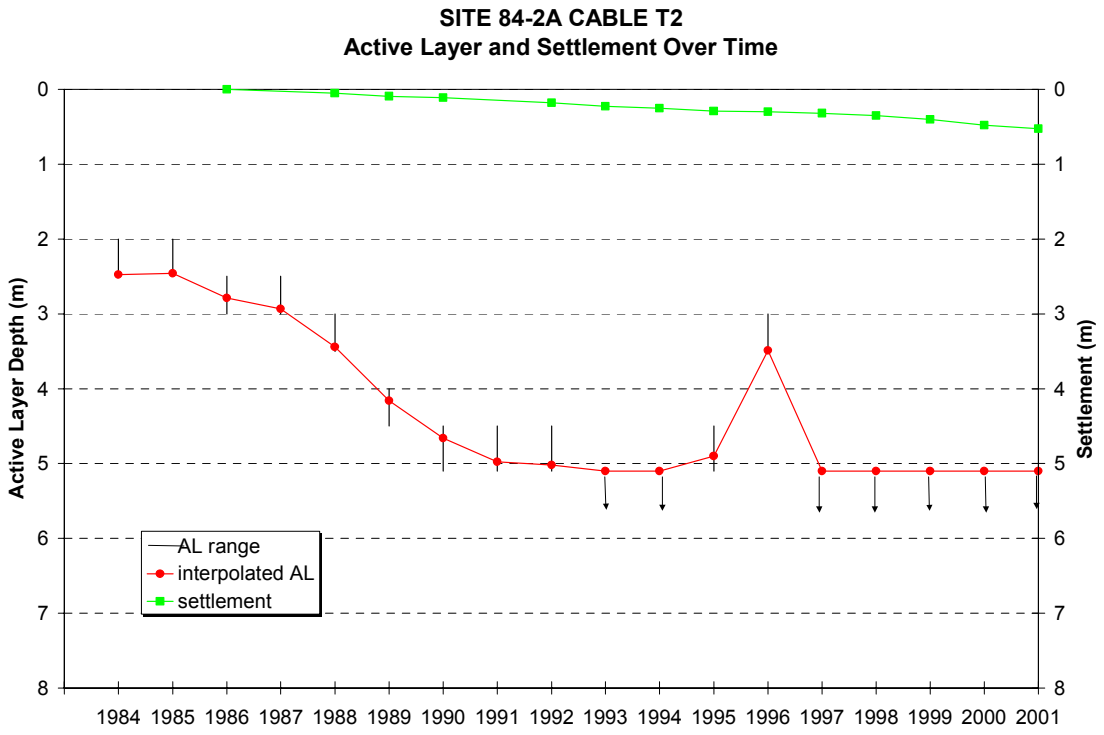

SITE 84-1 CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
AL range
interpolated AL
settlement

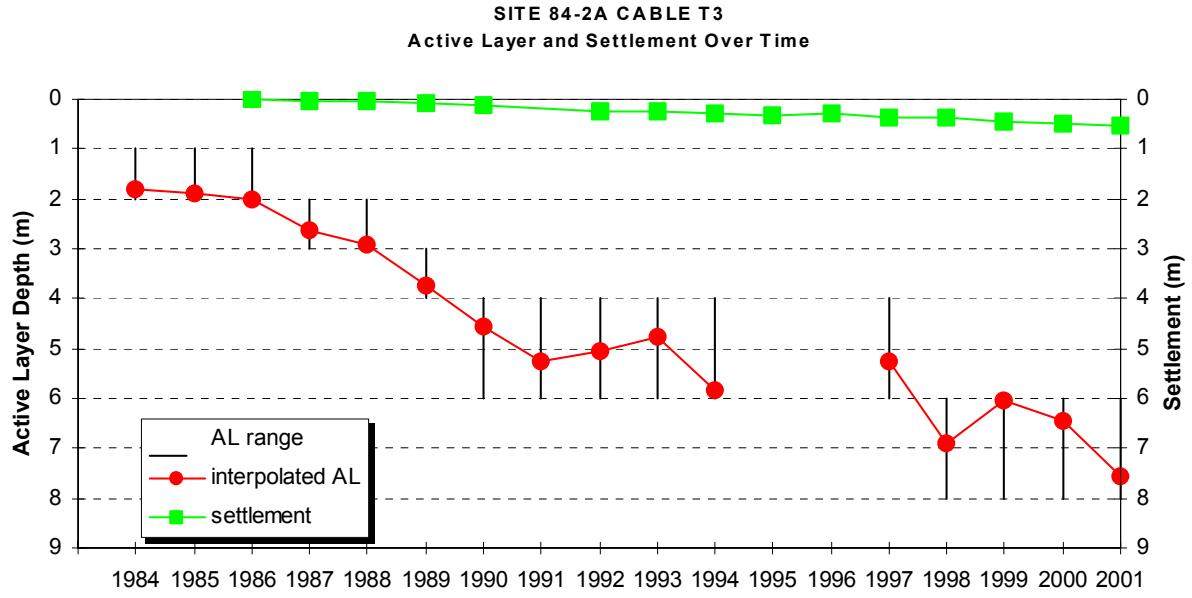

SITE 84-1 CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-1
0
1
2
3
4
5
AL range
interpolated AL
settlement
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

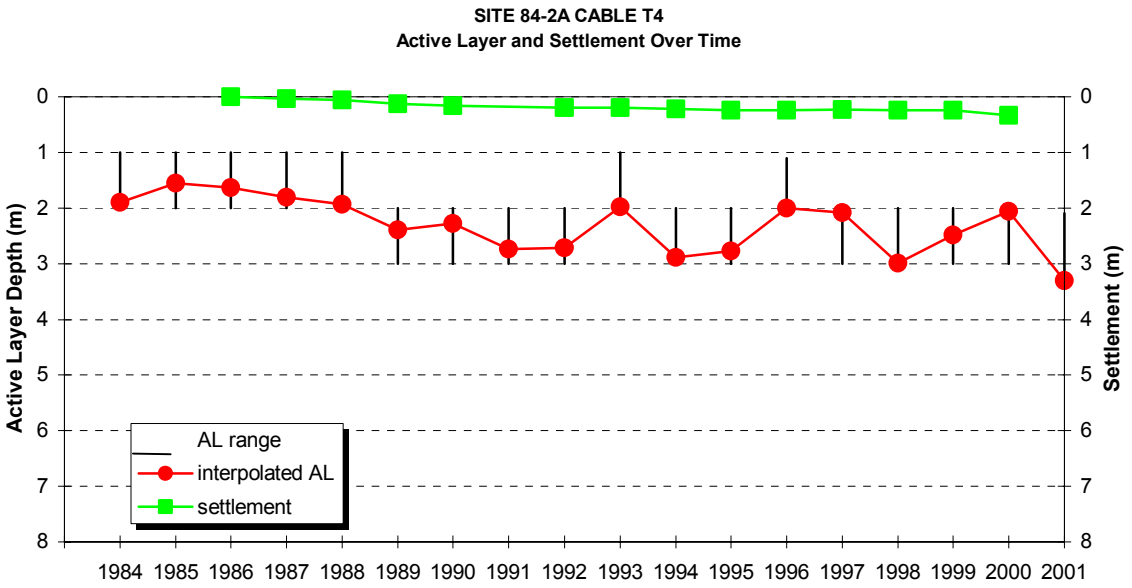

SITE 84-1 CABLE T4
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

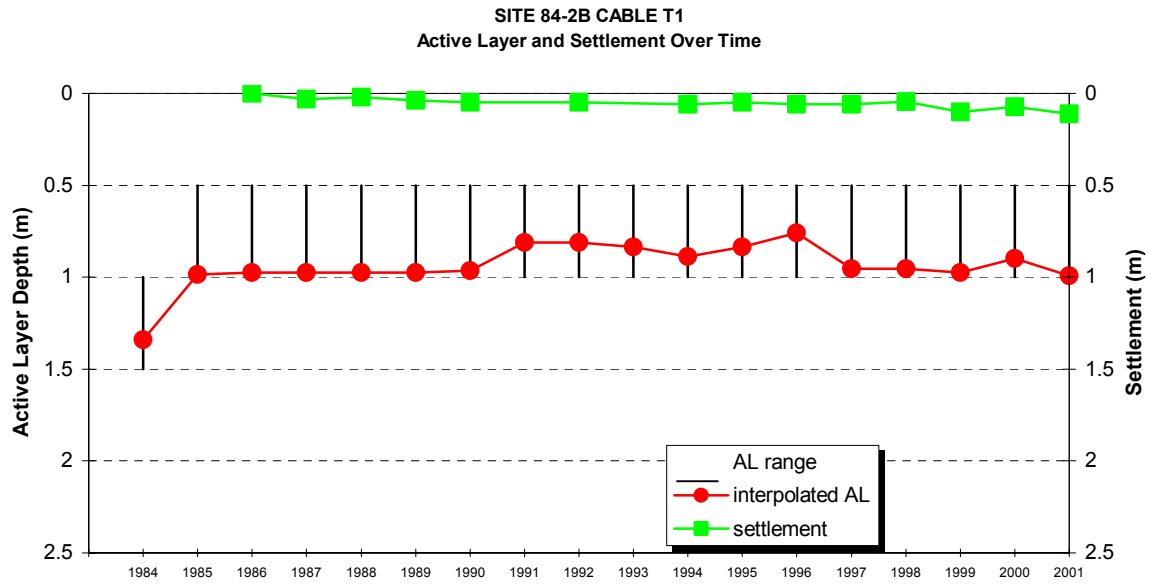

SITE 84-1 CABLE T5
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-1
0
1
2
3
4
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

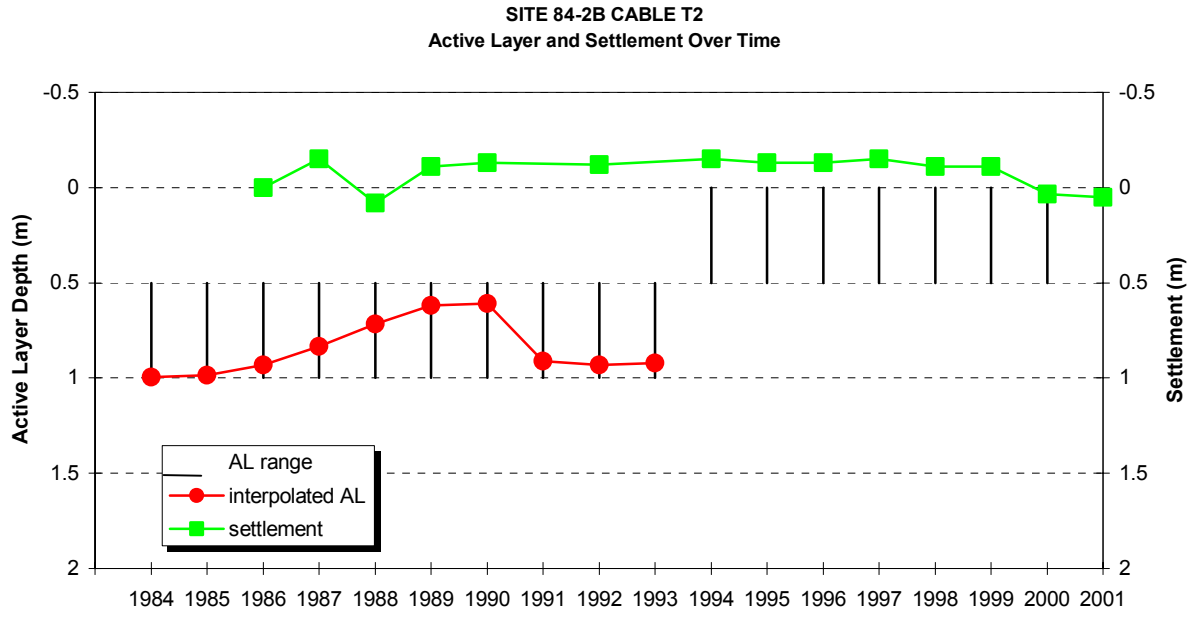

SITE 84-2A CABLE T1
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
7
8
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

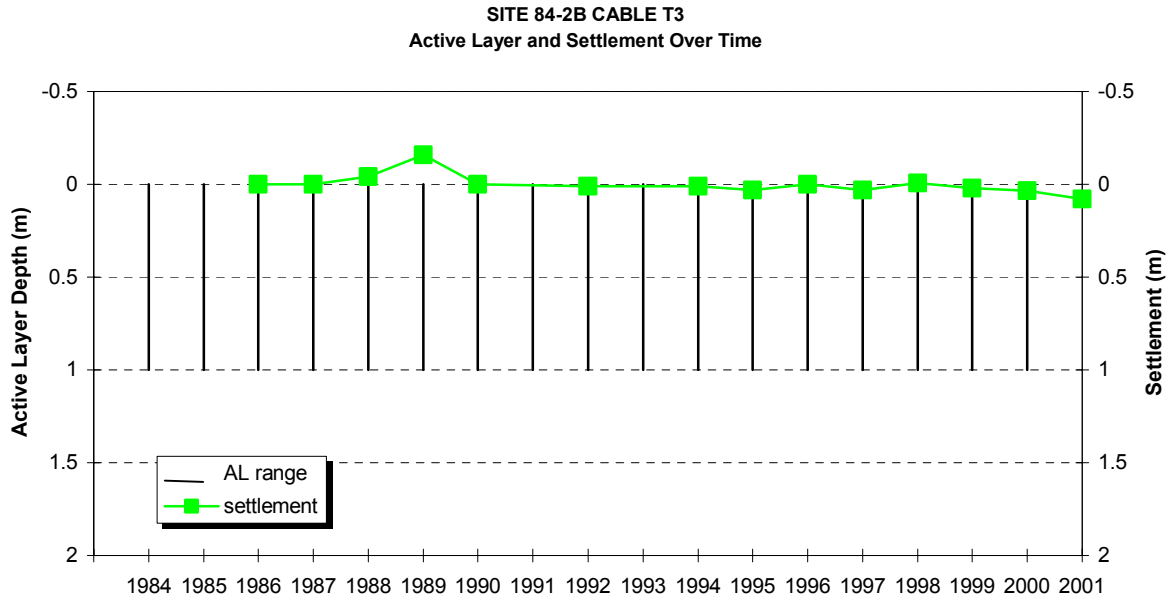

SITE 84-2A CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
AL range
interpolated AL
settlement
0
1
2
3
4
5
6
7
8
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

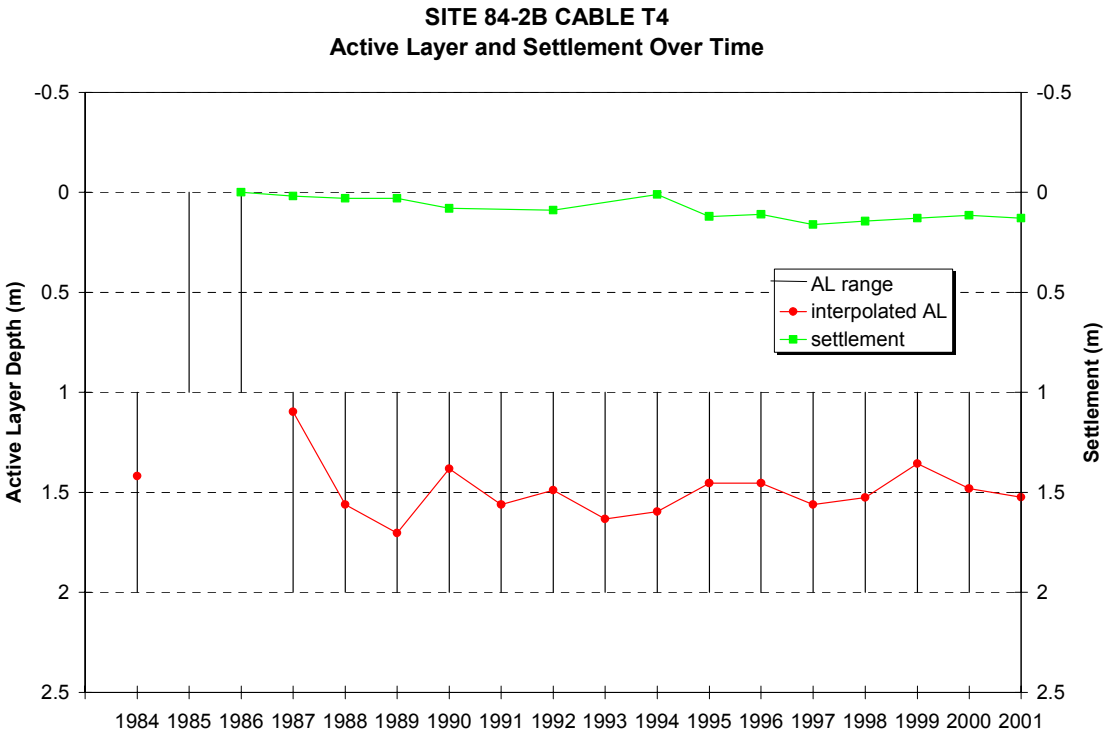

SITE 84-2A CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
AL range
interpolated AL
settlement
0
1
2
3
4
5
6
7
8
9
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

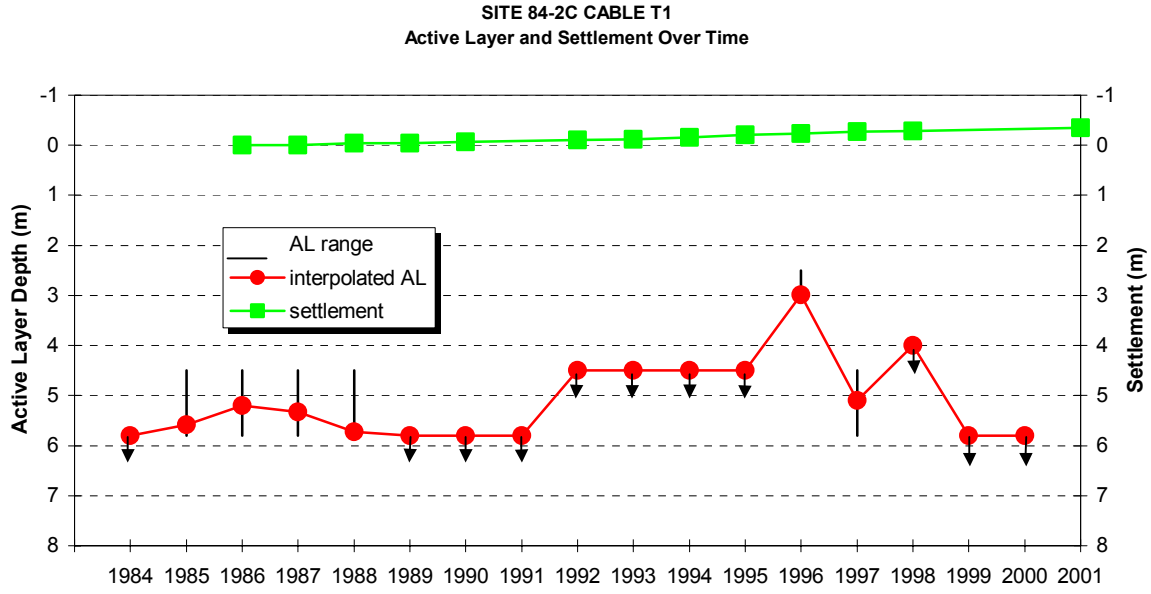

SITE 84-2A CABLE T4
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
7
8
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001


SITE 84-2B CABLE T1
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
0.5
1
1.5
2
2.5
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

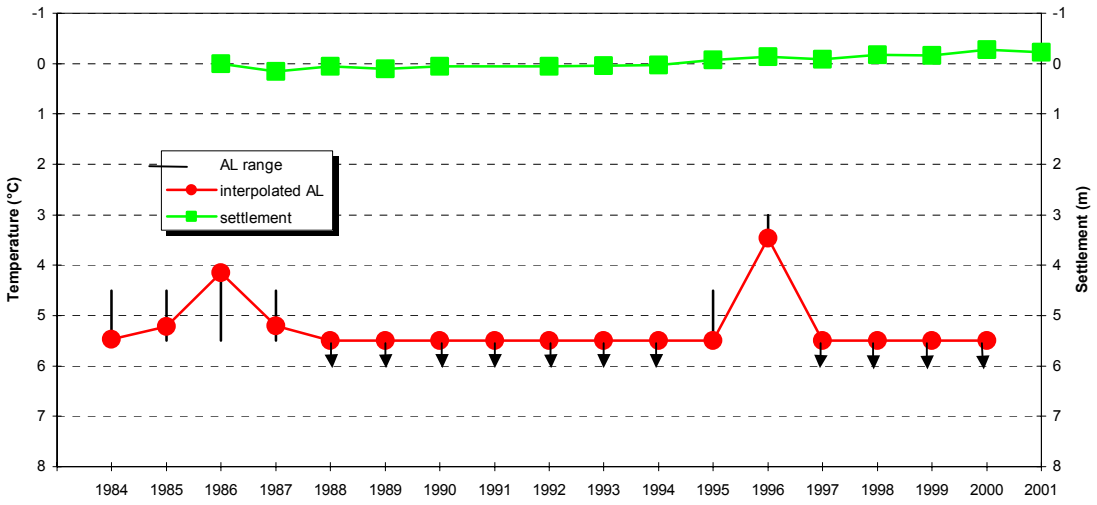

SITE 84-2B CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-0.5
0
0.5
1
1.5
2
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001


SITE 84-2B CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-0.5
0
0.5
1
1.5
2
AL range
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

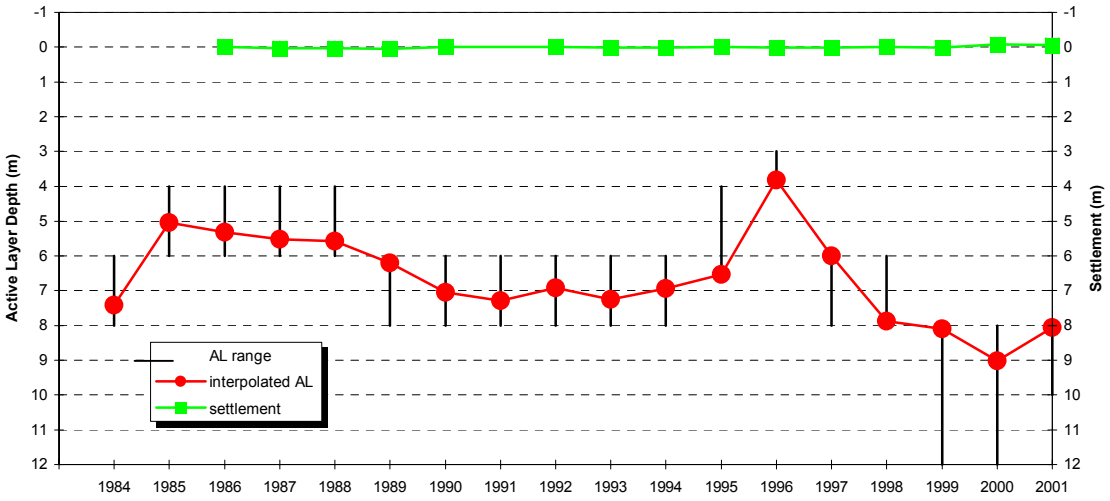

SITE 84-2B CABLE T4
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-0.5
0
0.5
1
1.5
2
2.5
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

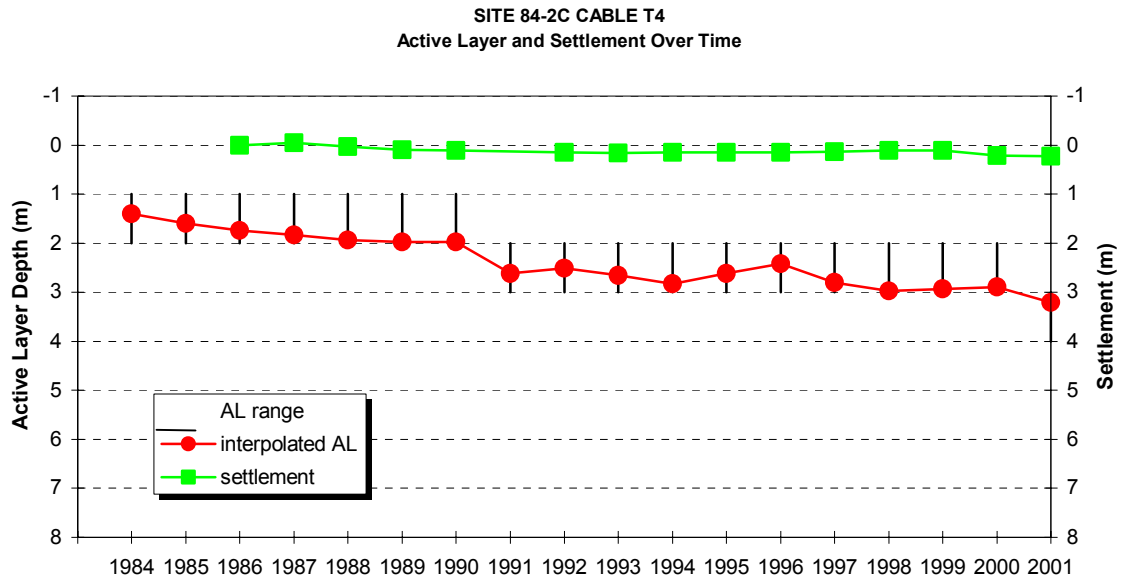

SITE 84-2C CABLE T1
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-1
0
1
2
3
4
5
6
7
8
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

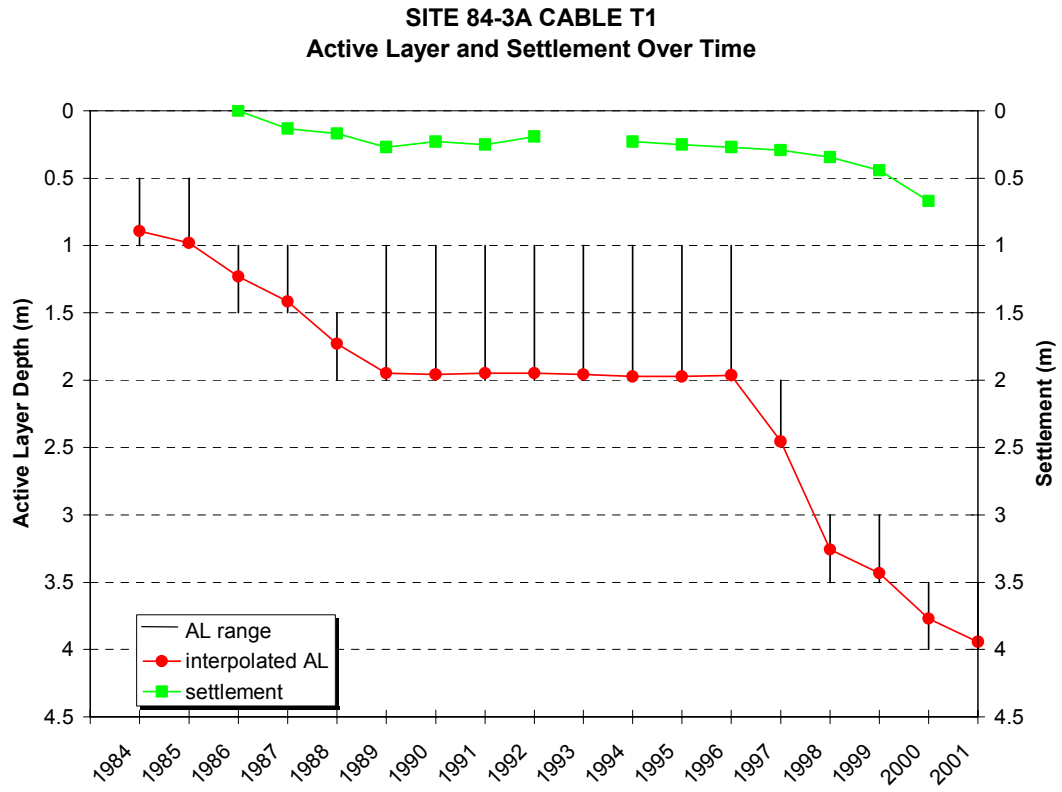
SITE 84-2C CABLE T2
Active Layer and Settlement Over Time



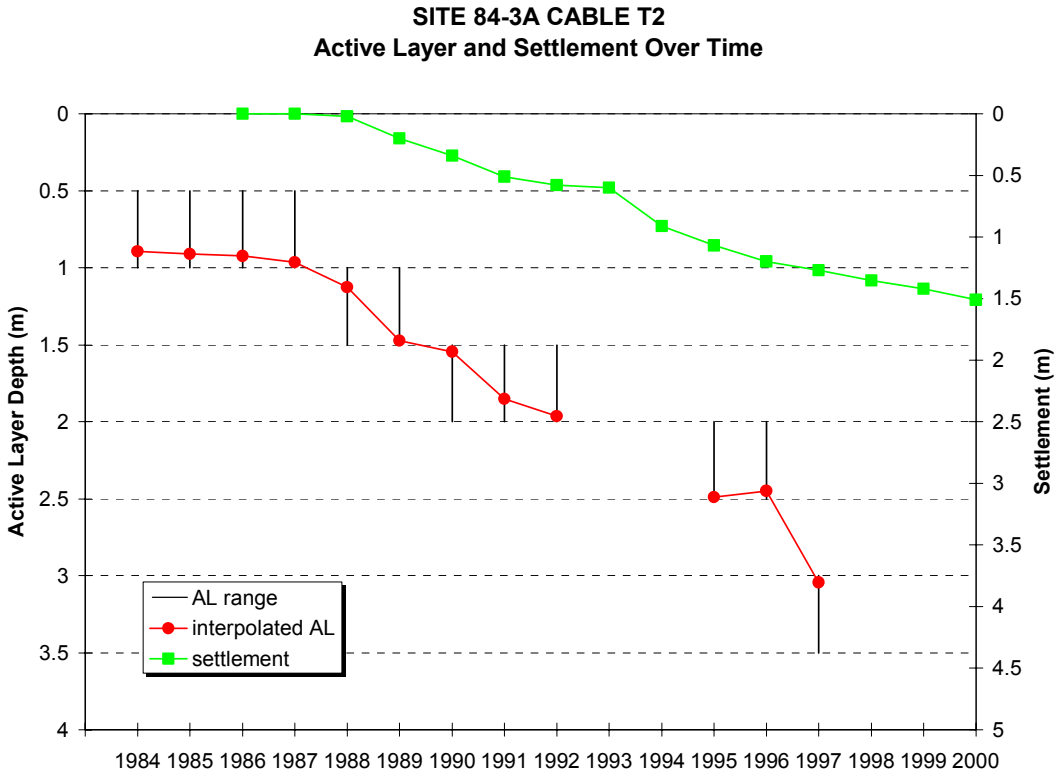
SITE 84-2C CABLE T3
Active Layer and Settlement Over Time



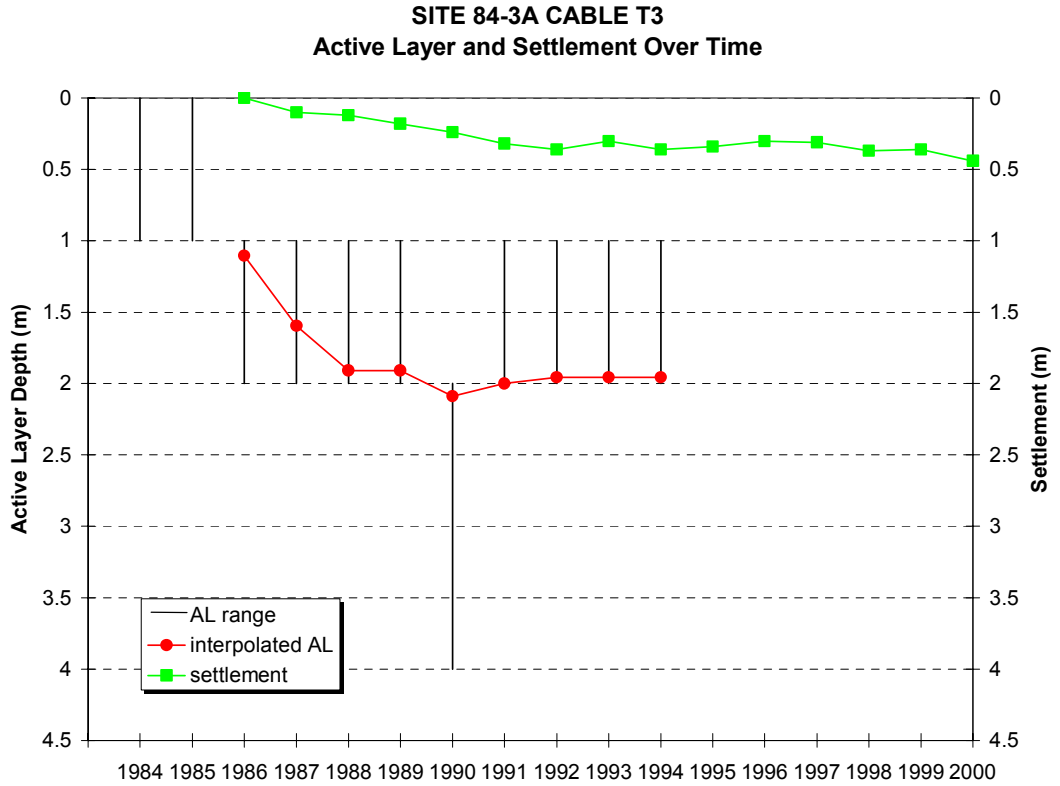




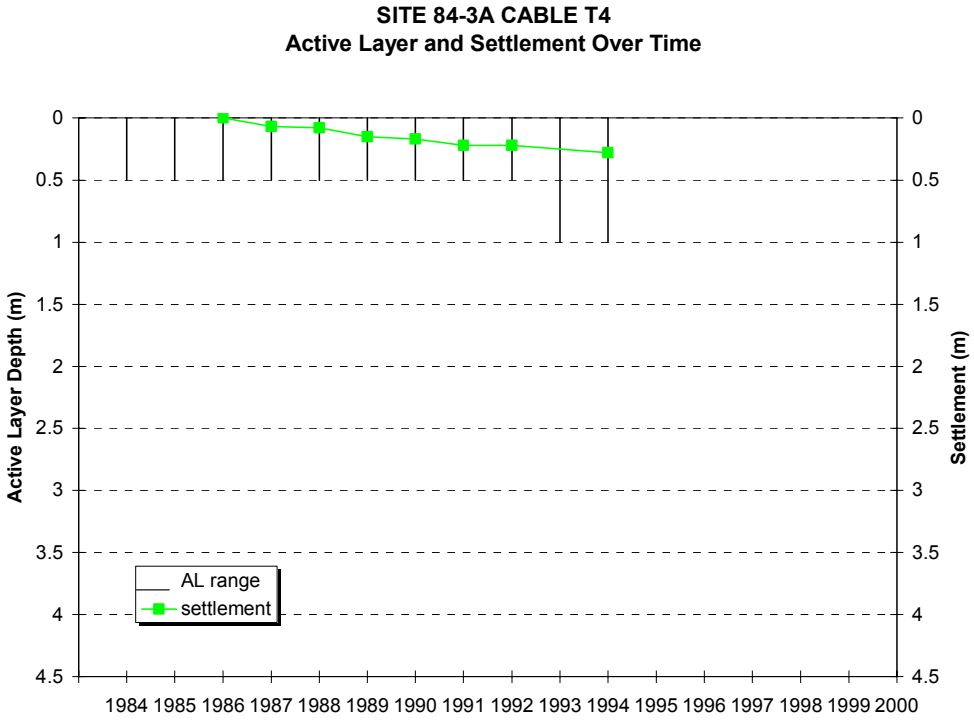
Note: Fire at Great Bear site June 1995



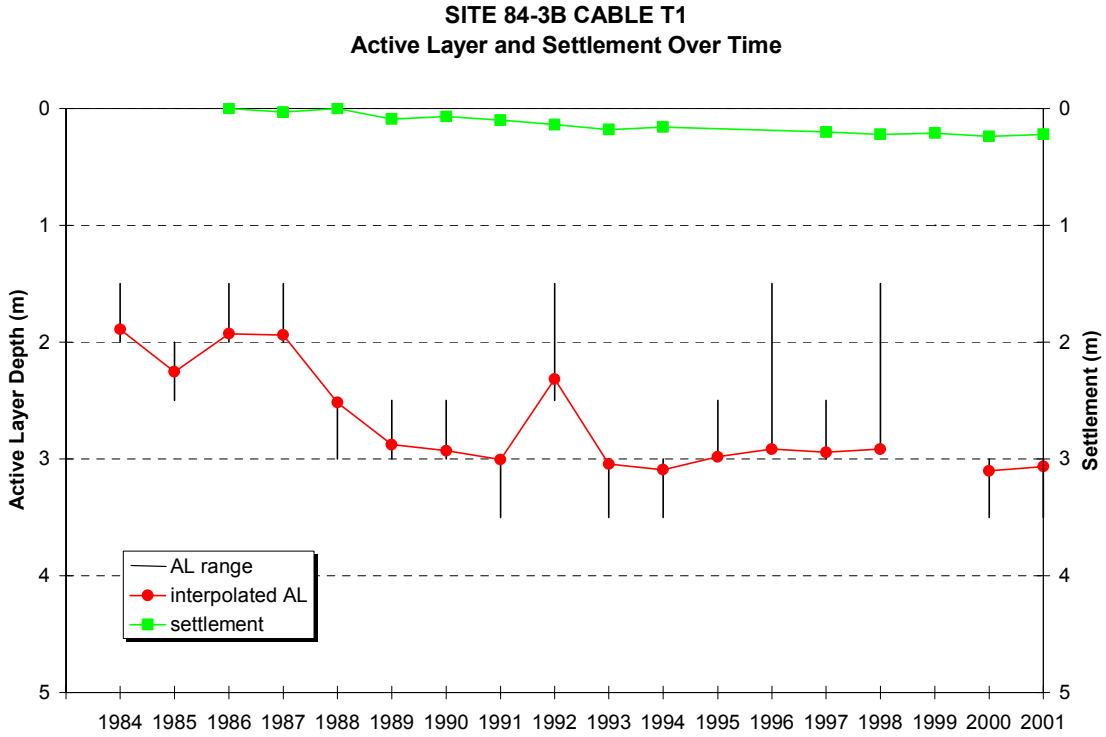
Note: Difficult to estimate thaw depth 1992 onwards – unreliable results

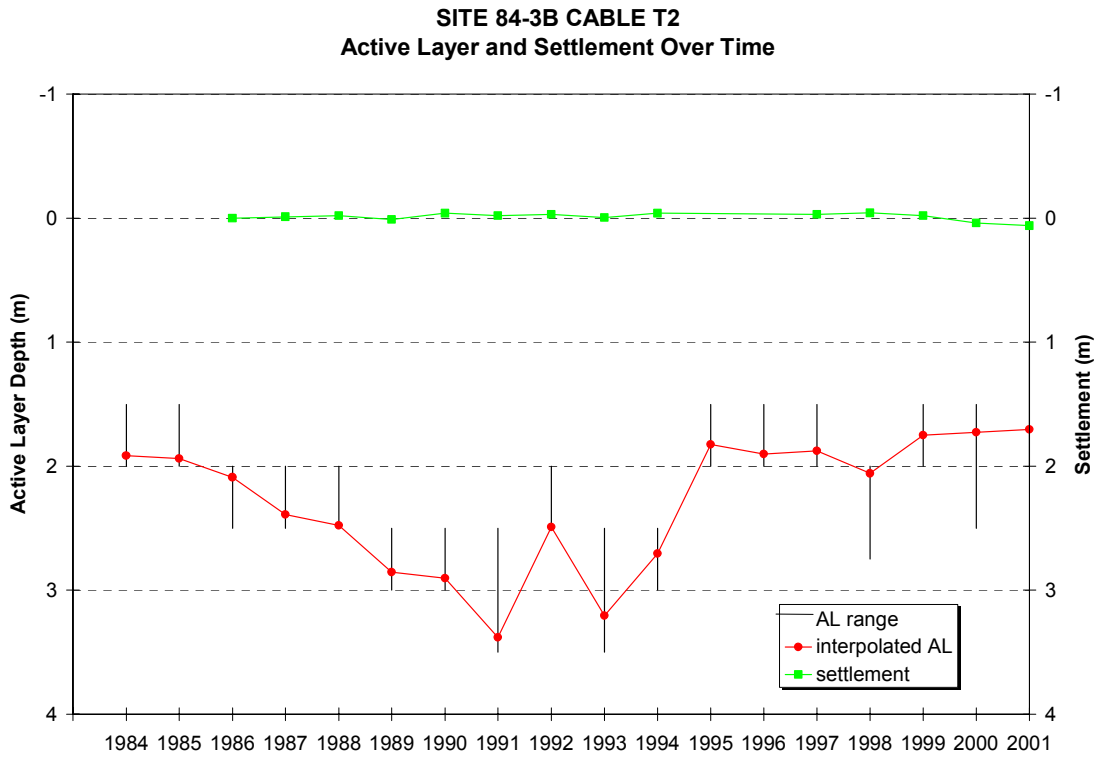


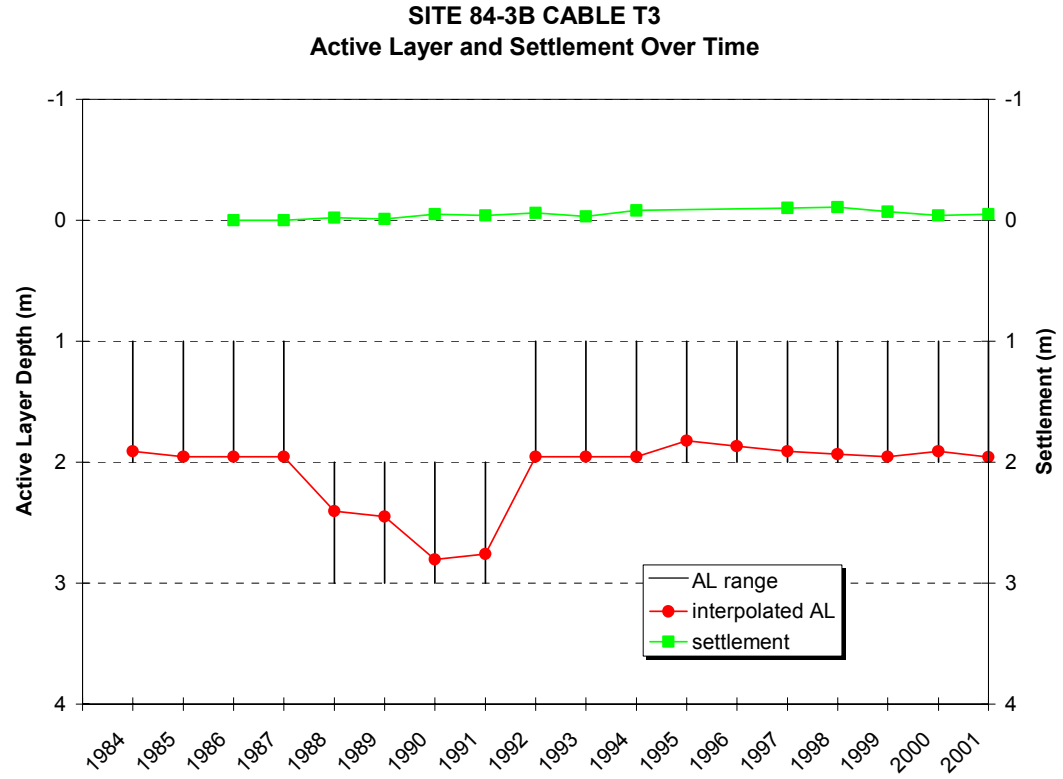
Note: Sensor unreliable at 2 m after 1994 – thaw depth can not be determined



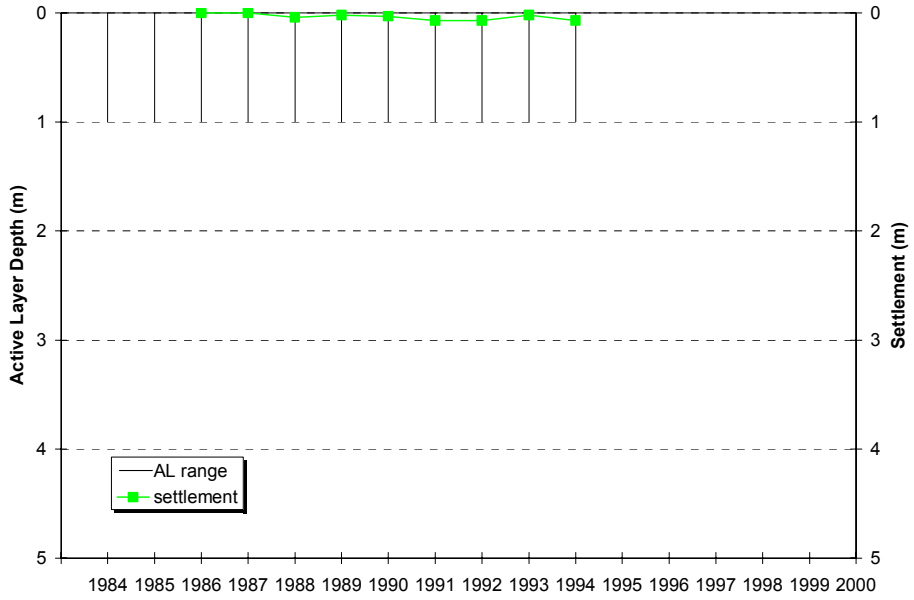
Cable destroyed by fire in 1995



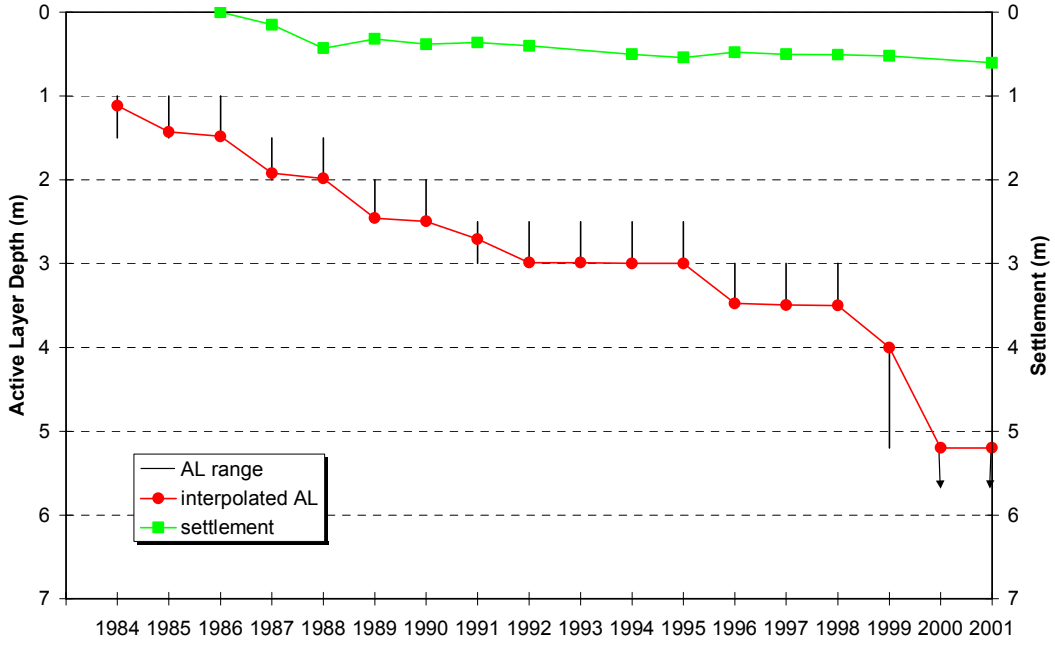

SITE 84-3B CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-1
0
1
2
3
4
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
AL range
interpolated AL
settlement

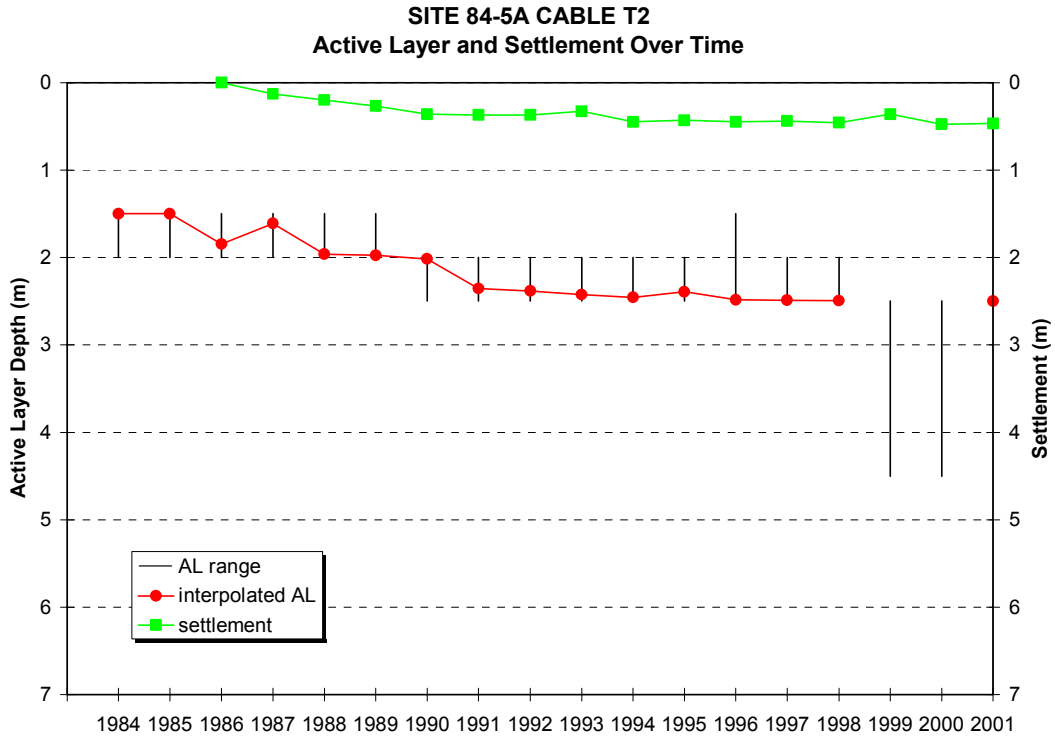

SITE 84-3B CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-1
0
1
2
3
4
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
AL range
interpolated AL
settlement

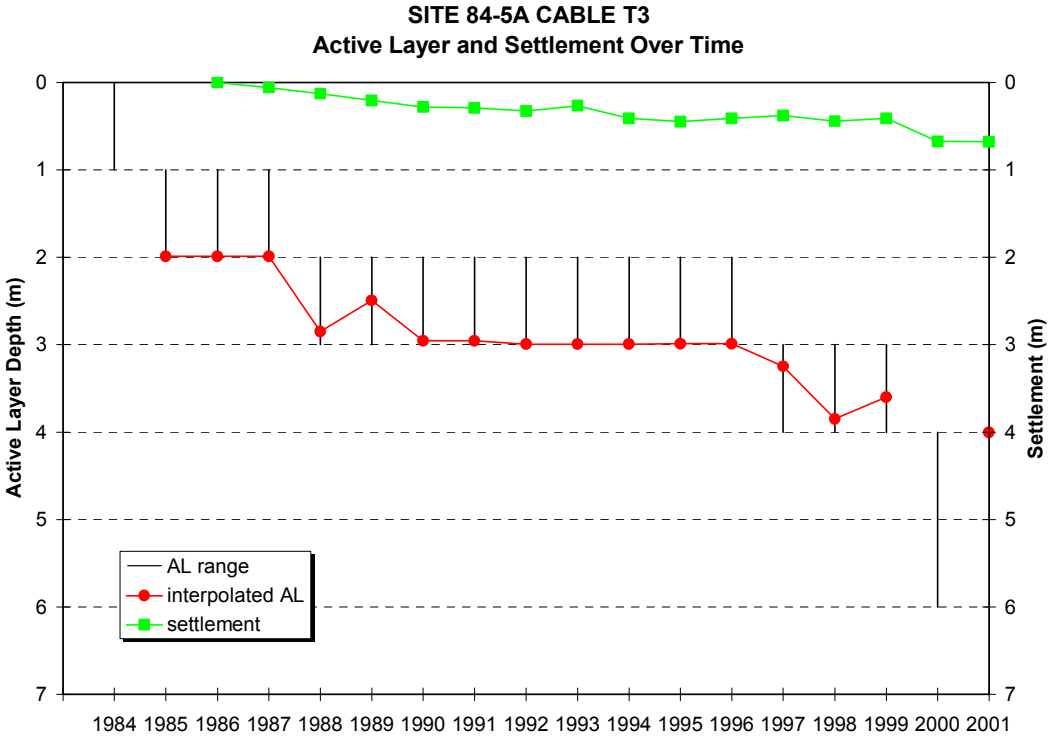
SITE 84-3B CABLE T4
Active Layer and Settlement Over Time

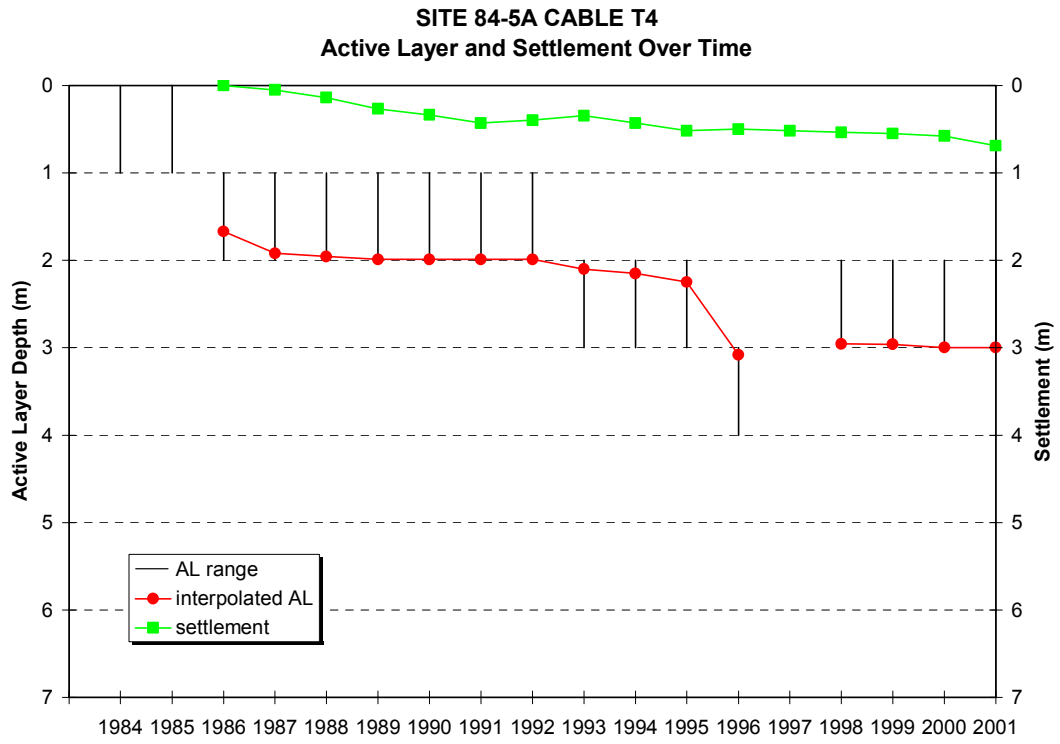


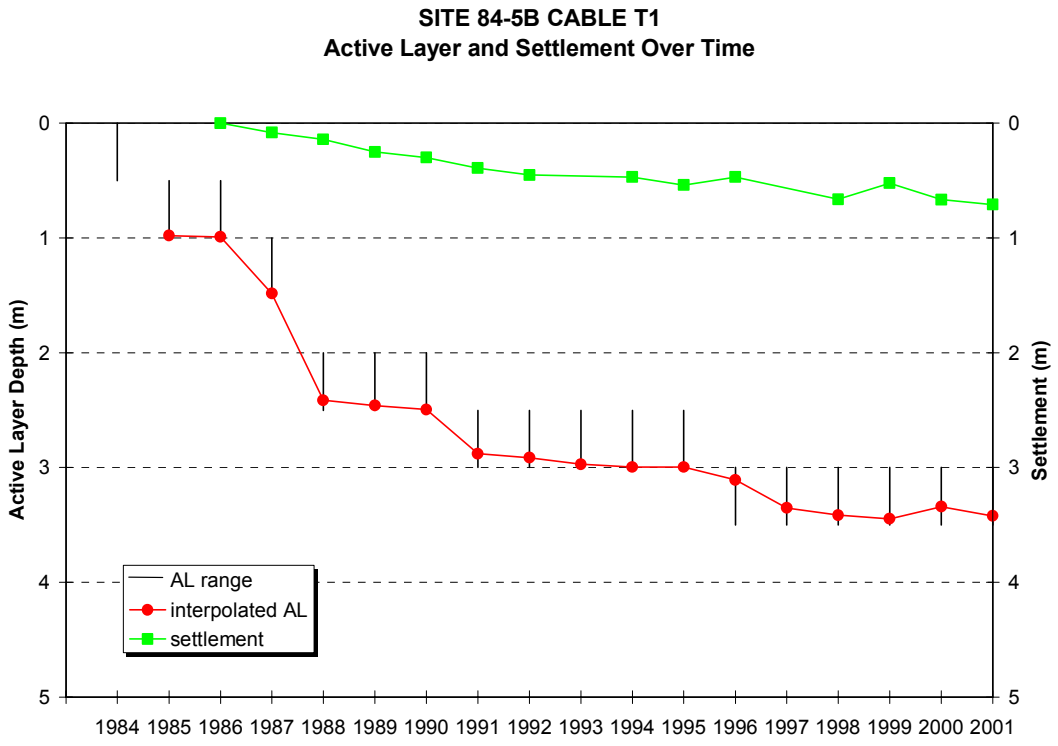
SITE 84-5A CABLE T1
Active Layer and Settlement Over Time

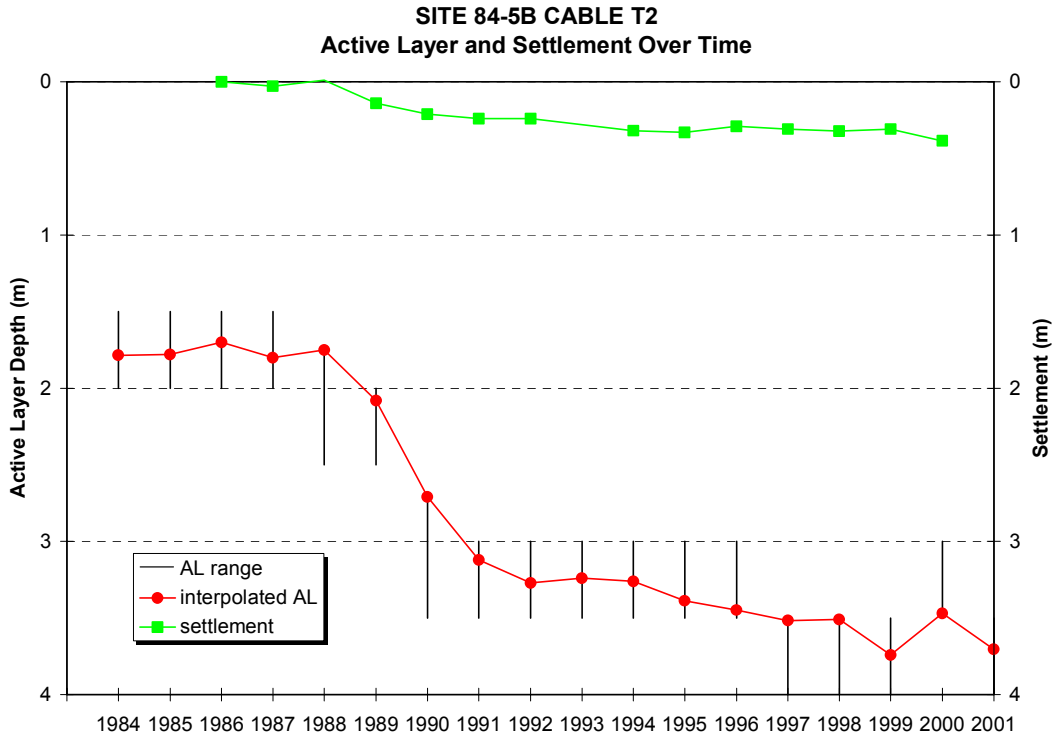


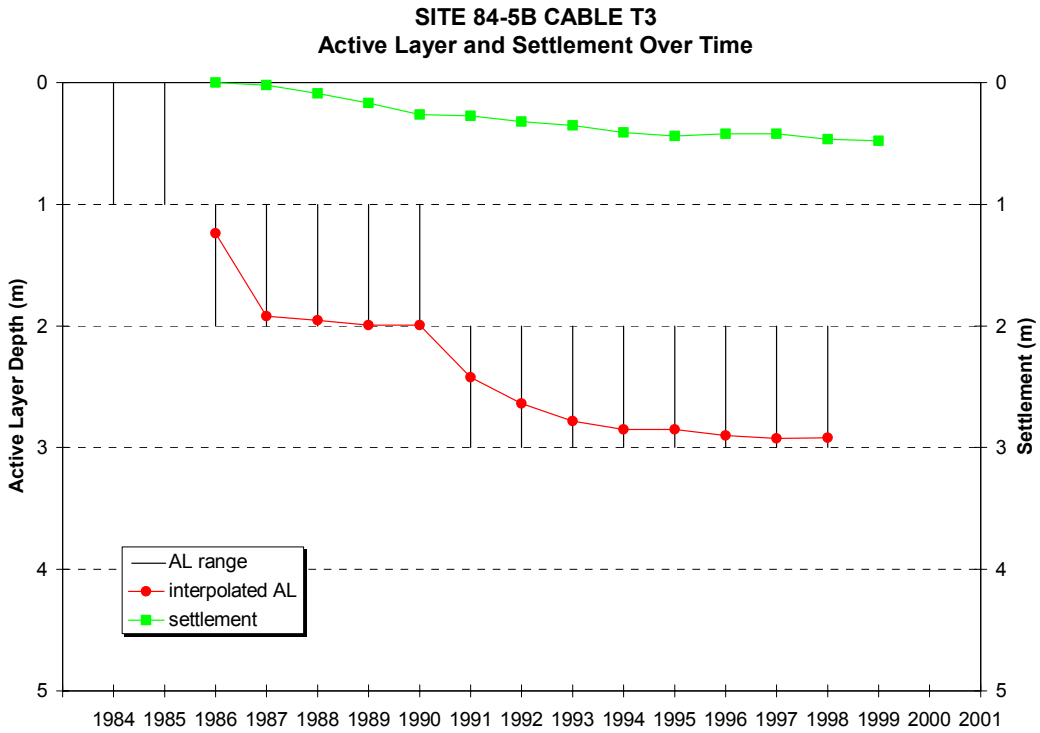

SITE 84-5A CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
7
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
AL range
interpolated AL
settlement


SITE 84-5A CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
7
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
AL range
interpolated AL
settlement

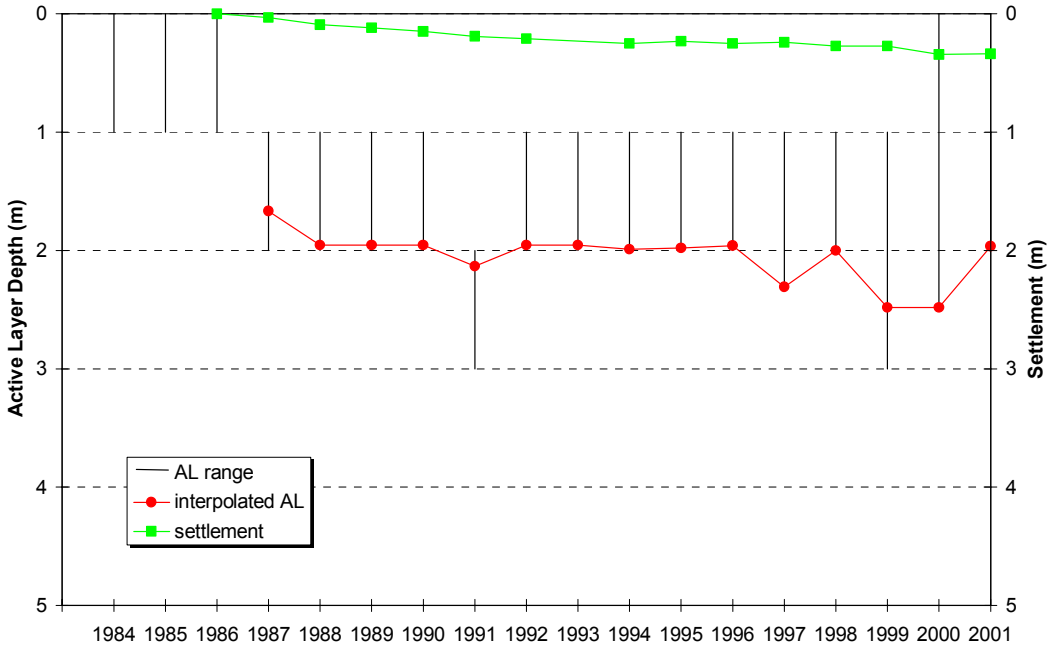

SITE 84-5A CABLE T4
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
7
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001


SITE 84-5B CABLE T1
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

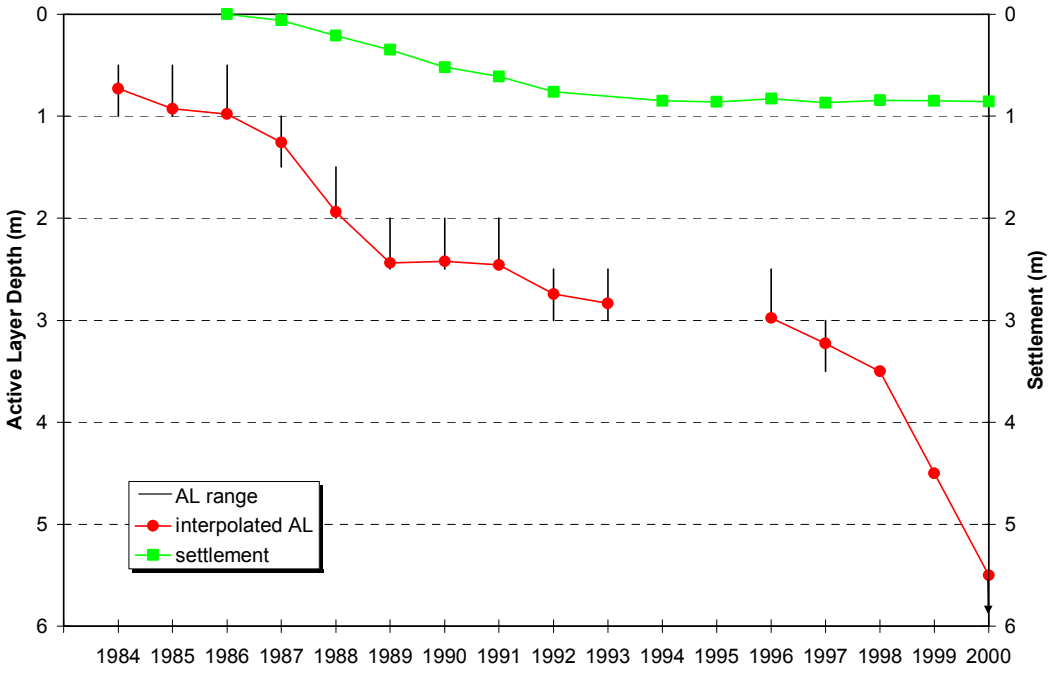

SITE 84-5B CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

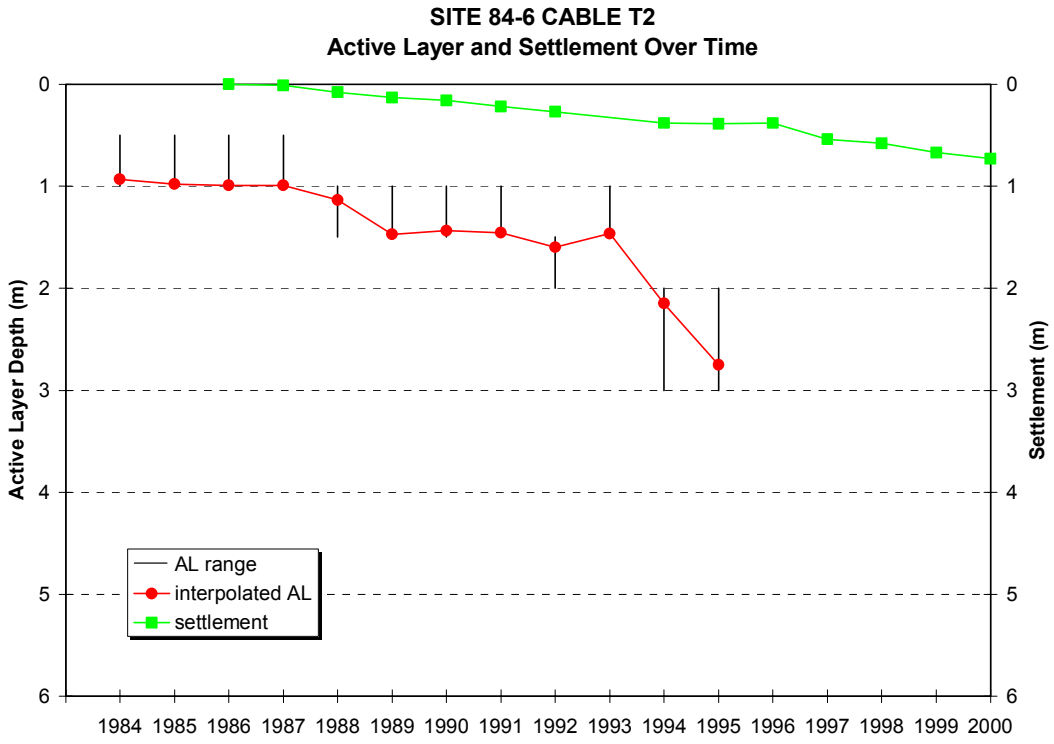

SITE 84-5B CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

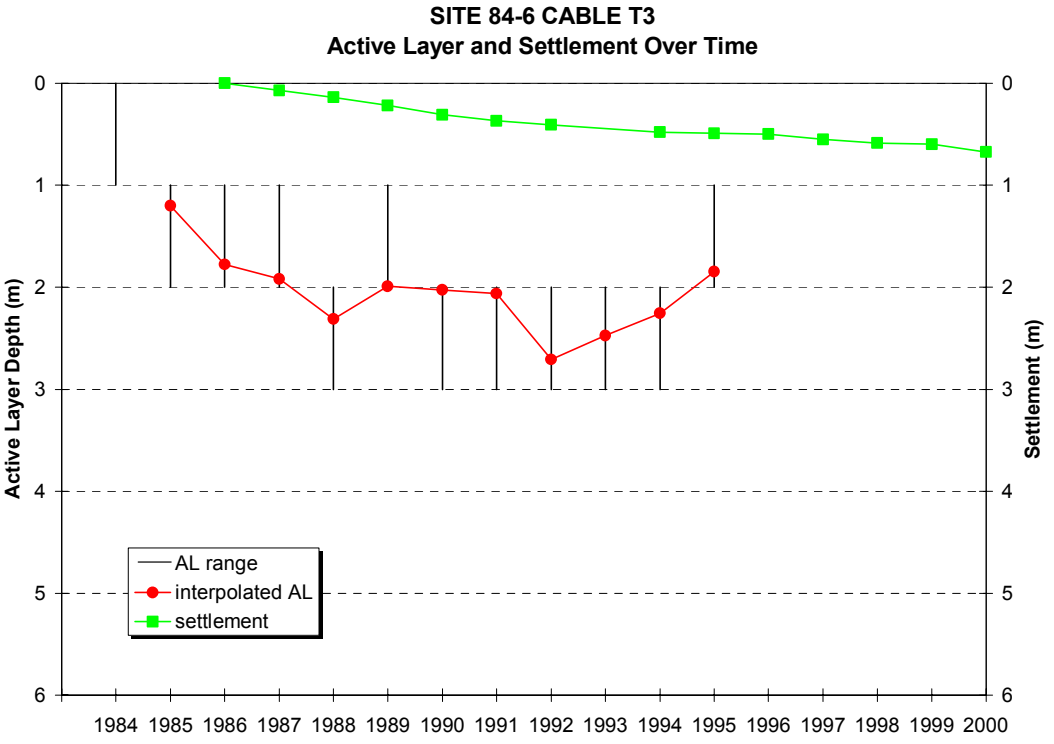
SITE 84-5B CABLE T4
Active Layer and Settlement Over Time

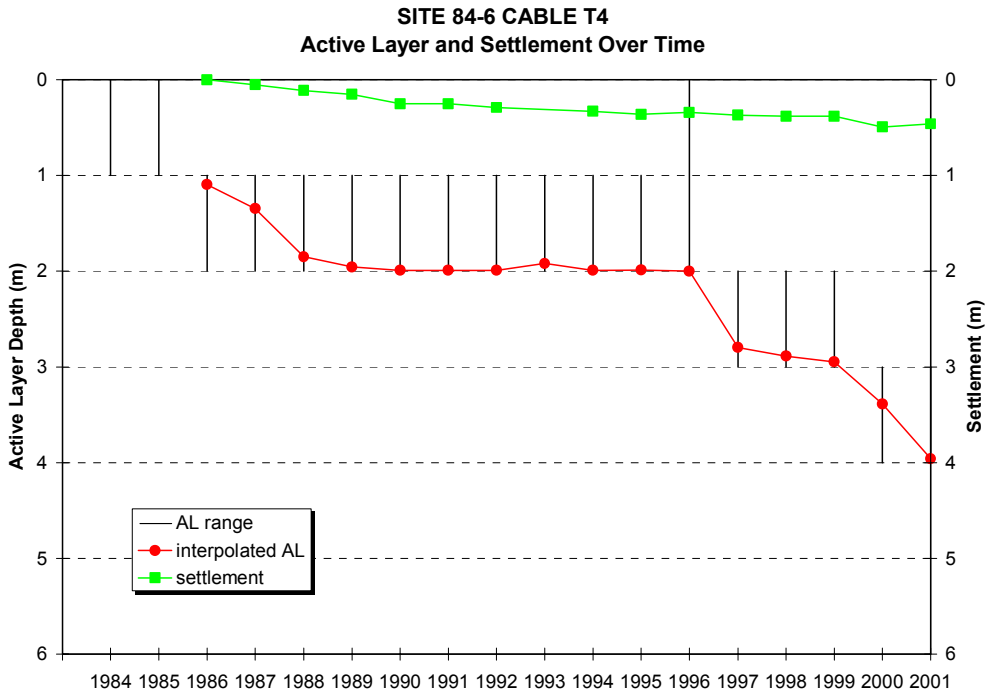


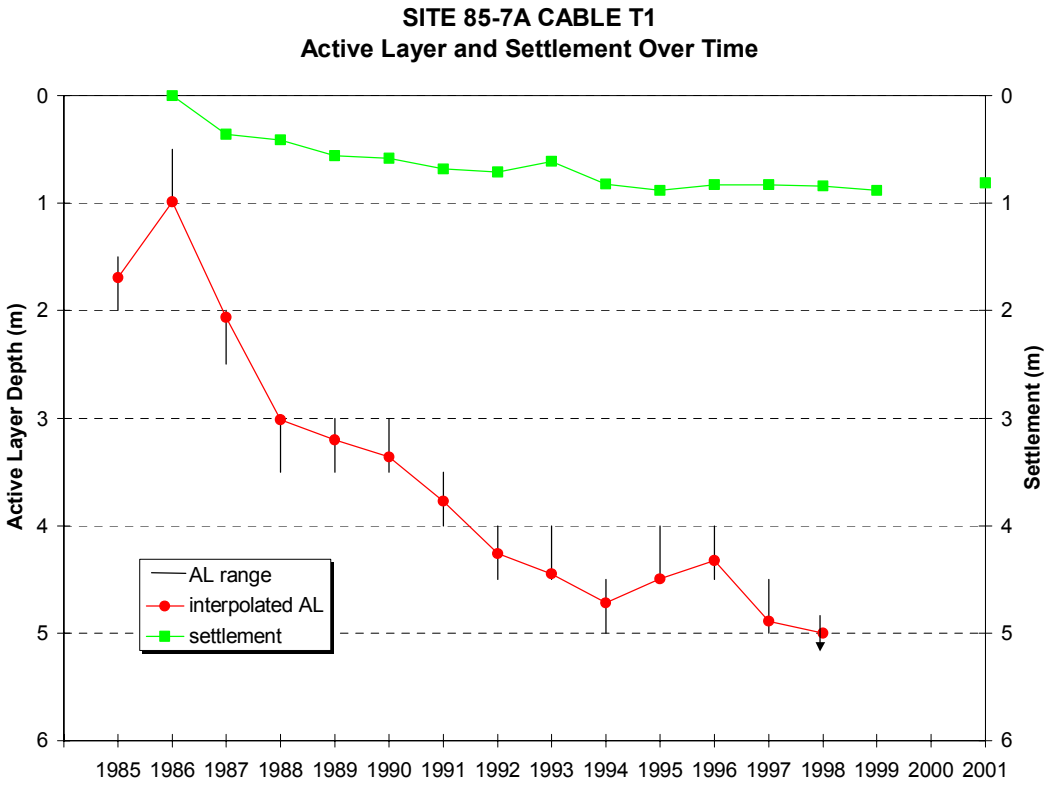
SITE 84-6 CABLE T1
Active Layer and Settlement Over Time

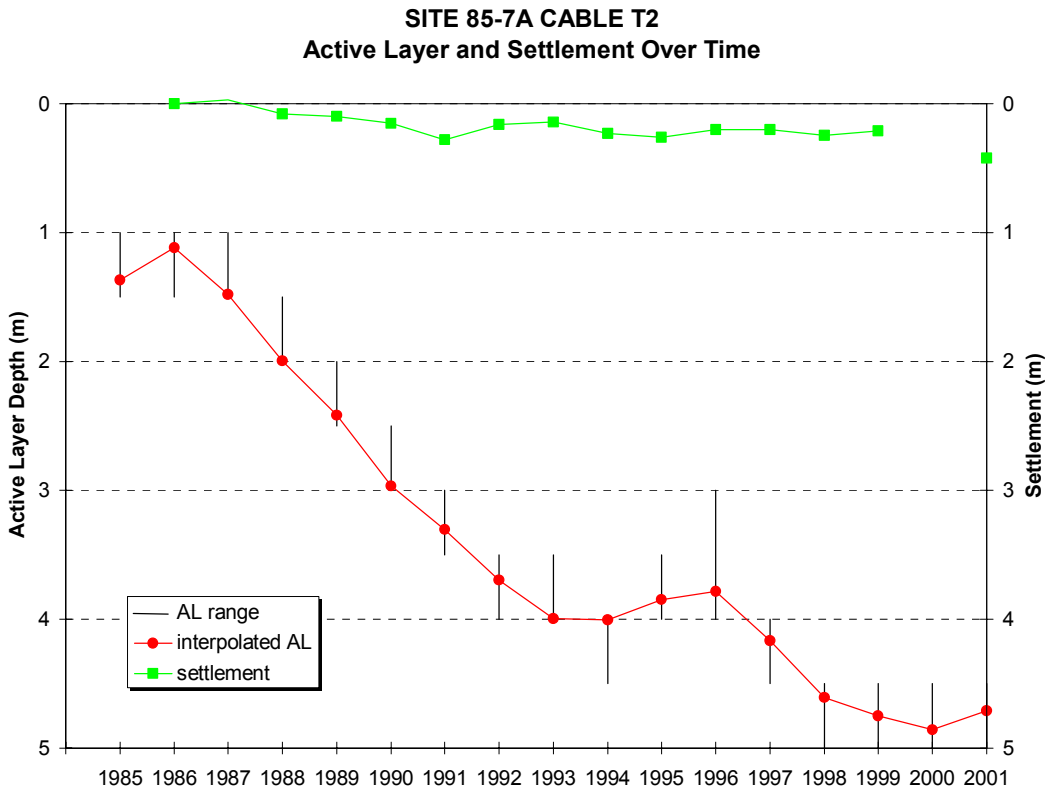


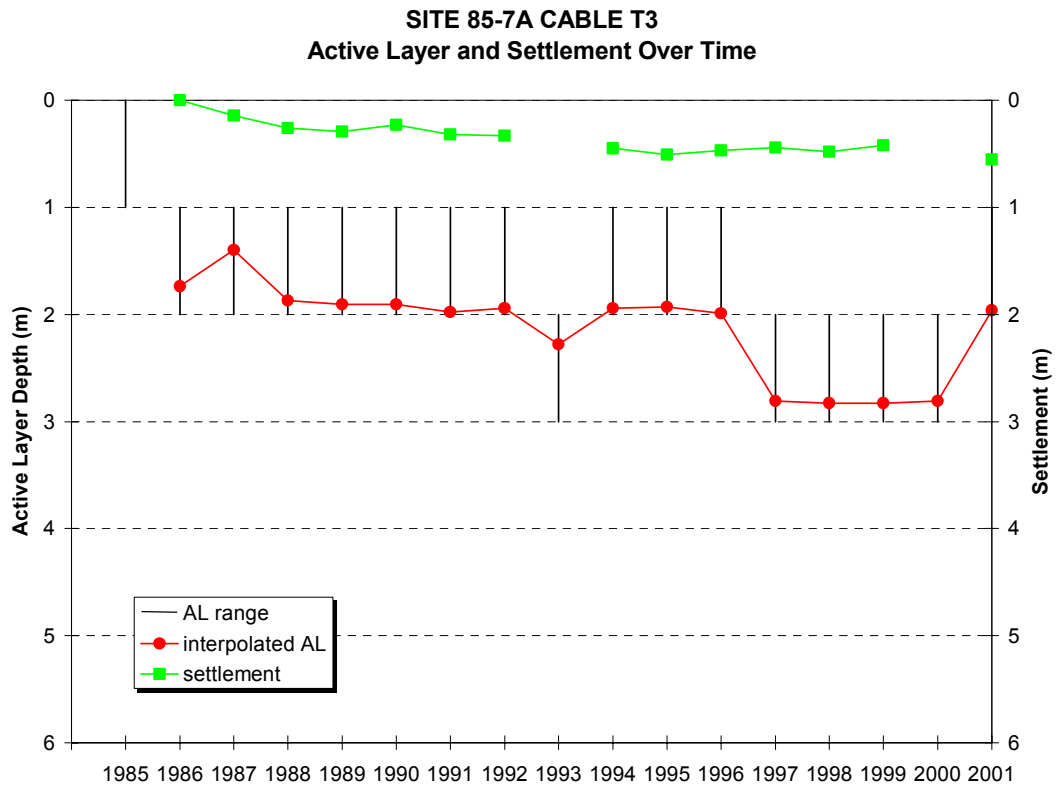

SITE 84-6 CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000


SITE 84-6 CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

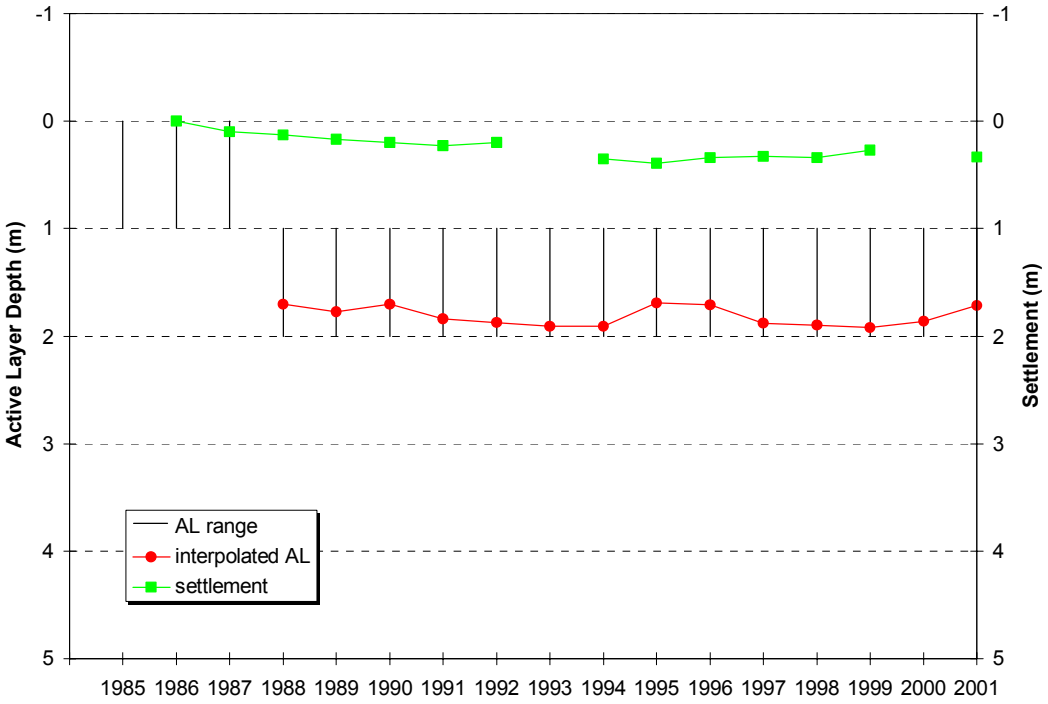

SITE 84-6 CABLE T4
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
AL range
interpolated AL
settlement
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001


SITE 85-7A CABLE T1
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
AL range
interpolated AL
settlement
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

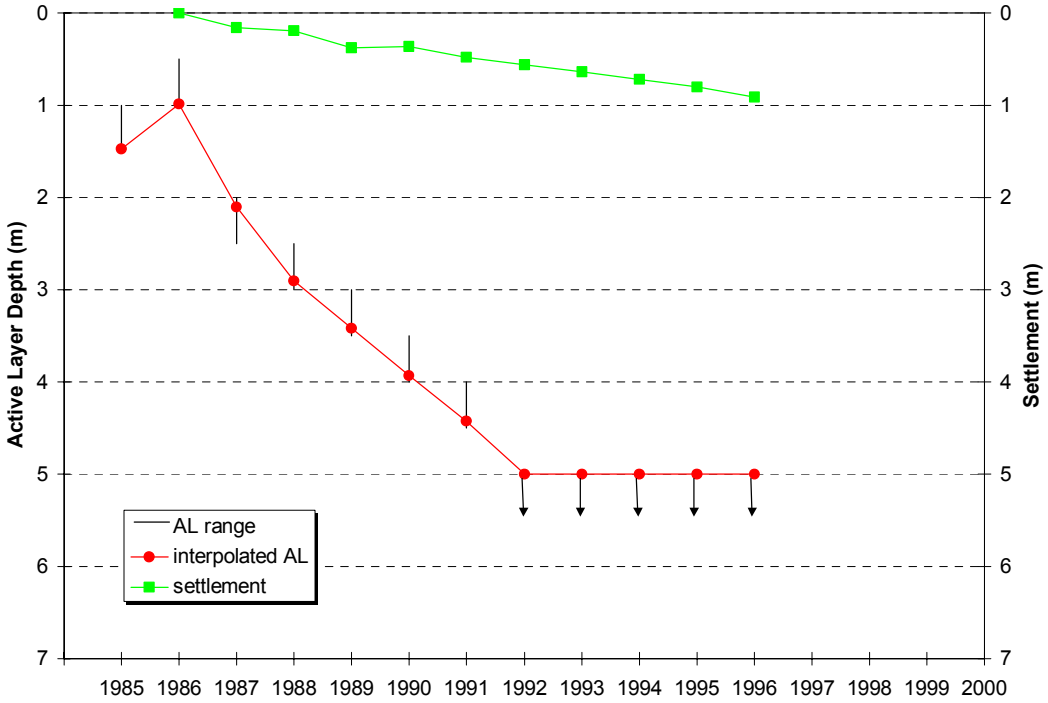

SITE 85-7A CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
AL range
interpolated AL
settlement

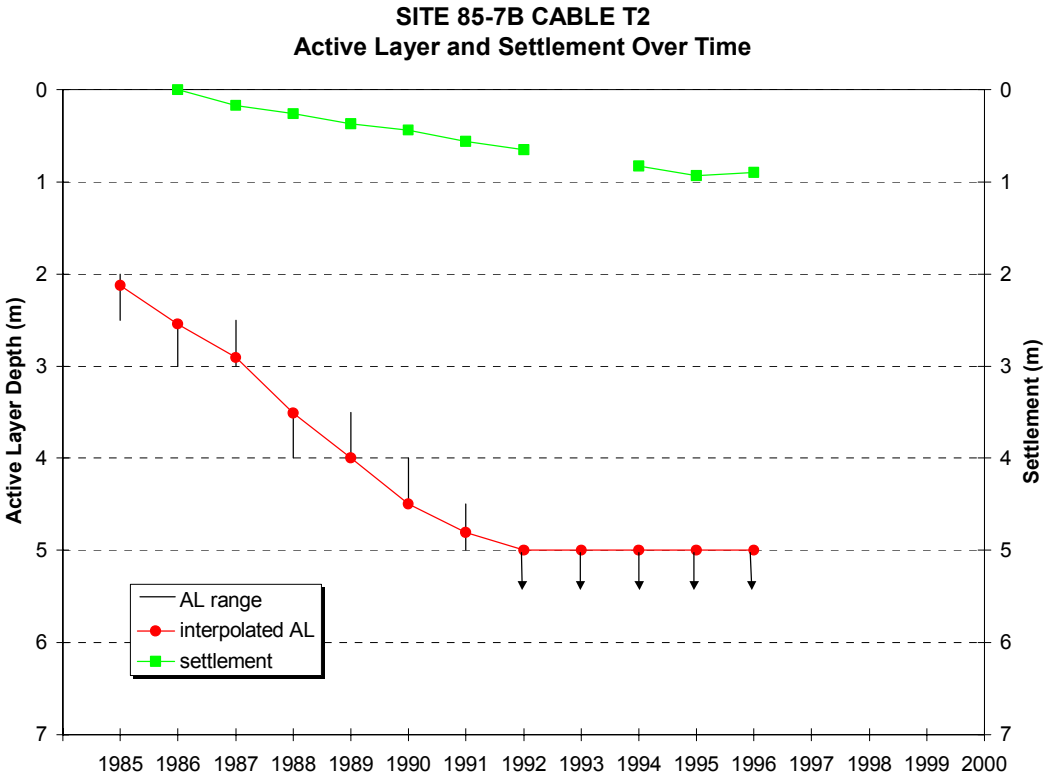

SITE 85-7A CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
AL range
interpolated AL
settlement

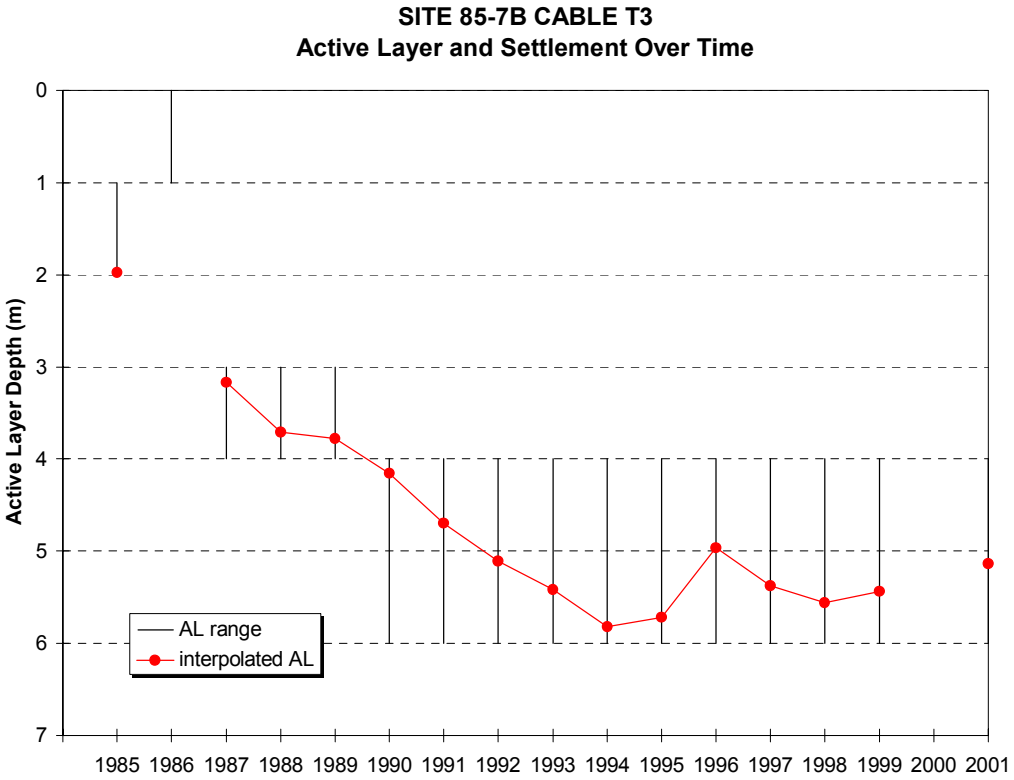
SITE 85-7A CABLE T4
Active Layer and Settlement Over Time



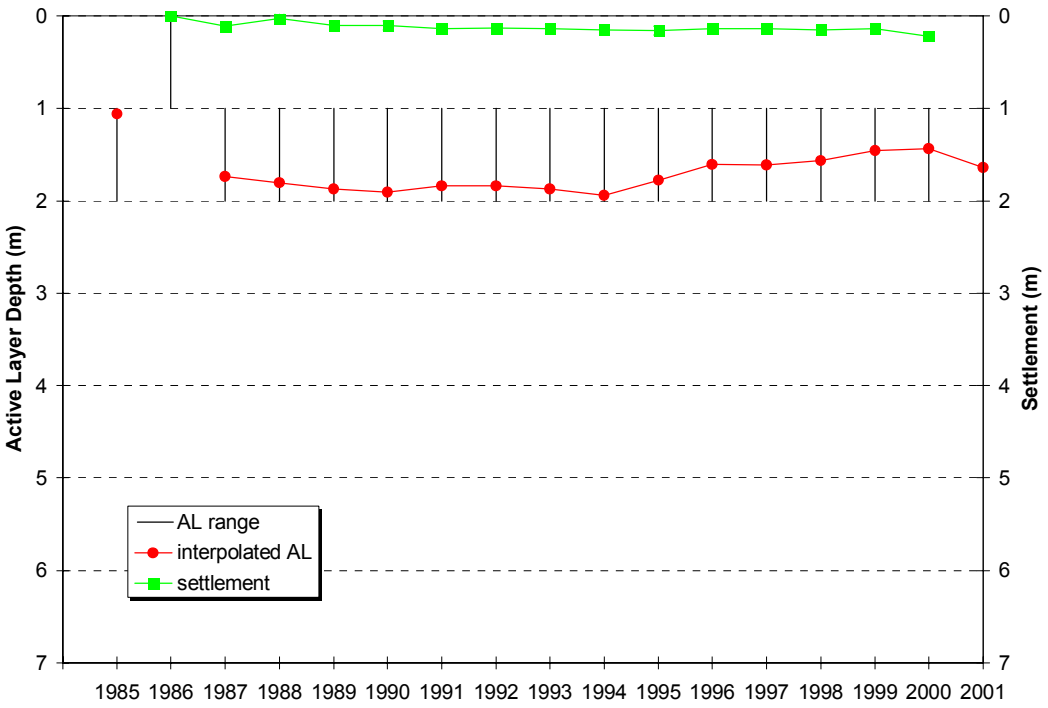
SITE 85-7B CABLE T1
Active Layer and Settlement Over Time



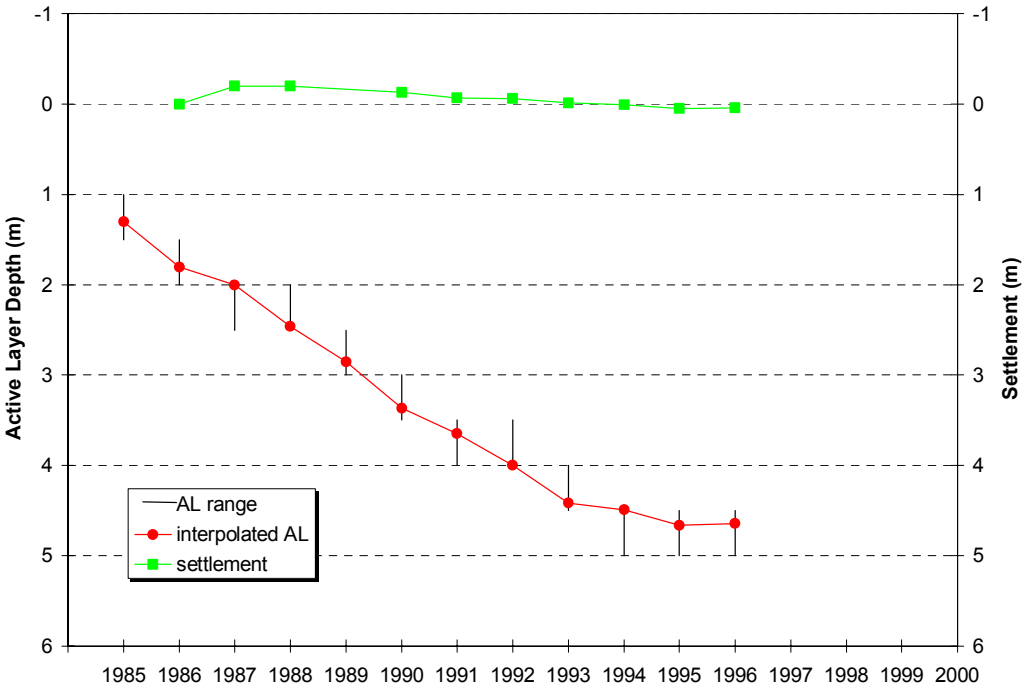

SITE 85-7B CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
7
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
AL range
interpolated AL
settlement

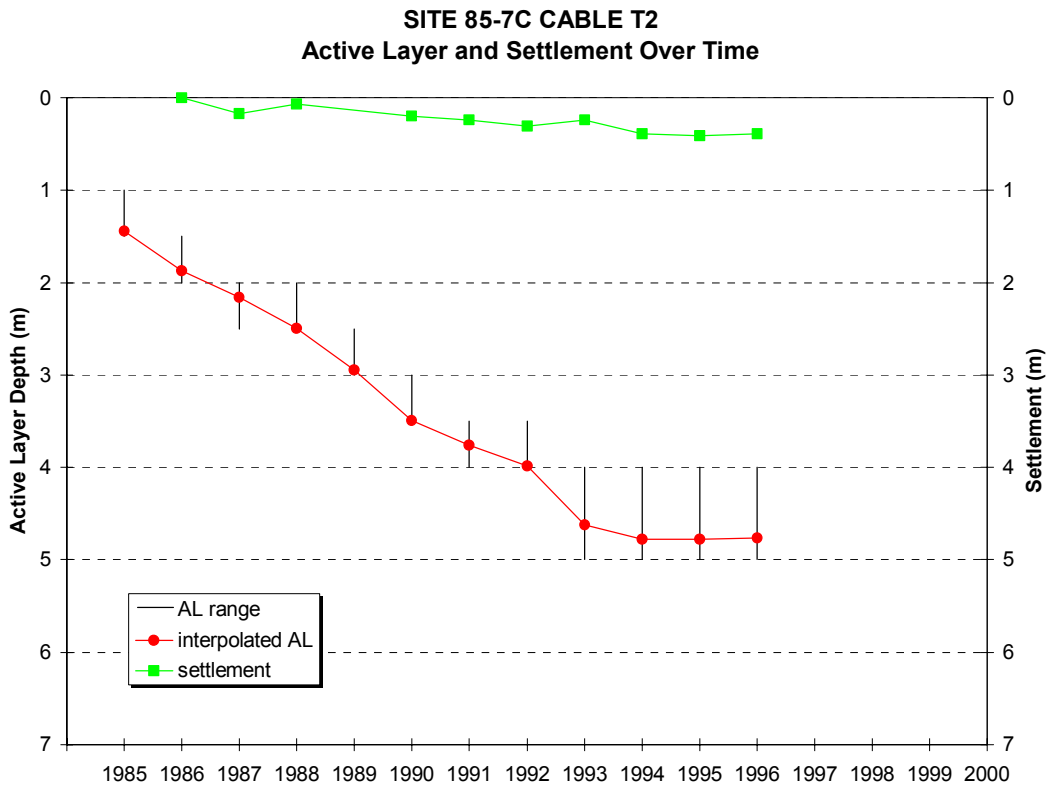

SITE 85-7B CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
0
1
2
3
4
5
6
7
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
AL range
interpolated AL

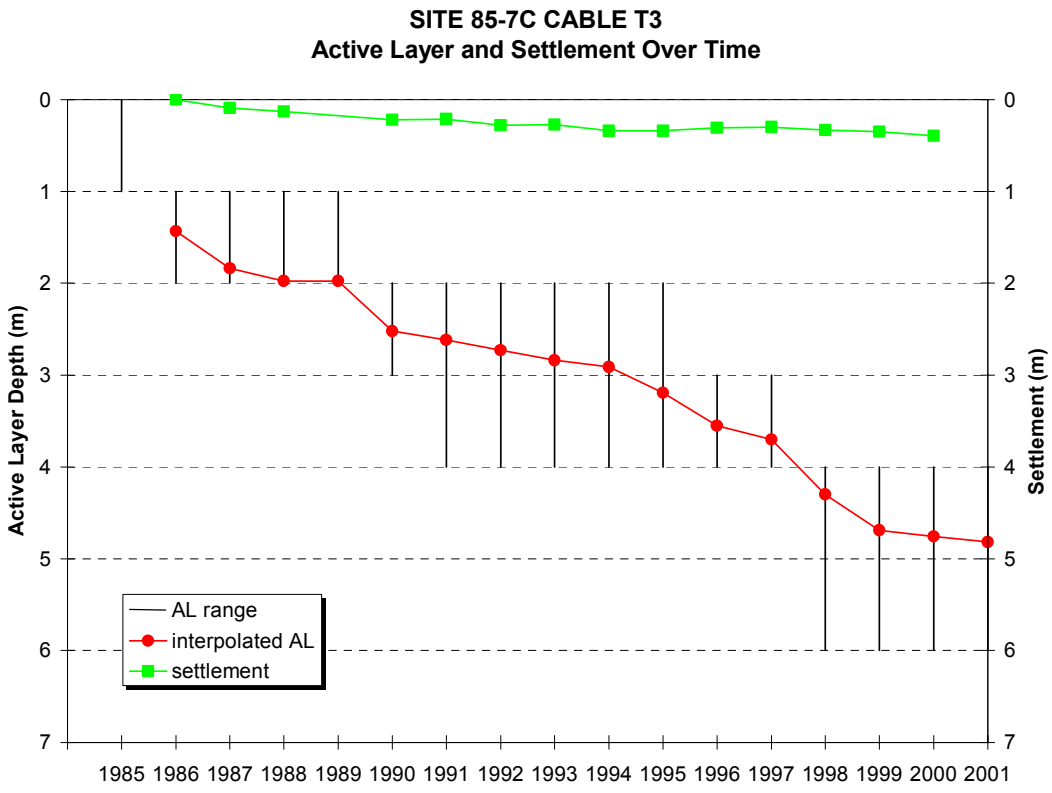
SITE 85-7B CABLE T4
Active Layer and Settlement Over Time

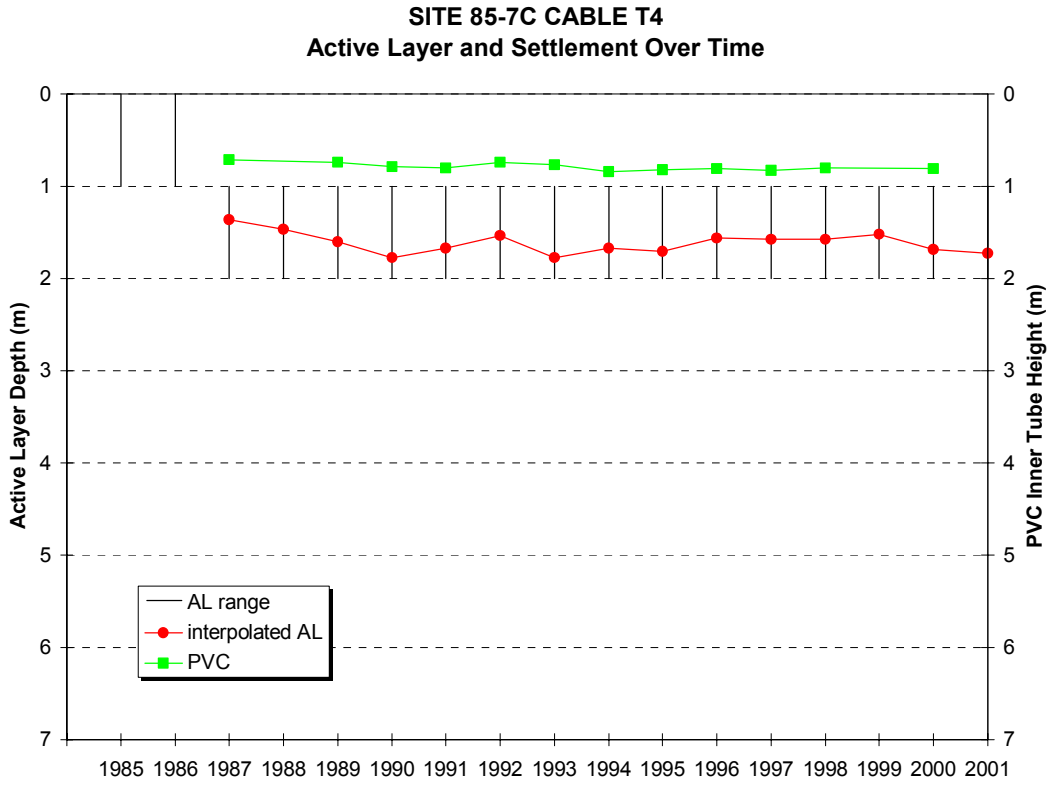


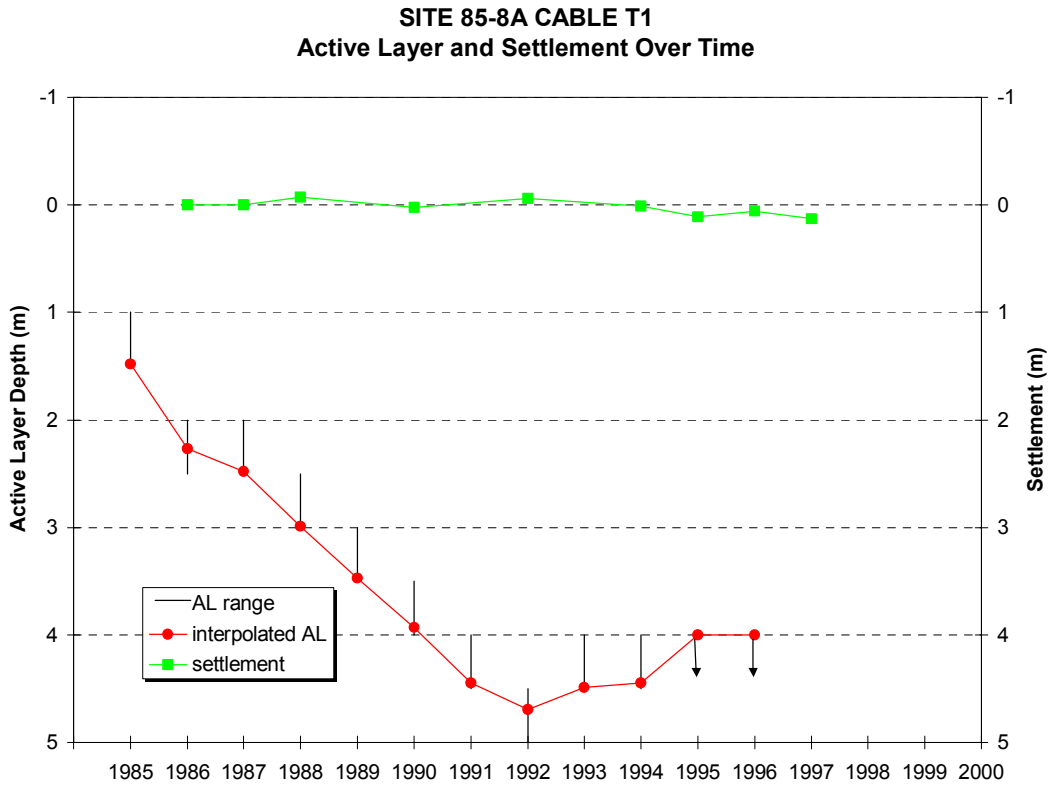
SITE 85-7C CABLE T1
Active Layer and Settlement Over Time



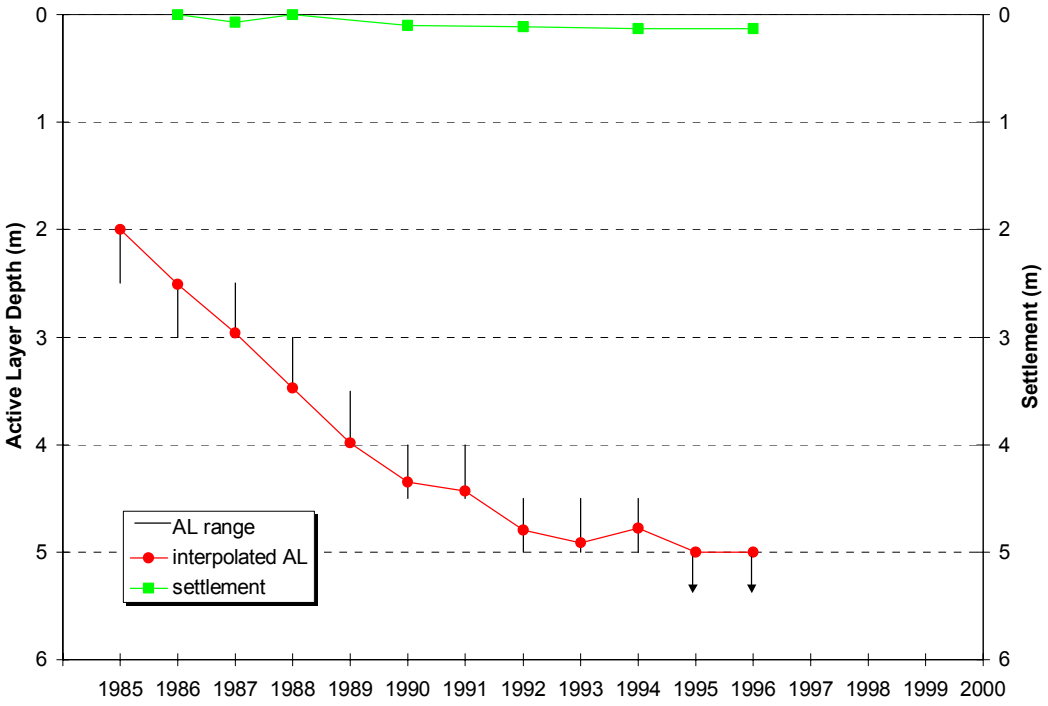

SITE 85-7C CABLE T2
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
7
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
AL range
interpolated AL
settlement


SITE 85-7C CABLE T3
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
0
1
2
3
4
5
6
7
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
AL range
interpolated AL
settlement

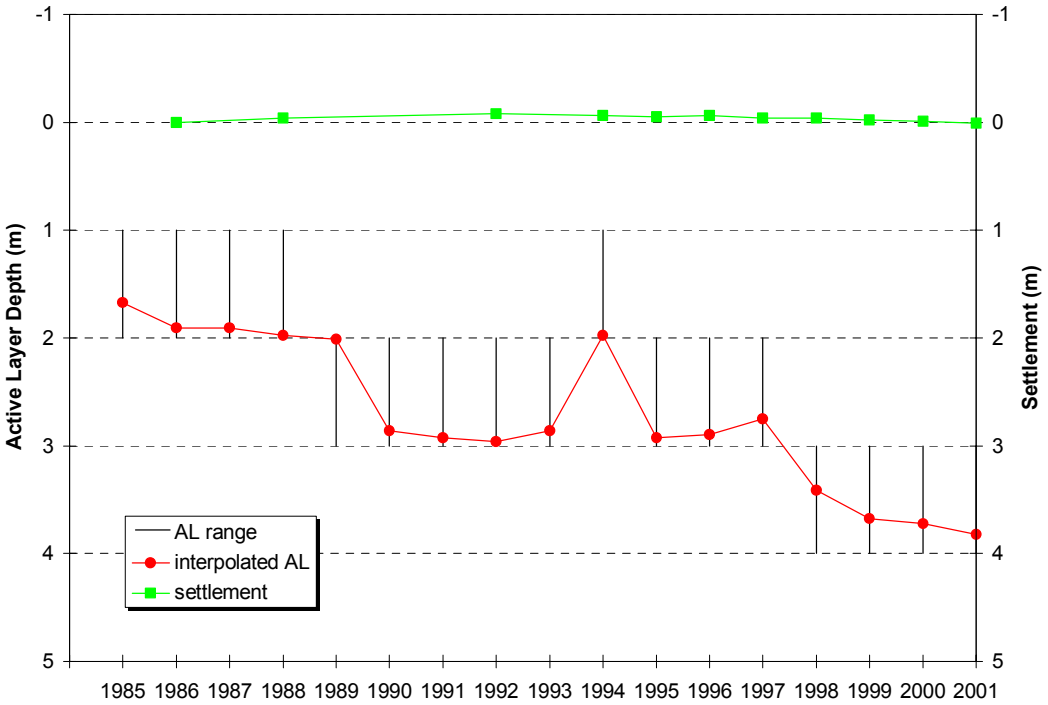

SITE 85-7C CABLE T4
Active Layer and Settlement Over Time
Active Layer Depth (m)
PVC Inner Tube Height (m)
0
1
2
3
4
5
6
7
AL range
interpolated AL
PVC
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001


SITE 85-8A CABLE T1
Active Layer and Settlement Over Time
Active Layer Depth (m)
Settlement (m)
-1
0
1
2
3
4
5
AL range
interpolated AL
settlement
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

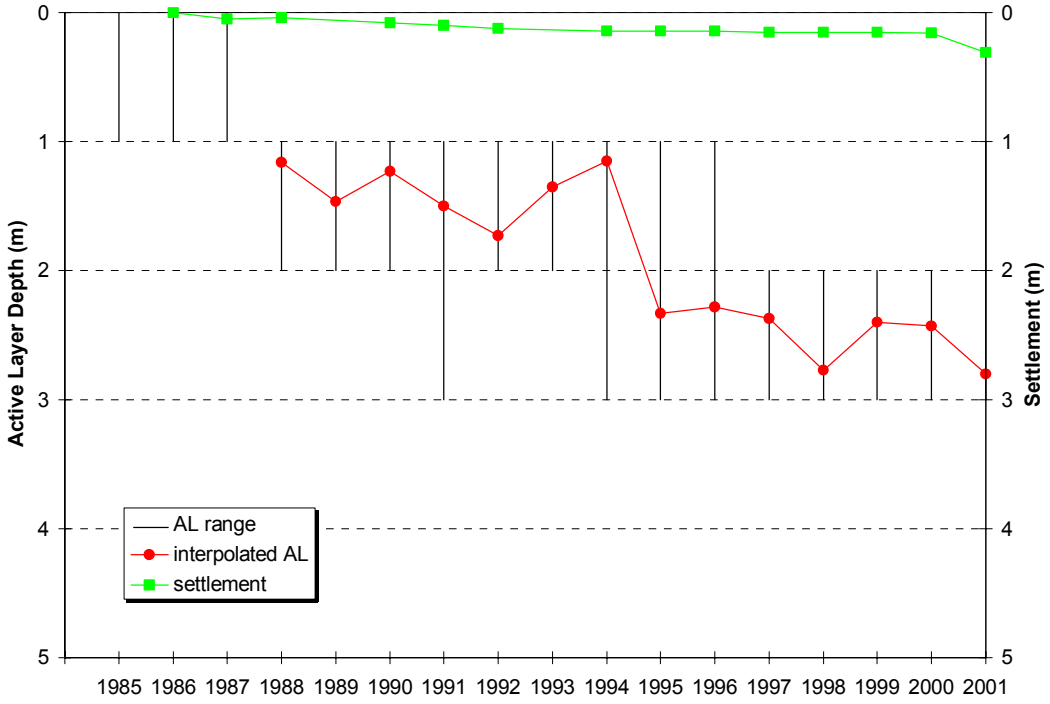
SITE 85-8A CABLE T2
Active Layer and Settlement Over Time



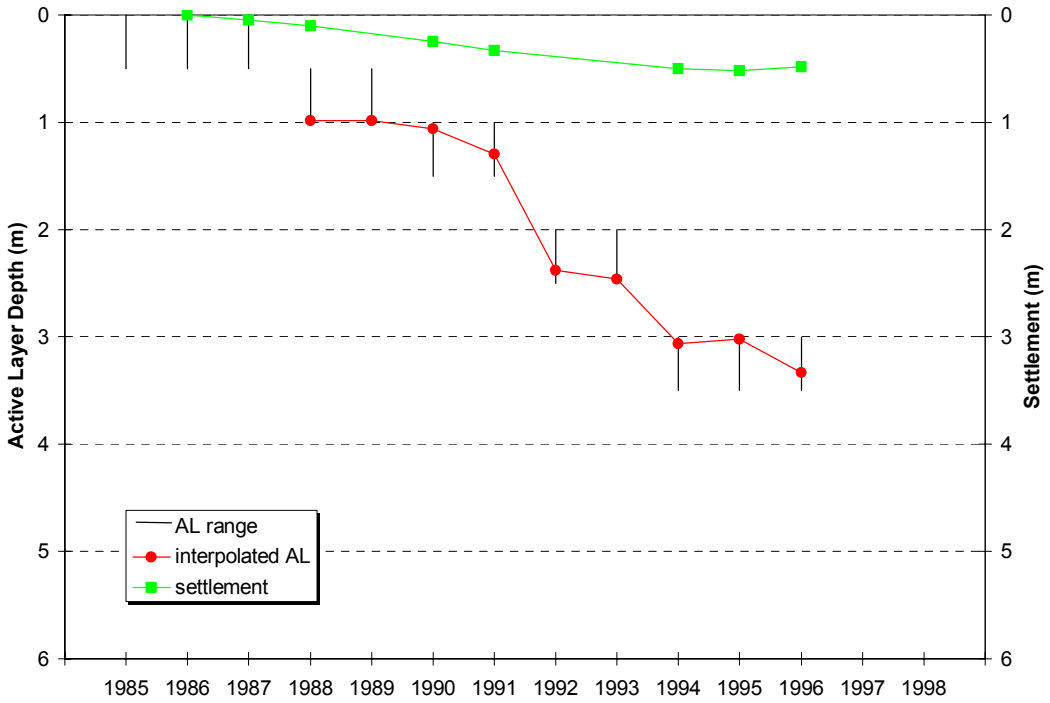
SITE 85-8A CABLE T3
Active Layer and Settlement Over Time



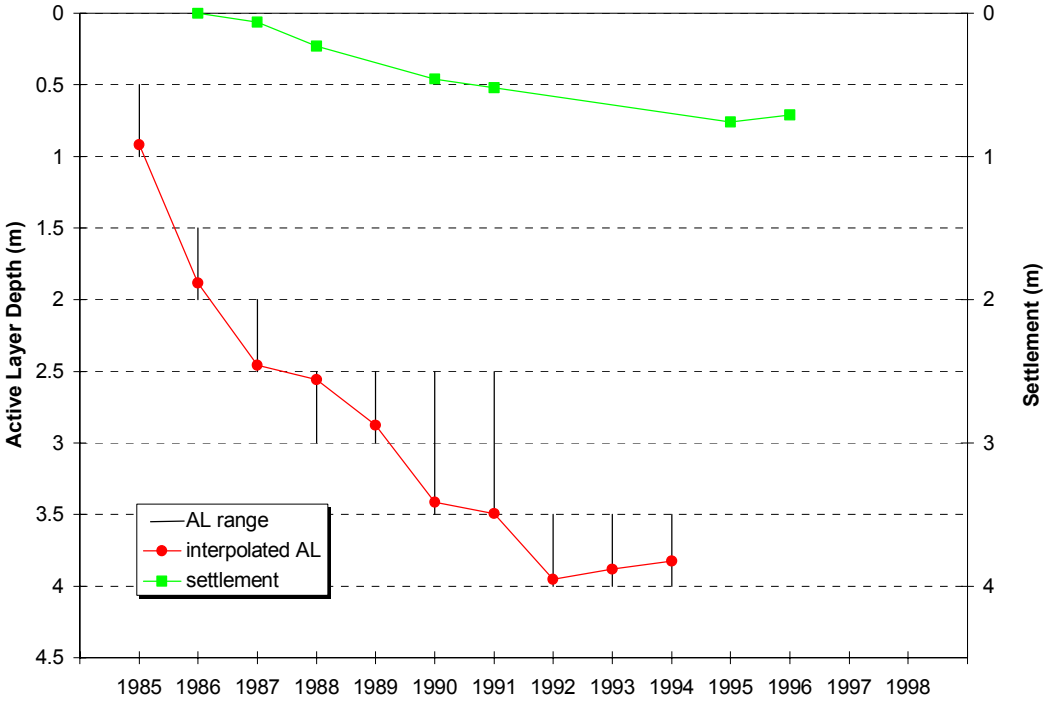
SITE 85-8A CABLE T4
Active Layer and Settlement Over Time



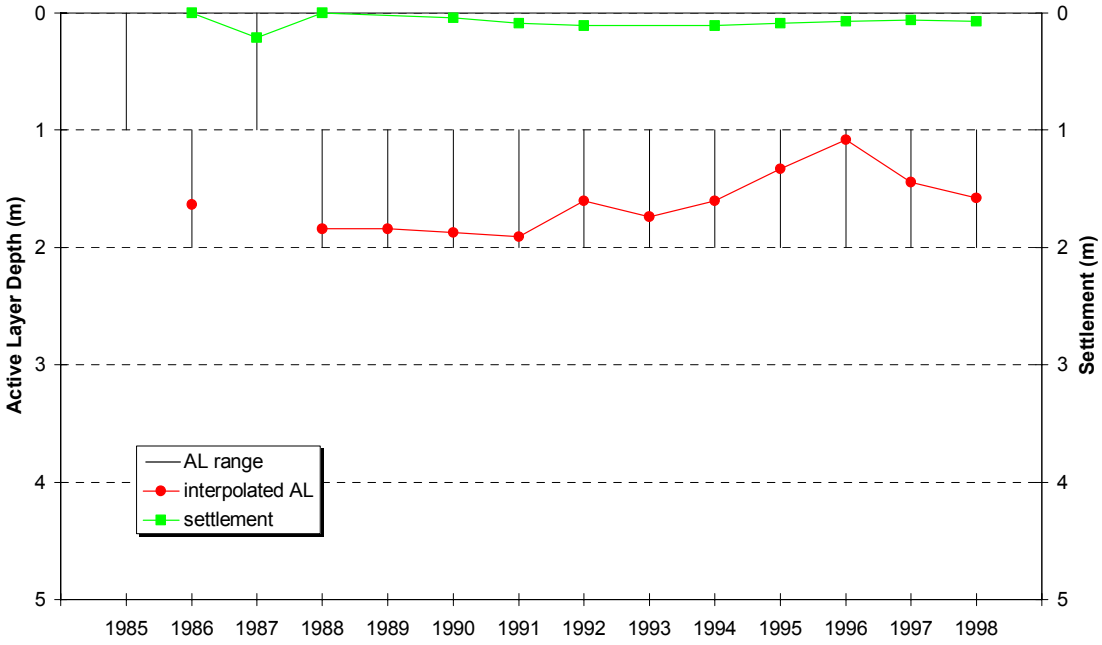
SITE 85-8B CABLE T1
Active Layer and Settlement Over Time



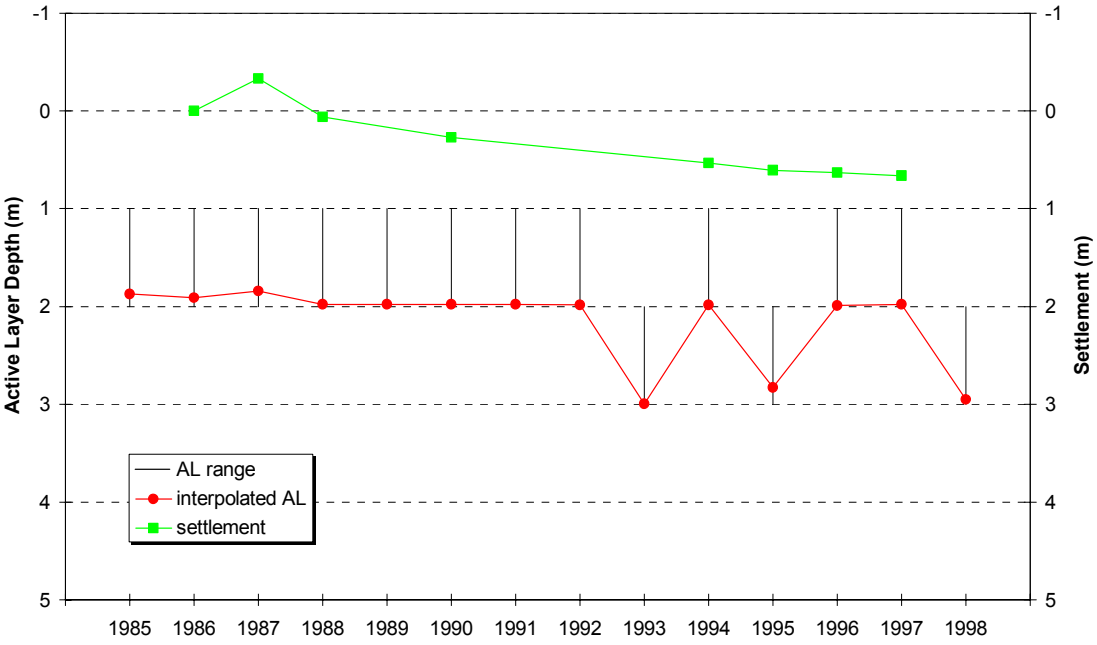
SITE 85-8B CABLE T2
Active Layer and Settlement Over Time



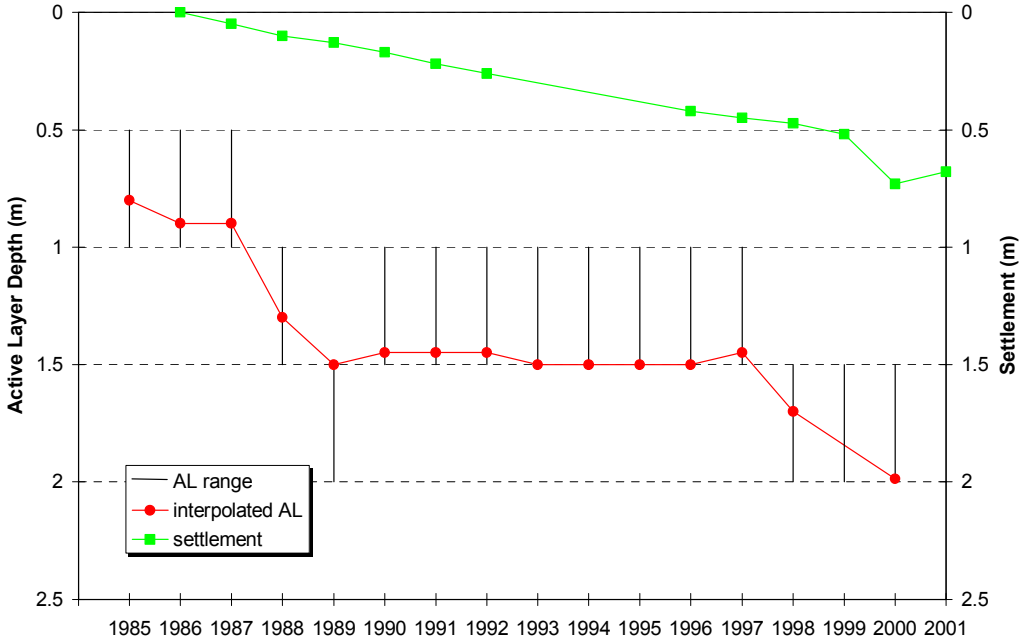
SITE 85-8B CABLE T3
Active Layer and Settlement Over Time



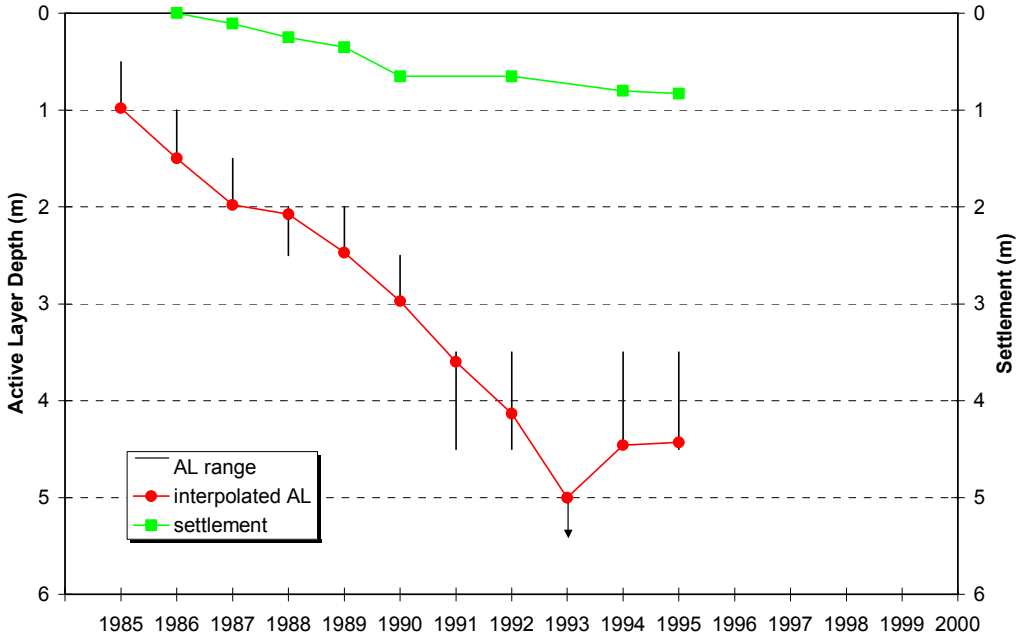
SITE 85-8B CABLE T4
Active Layer and Settlement Over Time



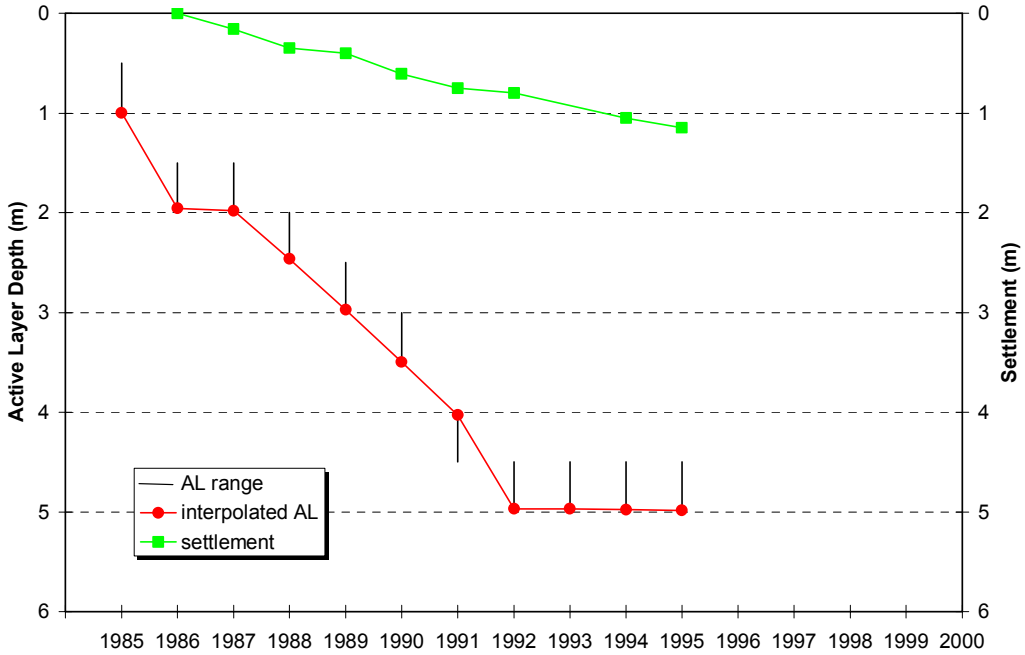
SITE 85-10B CABLE T4
Active Layer and Settlement Over Time



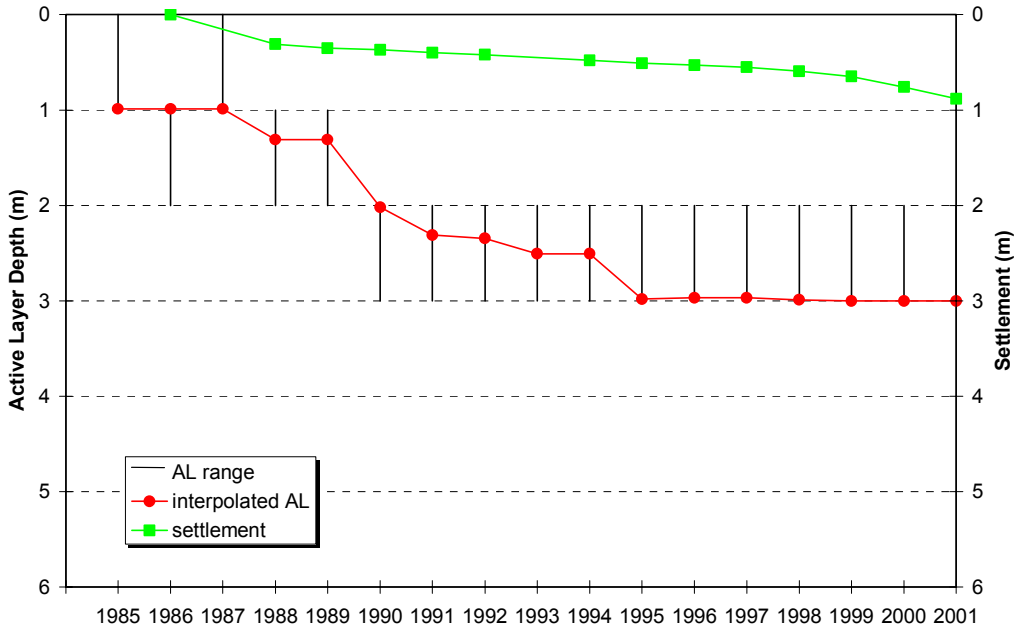
SITE 85-12B CABLE T1
Active Layer and Settlement Over Time



SITE 85-12B CABLE T2
Active Layer and Settlement Over Time



SITE 85-12B CABLE T3
Active Layer and Settlement Over Time



SITE 85-12B CABLE T4
Active Layer and Settlement Over Time