



## **GEOLOGICAL SURVEY OF CANADA**

### **OPEN FILE 4635**

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

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

2004



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Available from  
Geological Survey of Canada  
601 Booth Street  
Ottawa, Ontario K1A 0E8

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

**2004:** Digital summary database of permafrost and thermal conditions – Norman Wells Pipeline study sites,  
Geological Survey of Canada, Open File 4635, 104 p.

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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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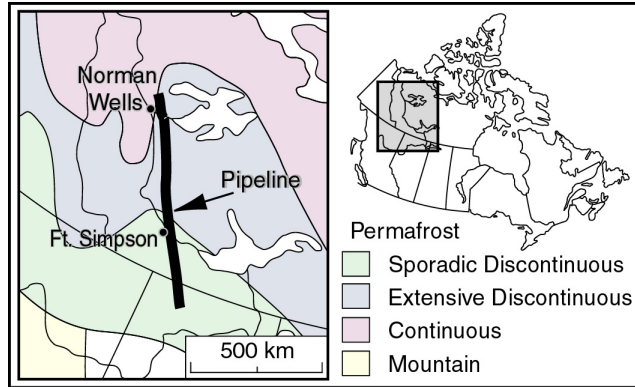
# 1. INTRODUCTION

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).

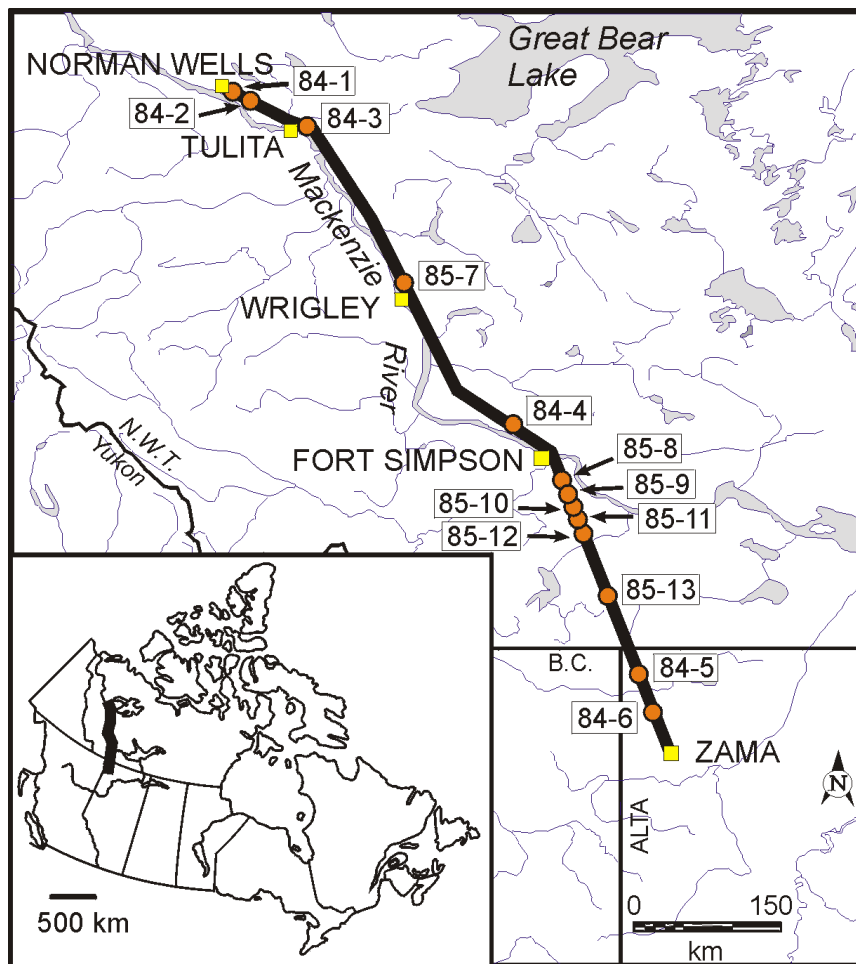
Since construction, in 1984-1985, the Canadian Government and Enbridge have collaborated to monitor the ground thermal regime along the pipeline route. This monitoring project contributed to a larger Permafrost and Terrain Research Monitoring Program established to improve impact evaluation and mitigation 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

<b>SITE NO.</b>	<b>NAME</b>	<b>KM POST</b>	<b>DESCRIPTION (at time of establishment)</b>
84-1	Pump Station 1	0.02	<b>Widespread permafrost</b> Ice-rich silty clay
84-2	Canyon Creek		<b>Previously cleared alignment, thaw sensitive slopes, widespread permafrost</b>
	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		<b>Thaw sensitive terrain (joint with Enbridge slopes)</b>
	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		<b>Thaw sensitive terrain (joint with Enbridge slopes)</b>
	A	271.2	Ice-rich lacustrine plain (old seismic line)
		272.0	Drillpad clearing at bend on top of north facing slope, ice-rich lacustrine plain
	B		
	C	272.3	New clearing on ice-rich lacustrine plain
84-4	Trail River		<b>Pipeline previously traversed frozen ground</b>
	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		<b>Rapidly changing permafrost conditions</b>
	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		<b>Pipe previously traversed frozen section</b>
		588.3	Unfrozen granular soils
85-10	Mackenzie Hwy. S.		<b>Unfrozen/frozen interface</b>
	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		<b>Unfrozen/frozen interface</b>
	A	608.6	Thin unfrozen peat
	B	608.7	Thick ice-rich peat plateau; 4 m permafrost
85-13	Redknife Hills		<b>Frozen/unfrozen interface; single cables only</b>
	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.		<b>Degrading peat plateau</b>
	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.		<b>Peat plateau preceded by unfrozen fen</b>
		819.5	Thick (5 m ) ice-rich peat; 7 m permafrost

## 2. BACKGROUND

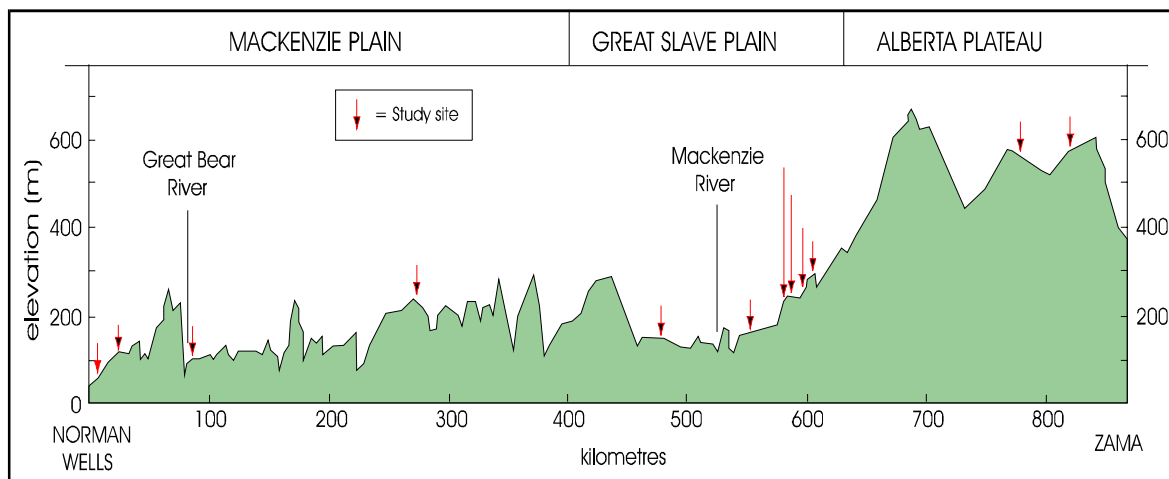
### 2.1 Project Setting

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.

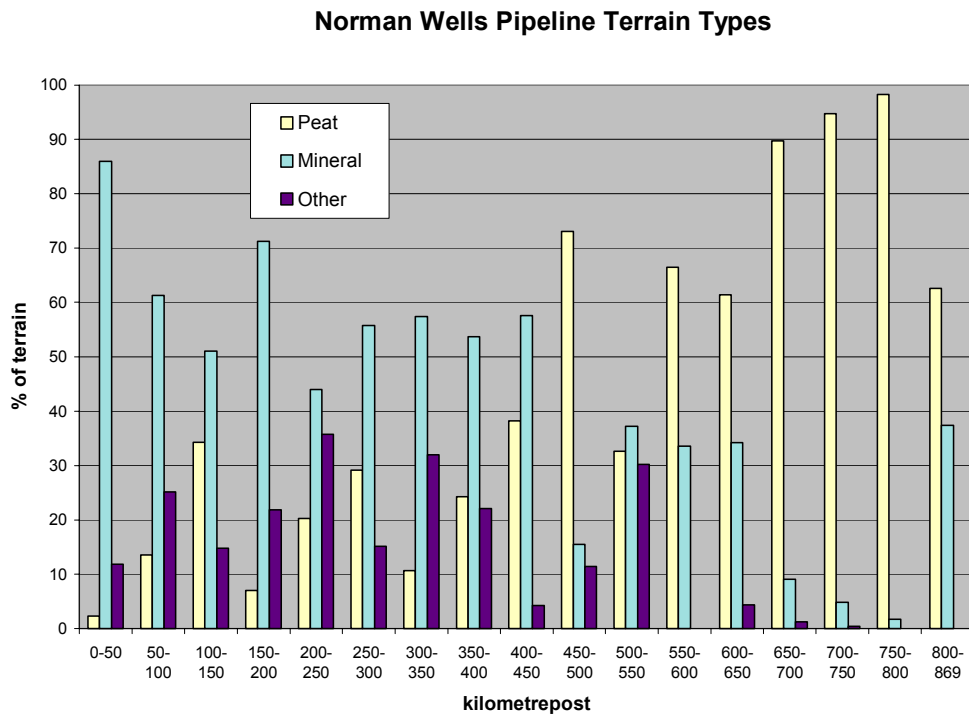
Over the northern half of the pipeline route, lacustrine soils and tills are dominant while in the south, tills and organic terrain predominate (Fig. 4). The fine-grained lacustrine soils and frozen organic soils (peat plateaus) are often ice-rich and thaw sensitive. In the northern section, frozen ground underlies more than 65% of the corridor (Fig. 5) and undisturbed permafrost temperatures range from  $-2.5^{\circ}\text{C}$  to  $-1^{\circ}\text{C}$ . Permafrost temperatures are warmer than  $-1^{\circ}\text{C}$  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 1 metre. 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  $-1^{\circ}\text{C}$  throughout the year. A seasonal chilling cycle was introduced in 1993 with oil entering the line at a temperature ranging from  $-4^{\circ}\text{C}$  in winter to  $+9^{\circ}\text{C}$  in summer for an average annual temperature between 0 and  $-1^{\circ}\text{C}$ .

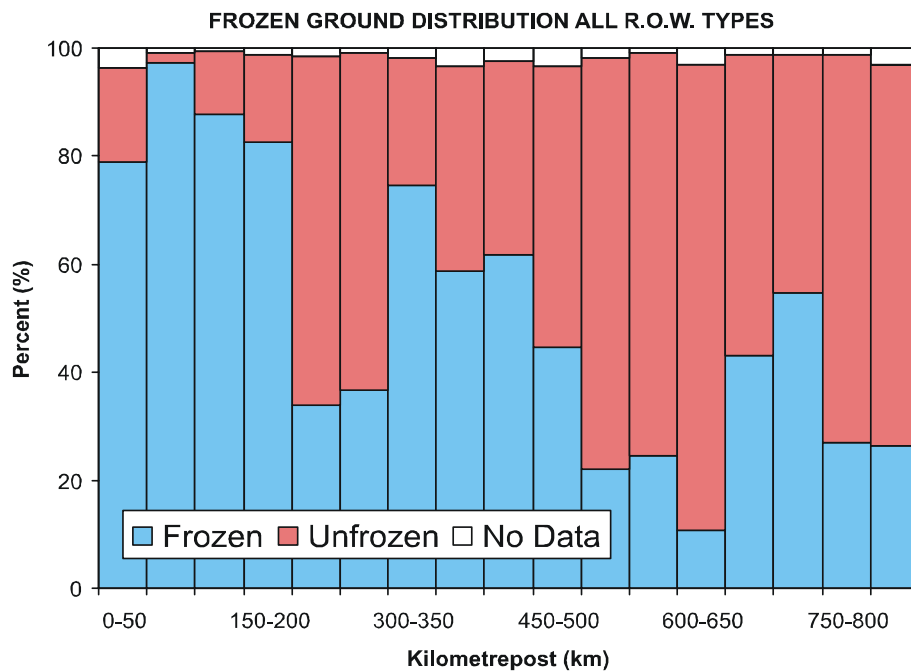
Numerous papers and reports have been published on the project setting, design, geothermal and terrain response, on geotechnical performance and pipe-soil interaction (see for example, Burgess and Lawrence, 1997; Nixon and Burgess, 1999; Burgess and Smith, 2003). MacInnes et al. (1989, 1990) provides 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  $\pm 0.1$  K, while the measurement system allows for a resolution of  $\pm 0.01$  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**

<i>b</i>	<i>bar</i>
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
<i>r</i>	<i>ridge</i>
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
<i>p</i>	<i>plain</i>
r	ridged
v	moraine veneer

**R – Bedrock (undifferentiated)**

***S – Coastal***

<i>c</i>	<i>cliff, bluff</i>
<i>d</i>	<i>delta</i>
<i>p</i>	<i>plain</i>
<i>t</i>	<i>terrace</i>

**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  $\pm 10$  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.

## 7. REFERENCES

Agra Earth and Environmental Limited & Nixon Geotech Ltd. 1999. Monograph on Norman Wells pipeline geotechnical design and performance. Final report to Department of Natural Resources, March 1999. Geological Survey of Canada Open File 3773.

Burgess, M.M. 1986a. Norman Wells pipeline monitoring sites ground temperature data file: 1984-1985. Energy Mines and Resources Canada, Earth Physics Branch Open File 86-6, 147 p.

Burgess, M.M. 1986b. Norman Wells pipeline monitoring sites ground temperature data file: 1986. Geological Survey of Canada, Open File 1621, 260 p.

Burgess, M.M. and Lawrence, D.E. 2000. Permafrost and surficial materials along a north-south transect: observations from the Norman Wells pipeline. *In* The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks. Geological Survey of Canada, Bulletin 547, p. 127-141.

Burgess, M.M. and Lawrence, D.E. 1997. Thaw settlement in permafrost soils: 12 years of observations on the Norman Wells pipeline right-of-way. In Proc., 50<sup>th</sup> Canadian Geotechnical Society Conference, Ottawa, p. 77-84.

Burgess, M.M. and Naufal, J.A. 1989. Norman Wells pipeline monitoring sites ground temperature data file: 1987. Geological Survey of Canada, Open File 1987, 27 pp. +appendices.

Burgess, M.M. and Naufal, J.A. 1990. Norman Wells pipeline monitoring sites ground temperature data file: 1987. Geological Survey of Canada, Open File 2155, 203 p.

Burgess, M.M. and Naufal, J.A. 1991. Norman Wells pipeline monitoring sites ground temperature data file: 1989. Geological Survey of Canada, Open File 2406, 127 p.

Burgess, M.M. and Smith, S.L. 2003. 17 years of thaw penetration and surface settlement observations in permafrost terrain along the Norman Wells pipeline, Northwest Territories, Canada. Proceedings of 8<sup>th</sup> International Conference on Permafrost, p. 107-112.

MacInnes, K.L., Burgess, M.M., Harry, D.G. and Baker, T.H.W. 1989. Permafrost and terrain research and monitoring: Norman Wells Pipeline, Volume 1 Environmental and Engineering Considerations. Indian and Northern Affairs Canada, Environmental Studies No. 64, 132 p.

MacInnes, K.L., Burgess, M.M., Harry, D.G. and Baker, T.H.W. 1990. Permafrost and terrain research and monitoring: Norman Wells Pipeline, Volume 2 Research and Monitoring Results 1983-1988. Indian and Northern Affairs Canada, Environmental Studies No. 64, 204 p.

Nixon, J.F. and Burgess, M.M. 1999. Norman Wells Pipeline settlement and uplift movements. Canadian Geotechnical Journal, v. 36, p. 119-135.

Pilon, J.A., Burgess, M.M., Judge, A.S., Allen, V.S., MacInnes, K.L., Harry, D.G., Tarnocai, C. and Baker, H. 1989. Norman Wells to Zama pipeline permafrost and terrain research and monitoring program: site establishment report. Geological Survey of Canada Open File 2044, 332 p.

Smith, S.L., Burgess, M.M., and Heginbottom, J.A. 2001. Permafrost in Canada, a challenge to northern development; *in* A Synthesis of Geological Hazards in Canada, (ed.) G.R. Brooks; Geological Survey of Canada Bulletin 548, p. 241-264.

## **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.

Patterson, D.E. and Riseborough, D.W. 1988. A detailed study of the physical and thermal properties of Norman Wells-Zama Pipeline core specimens. Geological Survey of Canada Open File 1896.

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Clay: Clay (Till) - Silty, trace Gravel, low plastic, brown	Vs, ice lenses to 10mm						
-2									
-4		Silt: Silt (Till?) - Clayey, trace angular Shale fragments, low plastic, brown	Nbn						
-6									
-8		Bedrock: Shale - Silty, fractured (unable to core the weathered, fractured Shale)	Nbn with Vx, few ice crystals						
-10									
-12		Bedrock: Shale - hard (competent) Shale							

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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, Peaty, rootlets	Nbc Vs, ice lenses to 5mm						
-2		Clay: Clay (Till) - Silty, trace Gravel, low plastic, brown							
-4		Silt: Silt - Clayey, some (weathered) Shale fragments, low to non- plastic, brown	Nbe						
-6									
-8		Bedrock: Shale - Silty, fractured, weathered	Nbe with Vc, few ice crystal						
-10									
-12									
-14		Bedrock: Shale - hard (competent) Shale							



Borehole #: EMR84-2A-G1	Date: 08-Mar-84
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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Clay: Clay (Till) - Silty, some Gravel to 100mm,	Nbn						
-2									
-4									
-6		Silt: Silt (Till) - Clayey, trace Shale fragments, low to non- plastic							
-8									
-10		Bedrock: Shale - Silty, fractured	Frozen? (possibly unfrozen)						
-12									
-14									
-16									
-18									
-20									

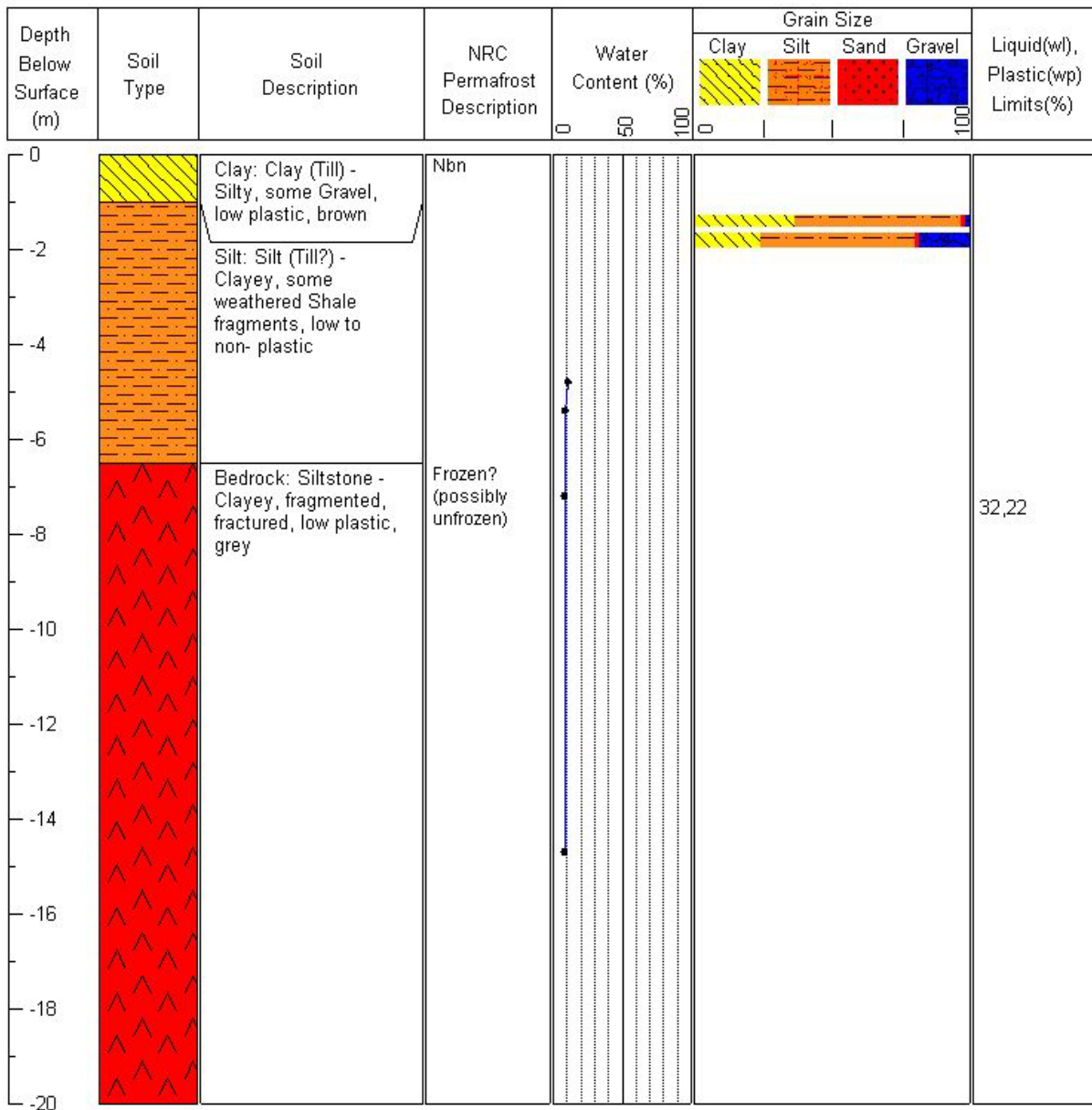
Borehole # : EMR84-2B-T3	Date: 11-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7236436
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 616013
Original Borehole # : EMR-84-2B-T-3	Zone: 9
Report# : HAL84NWZM	Elevation(m): 110
Permafrost Conditions: Frozen      Landform: ground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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0									
-2		Clay: Clay (Till) - Silty, some Gravel to 30 mm, low plastic, brown	Nbn Vc Vx						
-4		Clay: Clay (Till) - trace Shale fragments, low plastic, brown	Vx, few ice crystals						
-6		Bedrock: Shale - fractured, fragmented	Unfrozen						
-8									
-10									
-12									
-14									
-16									
-18									
-20									

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, Peaty, roots	Frozen Nbn Vc Vx						
-2		Clay: Clay (Till) - Silty, some Gravel to 40mm, low plastic, brown	Vx, few ice crystals and ctgs						
-4		Clay: Clay (Till) - trace Shale fragments, low plastic	Unfrozen						
-6		Bedrock: Shale - fractured, fragmented							
-8		Bedrock: Shale - hard (competent)							
-10									
-12									
-14									
-16									
-18									
-20									

Borehole #: EMR84-2C-T3	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-3	Zone: 9
Report#: HALB4NWZM	Elevation(m): 119
Permafrost Conditions: Frozen	Landform: ground moraine
Surface Material: clay/silt/siltstone, glacial till	

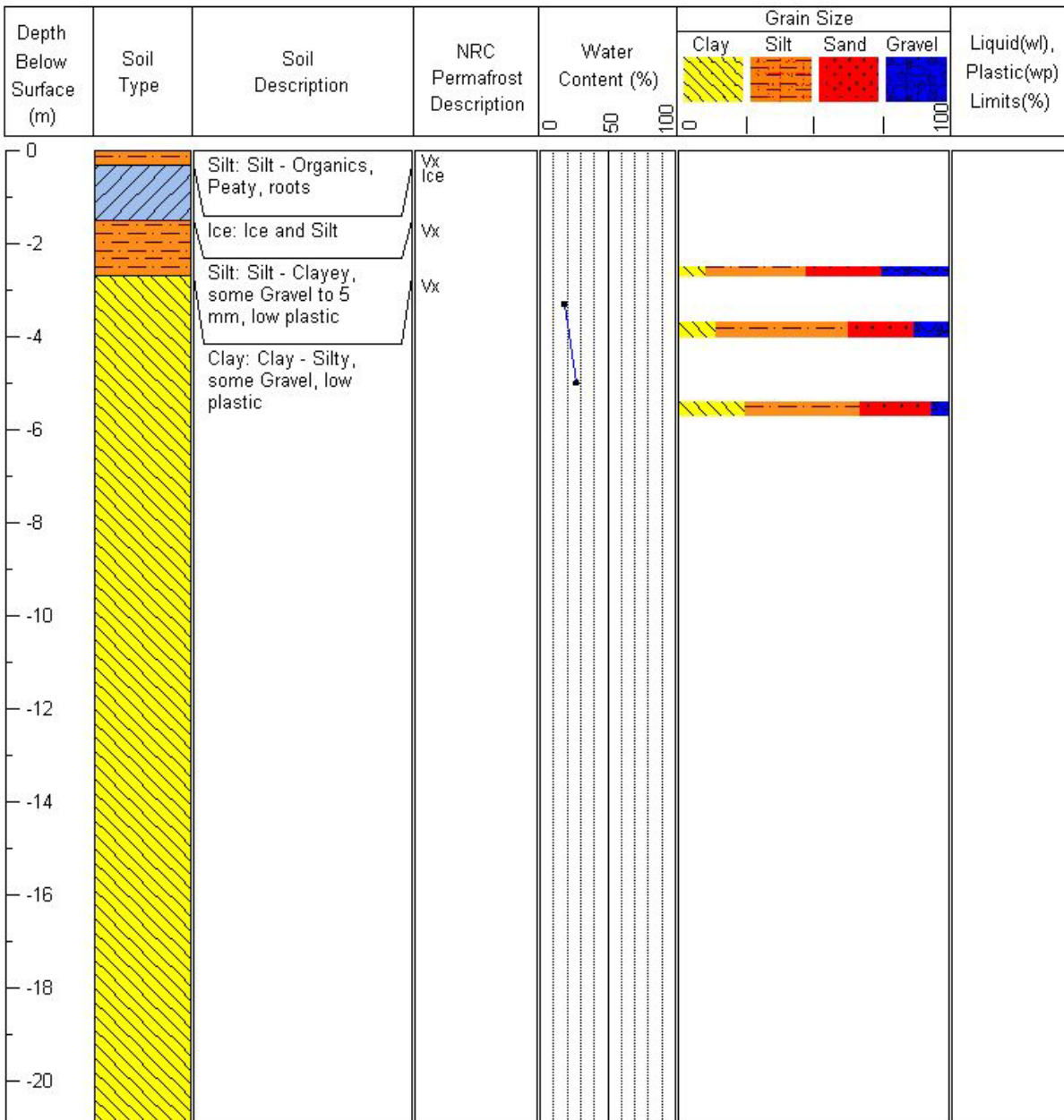


Borehole #: EMR84-2C-T4	Date: 09-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7236323
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 616290
Original Borehole #: EMR-84-2C-T-4	Zone: 9
Report#: HALB4NWZM	Elevation(m): 119
Permafrost Conditions: Frozen      Landform: ground moraine      Surface Material: clay/silt/siltstone, glacial till	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, Peat moss, roots	Frozen Nbn						
-2		Clay: Clay (Till) - Silty, some Gravel, low plastic, brown							
-4		Silt: Silt (Till?) - Clayey, some (weathered) Shale fragments, low to non- plastic							
-6									
-8		Bedrock: Siltstone - Clayey, low plastic, fragmented, fractured, grey	Frozen? (possibly unfrozen)						
-10									
-12									
-14									
-16									
-18									
-20									



Borehole # : EMR84-3A-G1	Date: 17-Mar-84
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 # : EMR84-3A-T4	Date: 18-Mar-84
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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, Peaty, roots, moss	Vx						
-2		Ice: Ice and Silt - low plastic	Vx, ice crystals pockets to 30 mm						
-4		Silt: Silt - some Gravel, non- plastic	Vx						
-6		Clay: Clay - Silty, some Gravel to 60 mm, low plastic							
-8									

Borehole #: EMR84-3B-G1	Date: 19-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7200917
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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, Peaty	Vc Vs, few ice lenses to 20 mm						
-2		Sand: Sand - some Silt lenses, uniform, fine-grained	Vc Vx						
-4		Sand: Sand - fine to coarse grained with trace fine Gravel for 600 mm	Vx Vs						
-6		Clay: Clay - Silty, low plastic, grey, slightly lensed							
-8									
-10		Ice: Ice and Clay	Ice, lenses to 100 mm Vs Vx						
-12		Clay: Clay - Silty, trace Gravel, low plastic							
-14									
-16									
-18									
-20									



Borehole # : EMR84-3B-T4	Date: 19-Mar-84
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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, Peaty, roots, twigs	Vx Vc						
-2		Sand: Sand - Silty lenses structured, uniform, fine grained	Vs, few ice lenses to 20 mm						
-4		Sand: Sand - fine to coarse grained with some Gravel for 400 mm	Vx Vs						
-6		Sand: Sand - few Silt lenses	Frozen (thawed by drilling)						
-8		Clay: Clay - Silty, some Gravel to 80 mm, low plastic							
-10									
-12									
-14									
-16									
-18									
-20									

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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - some fine Sand, trace Organics, brown	Nf						
-2		Sand: Sand - trace Silt, uniform, fine-grained, brown	Unfrozen						
-4		Sand: Sand - saturated, grey							
-6		Clay: Clay - firm, Silty, medium plastic, grey							
-8									
-10									
-12									
-14									
-16									
-18									
-20									

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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, rootlets	Nbe Nbn						
-2		Silt: Silt and Sand - trace Organics, fine-grained	Unfrozen						
-4		Sand: Sand - some Silt, uniform, fine-grained, brown							
-6		Sand: Sand - saturated, grey							
-8		Clay: Clay - firm, Silty, medium plastic, grey							
-10									
-12									
-14									
-16									
-18									
-20									

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

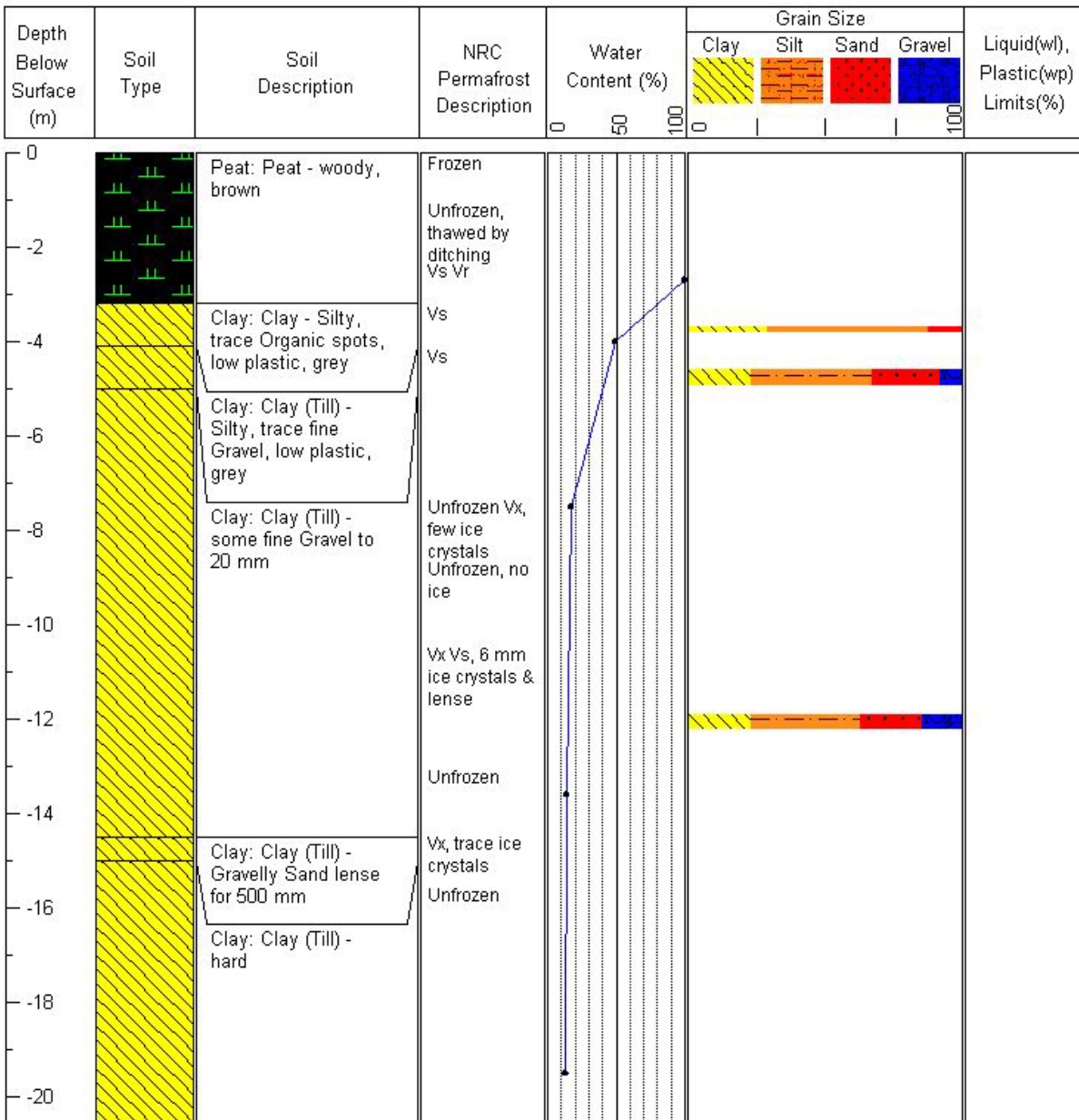
Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Sand: Sand - some Silt, uniform, fine- grained, brown	Nf						
-2			Unfrozen						
-4									
-6									
-8									
-10		Sand: Sand - Silt lenses to 30 mm for 3.5 m							
-12									
-14									
-16		Sand: Sand - saturated							
-18									
-20		Clay: Clay - firm, Silty, low plastic, grey							

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	

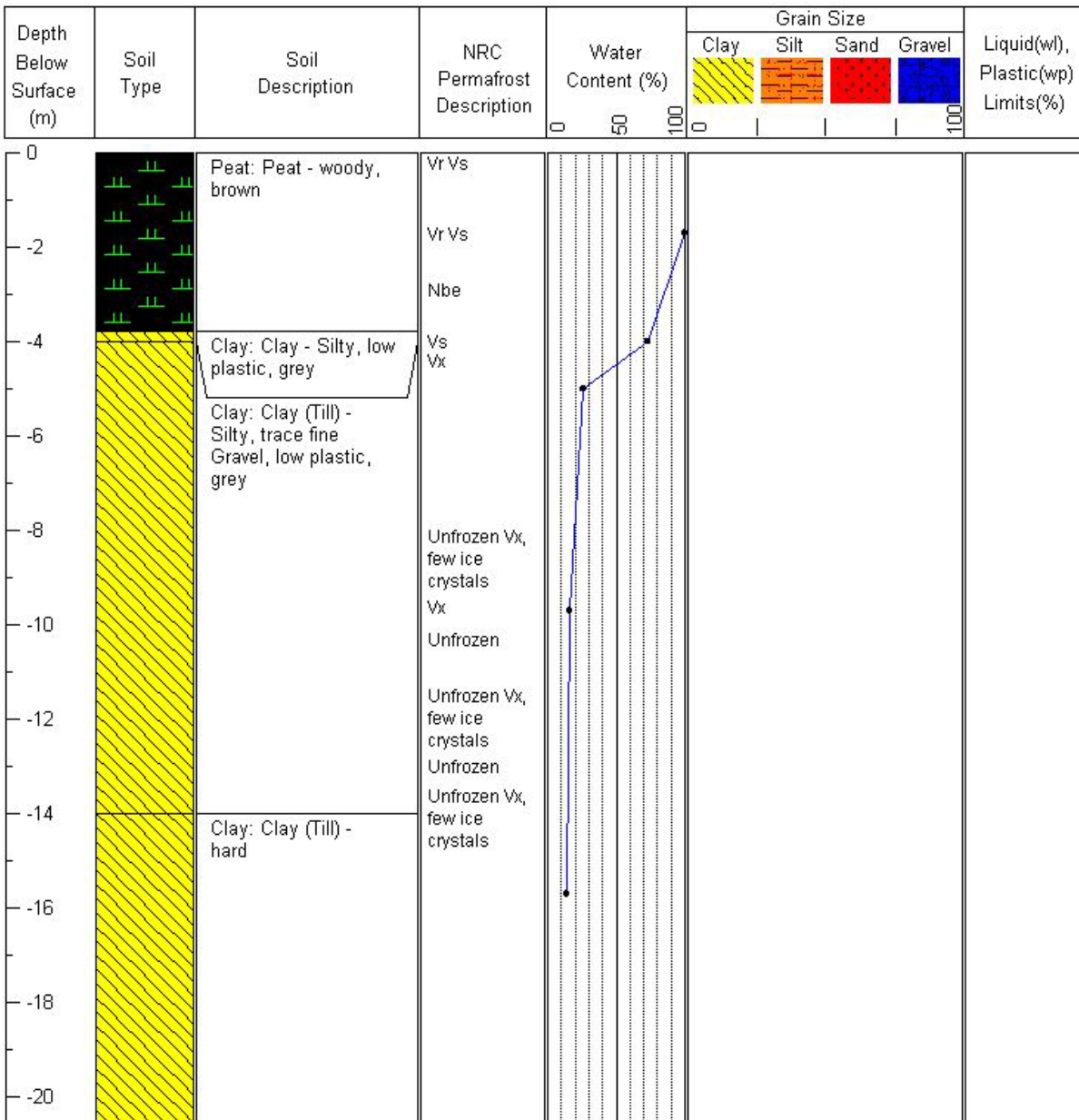
Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, rootlets	Frozen						
-2		Sand: Sand - some Silt, uniform, fine-grained, brown	Unfrozen						
-4									
-6									
-8									
-10									
-12									
-14									
-16		Sand: Sand - saturated, grey							
-18									
-20									



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	

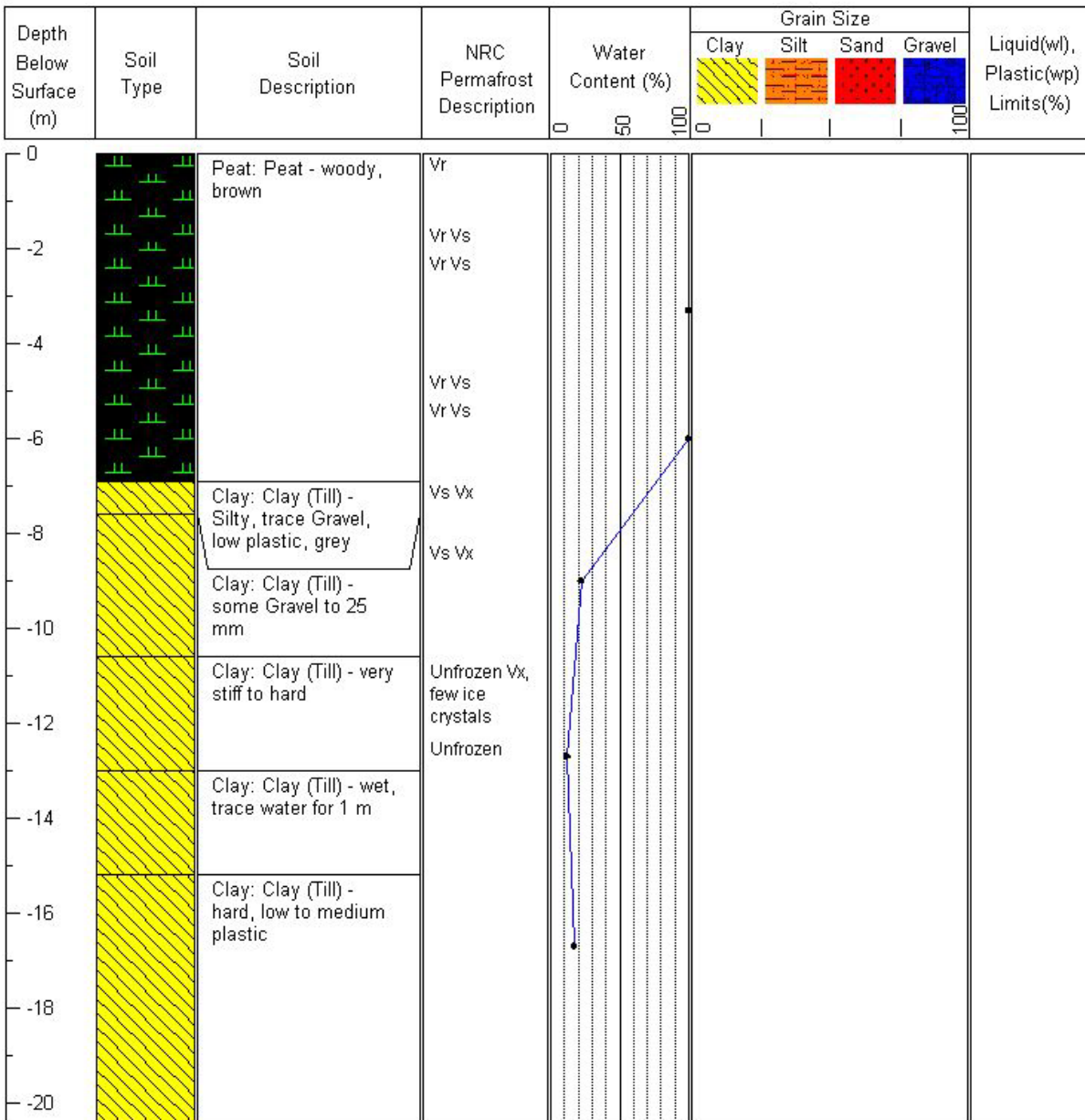


Borehole # : EMR84-5B-T3	Date: 16-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6626692
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 358686
Original Borehole # : EMR-84-5B-T3	Zone: 11
Report# : HAL84NWZM	Elevation(m): 552
Permafrost Conditions: Frozen      Landform: ground moraine      Surface Material: clay, glacial till	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Vr						
-2			Vr						
			Vr						
			Vr Vs						
-4			Vr Vs						
-6									
-8		Clay: Clay (Till) - Silty, trace fine Gravel, low plastic, grey	Nbn Vs Vx						
-10		Clay: Clay (Till) - very stiff to hard	Unfrozen						
-12									
-14		Clay: Clay (Till) - trace water							
-16									
-18		Clay: Clay (Till) - occasional cobbles							
-20									



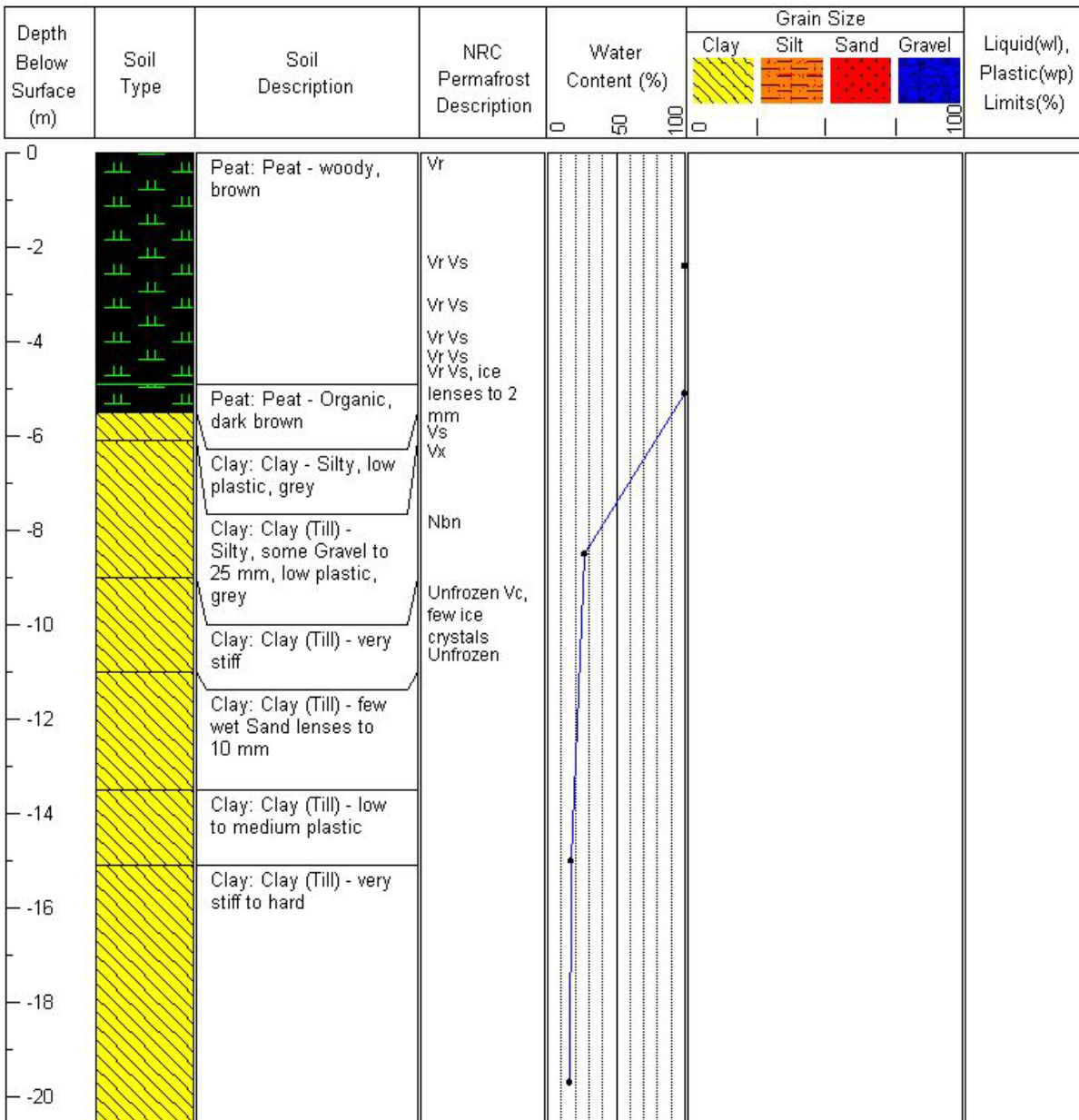
Borehole # : EMR84-5B-T4	Date: 17-Mar-84
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6626692
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 358686
Original Borehole # : EMR-84-5B-T4	Zone: 11
Report# : HAL84NWZM	Elevation(m): 552
Permafrost Conditions: Frozen      Landform: ground moraine      Surface Material: clay, glacial till	



Borehole # : EMR84-6-G1	Date: 20-Mar-84
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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen						
-2			Vr Vs						
-4		Ice: Ice - Ice lens 2.9 to 3.1 m	Vr Ice, ice lenses to 30 mm						
-6		Peat: Peat - Organics, dark brown	Vs Ice, ice zone						
-8		Ice: Ice - Ice lens	Vx, numerous ice crystals						
-10		Clay: Clay - Silty, low plastic, grey	Vc, trace ice						
-12		Clay: Clay - varved	Nbn						
-14		Clay: Clay (Till) - Silty, trace Gravel, low plastic, grey	Unfrozen?						
-16		Ice: Ice - thawed by drilling	Unfrozen						
-18		Clay: Clay (Till) - water							
-20		Clay: Clay - very stiff to hard, medium plastic							

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	



Borehole # : EMR84-6-T5	Date: 20-Mar-84
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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Vr Vs						
-2		Peat: Peat - water	Unfrozen						
		Peat: Peat - fibrous Peat							
-4									
-6		Peat: Peat - amorphous, trace Organics (odourless)							
-8		Clay: Clay - very soft, Silty, low plastic, grey							
		Clay: Clay - soft, trace coarse Sand							
-10		Clay: Clay (Till) - stiff, Silty, trace Gravel to 10 mm, low to medium plastic, grey							



Borehole # : EMR85-7A-G1	Date: 18-Feb-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7053844
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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Fill: Fill Peat and snow mixture	Frozen Vr Vx Vr						
-2		Clay: Clay - Silty, brown	Vr Vx Vr Vx Vr Vx						
		Clay: Clay - Ice + Clay Peat pockets	Vr Vx Vr Vx						
-4		Peat: Peat - some twigs, dark brown	Nbn Vx, occ. ice xstals						
-6		Clay: Clay - Silty, trace Peat, grey	Vx Vx						
-8		Clay: Clay - medium plastic	Frozen? Vx, 25 mm ice xstal						
		Clay: Clay - trace fine Gravel for 0.3 m							
-10		Clay: Clay (Till) - Silty, trace fine Gravel to 12 mm, medium to high plastic, greyish brown	Nbn Vx 75 mm clear ice lens						
-12		Clay: Clay - few unfrozen Clay pockets	125 mm cloudy ice lens Nbn Vx ice crystals						
-14		Clay: Clay - frozen and unfrozen Clay	50 mm ICE + CLAY						
-16		Clay: Clay - some Gravel sizes to 25 mm for 1.4 m	Ice, 150 mm ICE + CLAY						
-18		Clay: Clay - few Gravel sizes to 75 mm	Nbn Vx, occ. ice crystals						
-20		Clay: Clay - frozen and unfrozen Clay							
		Clay: Clay - Silty, medium plastic, brownish grey							
		Clay: Clay - Gravel to 38mm							
		Clay: Clay - few unfrozen Clay pockets							

Borehole # : EMR85-7A-T4	Date: 27-Feb-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 7053844
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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen Vr Vs Vr Vs						
-2		Clay: Clay - Silty, medium plastic, greyish- brown	Vr Vx						
-4		Clay: Clay (Till) - Silty, trace fine Gravel, medum plastic, greyish- brown	Nbn Vx, occ. ice xstals						
-6		Clay: Clay (Till) - medium to high plastic, Gravel sizes to 12 mm							
-8		Clay: Clay - high plastic, grey	Vx, few ice xstal pocket/vein Nbn						
-10									
-12									
-14			Frozen?						
-16			Unfrozen?						
-18		Clay: Clay - few cobbles							
-20									

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#: HALB5NWZM	Elevation(m): 265
Permafrost Conditions: Frozen Landform: ground moraine Surface Material: clay/sand, glacial till	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Fill: Fill Peat and snow mixture	Frozen Vr Vr Vs						
-2		Peat: Peat - woody, brown	Vr Vs						
-4		Clay: Clay - Silty, medium plastic, greyish- brown	Vr Vs Vr Vx						
-6		Clay: Clay - trace Peat inclusions	few ice lense, Vr Vs at 5.2 m Vx						
-8		Clay: Clay (Till) - Silty, trace fine Gravel, medium plastic, greyish- brown	Vx, 60 mm ice lense 50 mm I+Cl						
-10		Clay: Clay (Till) - no Gravel to 4.3 m	Vr Vx						
-12		Clay: Clay (Till) - Gravel sizes to 50 mm	Vx Nbn Vx, 25mm ice xstal lens						
-14		Clay: Clay - brownish- grey	3 mm ice xstal lens at 12.8 m						
-16		Clay: Clay - some Gravel to 8.2 m	Nbn Vx, occ. ice xstals						
-18		Clay: Clay - few angular Gravel to 75 mm	Nbn						
-20		Clay: Clay - olive grey							
		Clay: Clay - medium to high plastic	Nbn Vx, occ. ice xstals						
		Clay: Clay - Silty, medium plastic, grey							
		Clay: Clay - occ. CH pockets							
		Clay: Clay - 25 mm pocket of fine Gravel							
		Clay: Clay - occ. CH pockets							
		Clay: Clay - few gravel							
		Sand: Sand - Silty, trace Gravel to 38mm, brown							



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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Topsoil - Silt, Clay	Frozen Nbn						
-2		Clay: Clay - Silty, medium plastic, grey	Unfrozen (with Frozen), occ. frozen pockets Unfrozen						
-4		Clay: Clay (Till) - Silty, trace fine Gravel, medium plastic, greyish- brown							
-6		Clay: Clay (Till) - medium to high plastic							
-8		Boulder - Auger refusal, Continued with T4A at 1 m W							
-10									
-12		Clay: Clay - Silty, medium plastic, wet, greyish- brown							
-14		Clay: Clay - occ. fine Gravel							
-16									
-18									
-20									



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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Fill: Fill snow, Clay	Frozen						
		Clay: Clay - Silty, medium plastic, greyish- brown	Vr Vx Vr Vx Vr Vx						
-2		Clay: Clay (Till) - Silty, some Gravel, medium plastic, greyish- brown	Vr Vx Nbn Vx, few ice crystals						
-4		Clay: Clay (Till) - few high plastic pockets	Vr Vx Nbn Vs, occ. ice crystals						
-6		Clay: Clay (Till) - medium to high plastic	Nbn Vr Vx						
-8		Clay: Clay (Till) - few cobbles to 11.3	Nbn (with UF), unfroz. clay pock Vr Vx Vr Vx						
-10			Vr						
-12			Vx, 12 mm ice crystals pocket						
-14			Nbn Vr Vx, occ ice inclusion Nbn Vr Vx, 6 mm vert. Ice						
-16		Silt: Silt - Clayey, low plastic, laminated, grey							
-18		Clay: Clay - Silty, Silt pockets, medium to high plastic, laminated, brownish-grey							
		Clay: Clay and Silt - interbedded, low to medium plastic, laminated, grey							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen Nbn Vx, occ. ice xstals						
-2		Clay: Clay - Silty, medium plastic, mottled grey-brown							
-4		Clay: Clay (Till) - Silty, trace fine Gravel, medium plastic, greyish brown							
-6		Clay: Clay (Till) - cobble							
-8		Clay: Clay (Till) - some fine Gravel to 5.2 m							
-10		Clay: Clay (Till) - few unfrozen Clay pockets							
-12		Clay: Clay (Till) - medium to high plastic, some Gravel	Nbn (with UF)						
-14		Clay: Clay (Till) - some Gravel to 75 mm							
-16		Clay: Clay (Till) - Gravelly to 12.8 m	Unfrozen?						
-18		Silt: Silt - Sandy, Clayey, trace fine Gravel, slightly plastic, wet, brown	Unfrozen?						
-20		Sand: Sand - some Silt, trace fine Gravel, fine to medium grained, brown							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Organic: Peat moss	Frozen Vr Vx						
-2		Clay: Clay (Till) - Silty, trace fine Gravel, medium plastic, greyish-brown, trace rust specks							
-4									
-6		Clay: Clay (Till) - few cobbles to 4.7 m							
-8		Clay: Clay (Till) - medium high plastic							
-10		Clay: Clay (Till) - cobble							
-12		Clay: Clay (Till) - cobble							
-14		Clay: Clay (Till) - some Gravel to 10.4 m	Nbn						
-16		Clay: Clay - Silty, medium to high plastic, grey	Unfrozen?						
-18		Sand: Sand - Silty, trace Clay, fine grained, layered, slightly plastic, brown	Unfrozen						
-20									

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#: HAL85NVVZM	Elevation(m): 191
Permafrost Conditions: Frozen	Landform:
	Surface Material: clay/silt/sand

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen Nf						
-2		Sand: Sand and Silt - fine grained, light brown	partly frozen						
-4		Sand: Sand - fine to medium grained, light brown	Nbn Vr Vx, ice rich						
-6		Sand: Sand - grey	25 mm unfrozen sand lens						
-6		Sand: Sand - greyish-brown	100 mm cloudy ice lens						
-8		Sand: Sand - grey	Vr Ice Vr Vx in UF						
-10		Sand: Sand and Silt - fine grained, grey	Unfrozen Vx, few ice crystals						
-12		Silt: Silt - Clayey							
-12		Silt: Silt - Sandy, no Clay, dark grey	few large ice crystals to 25 mm						
-14		Sand: Sand - fine grained, uniform, grey							
-16		Clay: Clay - Silty, low to medium plastic, grey							
-16		Clay: Clay - medium plastic							
-18		Clay: Clay - 75 mm ice rich Clay							
-18		Clay: Clay - 75 mm unfrozen Clay							
-20		Ice: Ice and Clay - medium plastic, cloudy ice							
		Clay: Clay - medium plastic, grey, unfrozen ice rich Clay to 8.7mm							
		Clay: Clay - unfrozen Clay with few ice crystals to 11.0m							
		Clay: Clay - medium to high plastic							



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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen Vr						
-2		Clay: Clay - Silty, low plastic, grey	Nf						
		Peat: Peat and Clay							
-4		Sand: Sand and Silt - fine grained, grey	Nbn Vx						
-6		Clay: Clay - Silty, trace fine Gravel, medium plastic, grey							
-8									
-10		Clay: Clay - unfrozen Clay	Unfrozen Vx, numerous ice crystals						
-12		Clay: Clay - soft, very moist to wet							
-14									
-16									
-18									
-20									

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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, dark brown	Nf						
-2			Frozen?, UF zones to 2.0 m						
-4		Silt: Silt - Clayey, low plastic, grey	Unfrozen Vx, some ice crystals						
-6		Sand: Sand and Silt - fine grained, grey	Unfrozen						
-8		Clay: Clay - Silty, low to medium plastic, grey, few wet Silt lenses							
-10		Silt: Silt and Clay - interbedded, saturated, grey (hole caving, used hollow stem)							
-12									
-14									
-16									
-18		Silt: Silt and Clay - very stiff to hard, medium to high plastic							
-20									

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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, dark brown	Frozen Unfrozen						
-2		Silt: Silt - some fine Sand, trace Organics, grey	Frozen?						
-4		Clay: Clay - soft, Silty, low to medium plastic, wet, grey	Unfrozen						
-6									
-8		Clay: Clay - wet to saturated							
-10									
-12		Clay: Clay - water in Silt lenses							
-14									
-16									
-18									
-20									

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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Nbe Vr						
-2		Peat: Peat - humus, dark brown	Ice with Clay Inclusions						
-4		Peat: Peat - Ice + Peat zone for 300 mm	Vr Vx 50 mm cloudy ice lense						
-6		Clay: Clay - Silty, low to medium plastic, grey	Unfrozen VrVx, some ice crystals to 25mm						
-8		Clay: Clay - few Silt pockets and lenses							
-10		Silt: Silt - Clayey, some fine Sand, few Sandy							
-12		Silt: Silt lenses, low plastic, grey							
-14		Sand: Sand - Silty, fine grained, saturated, grey (switch to hollow stem)							
-16		Clay: Clay - soft, Silty, low to medium plastic, wet, grey							
-18		Clay: Clay - stiff, medium to high plastic							
-20									



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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen						
-2		Clay: Clay - Silty, low plastic, grey	Nbn Vx, occ. ice xstals						
-4		Silt: Silt - Sandy, Clayey, grey	Unfrozen						
-6		Clay: Clay - soft, Silty, low to medium plastic, wet, olive-grey							
-8		Clay: Clay - medium plastic, grey							
-10									
-12									
-14									
-16		Clay: Clay - medium to high plastic							
-18									
-20									

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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Silt: Silt - Organics, black	Frozen Nbn Nf Nbn Nf Nbn						
-2		Silt: Silt and Sand - Organics							
		Silt: Silt and Sand- no Organics, light brown							
		Sand: Sand and Gravel - light brown							
		Silt: Silt and Sand - trace Clay, brown							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Fill: Fill - snow, Peat	Frozen Vr						
		Peat: Peat - woody, dark brown	Unfrozen Vr						
-2		Sand: Sand - Silty, fine grained	Unfrozen						
		Silt: Silt (Till) - Sandy, trace fine Gravel, olive brown							
-4		Clay: Clay (Till) - very stiff, Silty, some Gravel, few cobbles, low plastic, brown							
		Clay: Clay (Till) - boulder, *AUGER REFUSAL*, continued with G- 1A at 1.5 m N of G- 1							
		Clay: Clay (Till) - grey							
		Clay: Clay (Till) - Gravel sizes to 50 mm							
		Bedrock: Siltstone? (Bedrock)							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Fill: Fill Peat - snow	Frozen Nf						
-1		Peat: Peat - woody, brown	Vr						
-2		Peat: Peat - 100 mm Peat and Silt layer, Organics, dark brown to black	Nbe NfVr						
-3		Peat: Peat - reddish-brown	Frozen?, barely frozen						
-4		Peat: Peat - saturated	Unfrozen						
-5		Clay: Clay - very soft, Silty, low plastic, wet, grey							
-6		Clay: Clay (Till) - stiff, Silty, some Gravel to 12 mm, low plastic, grey							
-7		Clay: Clay (Till) - some cobbles							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, dark brown	Frozen						
-2		Peat: Peat - wet	Unfrozen						
		Peat: Peat - saturated							
-4		Clay: Clay - very soft, Silty, low plastic, grey							
-6		Clay: Clay (Till) - soft, Silty, some Gravel to 12 mm, grey							
-8		Clay: Clay (Till) - stiff to very stiff							
-10		Clay: Clay (Till) - hard, Sandy, Gravelly, low plastic							
		Bedrock: Bedrock							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen						
-2		Clay: Clay - soft, Silty, low plastic, wet	Unfrozen						
-4		Clay: Clay (Till) - soft, Silty, trace fine Gravel to 6 mm, low plastic, grey							
-6		Clay: Clay (Till) - some Gravel							
-8		Clay: Clay (Till) - stiff to very stiff							
-10		Clay: Clay (Till) - hard, Gravel sizes to 50 mm, few cobbles							
		Clay: Clay (Till) - hard, Gravelly, Sandy, few cobbles, low plastic							
		Bedrock: Bedrock							



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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - humus, dark brown	Vr Nbn Nf						
-2		Silt: Silt - Organics	Vr Vs						
		Sand: Sand - some Silt, fine grained, light brown	Nbn Vr Unfrozen						
-4		Sand: Sand - trace Gravel							
-6		Clay: Clay - Silty, low plastic, olive- brown							
-8		Clay: Clay (Till) - Silty, some angular Gravel to 50 mm, low plastic, olive brown							
-10		Clay: Clay (Till) - some rounded Gravel to 25 mm, grey							
-12		Clay: Clay (Till) - hard							
-14		Bedrock: Shale (Bedrock) - few Siltstone lenses, grey, trace water							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - brown	Frozen						
-2		Silt: Silt - Clayey, Sandy, light brown	Unfrozen						
-4		Sand: Sand - Silty, fine grained, light brown							
-6		Clay: Clay (Till) - stiff, Silty, trace fine Gravel to 6 mm, low plastic, olive- brown							
-8		Clay: Clay (Till) - greyish-brown							
-10		Clay: Clay (Till) - hard, grey							
-12		Bedrock: Shale (Bedrock) -							



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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, some Organic Silt, mottled black- brown	Vr Vr few vertical ice lenses at 1.2 m Unfrozen						
-2		Clay: Clay - Silty, low plastic, brown							
-4		Clay: Clay (Till) - Silty, trace fine Gravel to 12 mm, low plastic, brown							
-6		Clay: Clay (Till) - greyish brown							
-8		Clay: Clay (Till) - trace rust spots							
-10		Gravel: Gravel - Sandy, trace Silt, saturated, grey							
-12		Clay: Clay (Till) - very stiff, Silty, some fine Gravel to 6 mm, low plastic, grey							
		Clay: Clay (Till) - Gravelly lens (GC)							
		Clay: Clay (Till) - hard, Gravelly, few cobbles, dark grey							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Nf						
-2		Clay: Clay - Silty, low plastic, brown	Unfrozen						
-4		Clay: Clay (Till) - firm to stiff, Silty, trace fine Gravel, low plastic, moist, brown							
-6		Clay: Clay (Till) - stiff							
-8		Clay: Clay (Till) - Gravel sizes to 12 mm, trace coal fragments							
-10		Sand: Sand - Gravelly, some Silt, saturated, grey							
-12		Clay: Clay - Gravelly, low to medium plastic, grey							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Nbe						
-2		Peat: Peat - some black Organic Silt	Vr, clear and cloudy zone clear and cloudy ice ice, soil inclusion						
-4		Peat: Peat - snow and Ice for 100 mm, trace Peat	Vr Vx Vr Vx						
-6		Peat: Peat - Peat and Organic Silt layer, dark brown	Vr Vx clean ice crystals to 25 mm						
-8		Clay: Clay (Till?) - Silty, low plastic, grey	Vx, lrg ice crstls to 6.6m Unfrozen Vx, few ice crystals to 7m						
-10		Clay: Clay (Till?) - trace Sand							
-12		Clay: Clay (Till?) - few unfrozen Clay pockets							
-14		Clay: Clay (Till?) - few Gravel sizes to 12 mm, Clay unfrozen							
-16		Clay: Clay (Till?) - 150 mm Clayey Gravel lens							
		Clay: Clay (Till?) - few Gravel sizes to 25 mm							
		Clay: Clay (Till?) - black coal pockets							
		Clay: Clay (Till?) - stiff, Silty, some Gravel to 25 mm, low plastic, grey							
		Clay: Clay (Till?) - hard, trace water							
		Gravel: Gravel - Clayey, low plastic, wet to saturated, grey							
		Gravel: Gravel - Silty, trace clay, saturated							

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen						
-2									
-4		Clay: Clay (Till?) - Silty with few Silt lenses, low plastic, grey	Unfrozen Vx, few ice crystals Unfrozen						
-6									
-8		Clay: Clay (Till?) - few Gravel sizes to 12 mm							
-10		Clay: Clay (Till) - Silty, some Gravel, low plastic, wet to saturated, grey							
-12									
-14		Clay: Clay (Till) - Gravelly, few saturated Sand lenses, wet							
-16									

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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, dark brown	Frozen						
-2			Vx						
-4									
-6		Clay: Clay - Silty, low plastic, wet, grey	Unfrozen Vx, few ice crystals						
-8		Clay: Clay (Till) - Silty, trace fine Gravel, low plastic, grey	Unfrozen						
-10									



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	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, dark brown	Frozen						
-2		Clay: Clay - Silty, low to medium plastic, grey	Vr Vx Vr Vx, few ice crystal to 25mm						
-4		Clay: Clay (Till) - Silty, some Gravel to 6 mm, low to medium plastic, grey	Frozen?, frozen w/ few unfrozen pock.						
-6			Unfrozen						32,13
-8		Clay: Clay (Till) - firm, wet							
-10									
-12		Clay: Clay (Till) - very stiff, moist							
-14									
-16									
-18									
-20									

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#: HAL85NWVZM	Elevation(m): 634
Permafrost Conditions: Frozen      Landform: ground moraine      Surface Material: clay, glacial till	

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen						
-2		Clay: Clay (Till) - Silty, some fine Gravel, low plastic, grey	Unfrozen Frozen?, barely frozen to 2.4 m Vx						
-4									
-6			Frozen?, barely frozen to 5.2 m						
-8			Unfrozen Vx, few ice crystals to 6m						
-10		Clay: Clay (Till) - wet	Unfrozen						
		Clay: Clay (Till) - few cobbles							



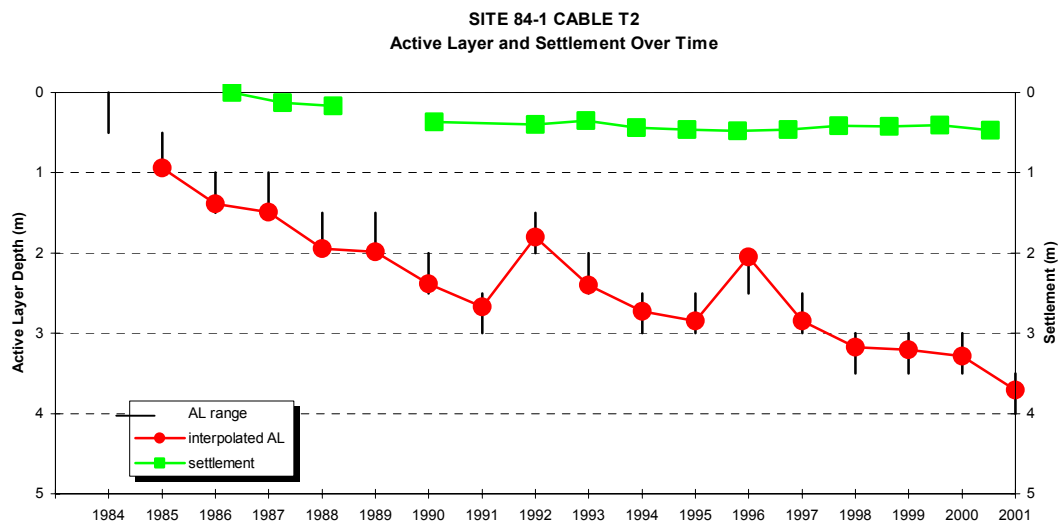
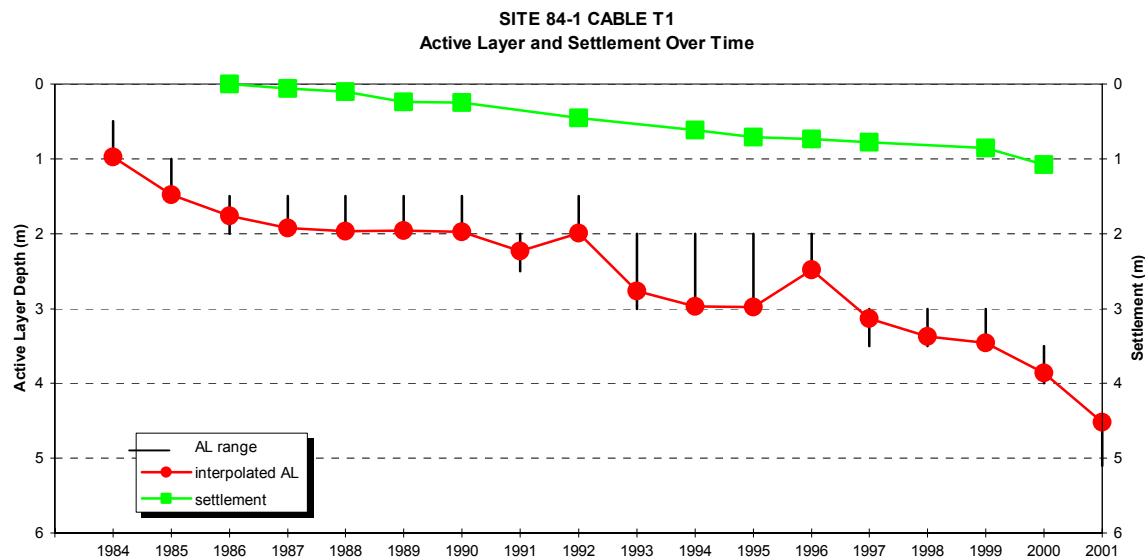
Borehole # : EMR85-13C-T1	Date: 04-Mar-85
Project: EMR INSTRUMENTATION PROGRAM	UTM Northing(m): 6717146
Consultant: HARDY ASSOCIATES (1978) LTD.	UTM Easting(m): 648786
Original Borehole # : EMR-85-13C-T-1	Zone: 10
Report# : HAL85NWZM	Elevation(m): 634
Permafrost Conditions: Frozen      Landform: ground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

Depth Below Surface (m)	Soil Type	Soil Description	NRC Permafrost Description	Water Content (%)	Grain Size				Liquid(wl), Plastic(wp) Limits(%)
					Clay	Silt	Sand	Gravel	
0		Peat: Peat - woody, brown	Frozen						
-2		Peat: Peat - saturated	Unfrozen						
-4		Peat: Peat - free water							
-6		Clay: Clay - soft, Silty, low to medium plastic, saturated, grey							
		Clay: Clay (Till) - firm, Silty, some Gravel, low to medium plastic, moist, grey							

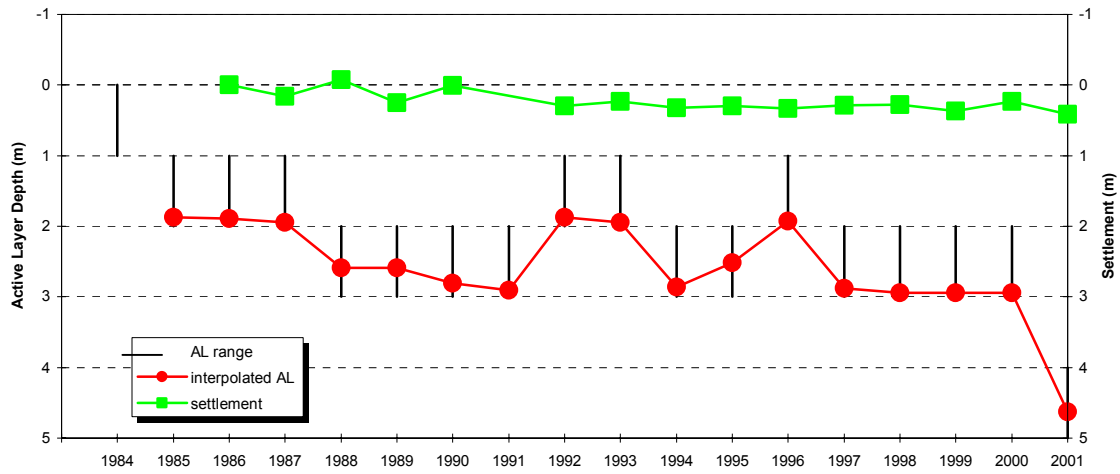
## **APPENDIX 2**

### **THAW DEPTH AND SETTLEMENT PLOTS**

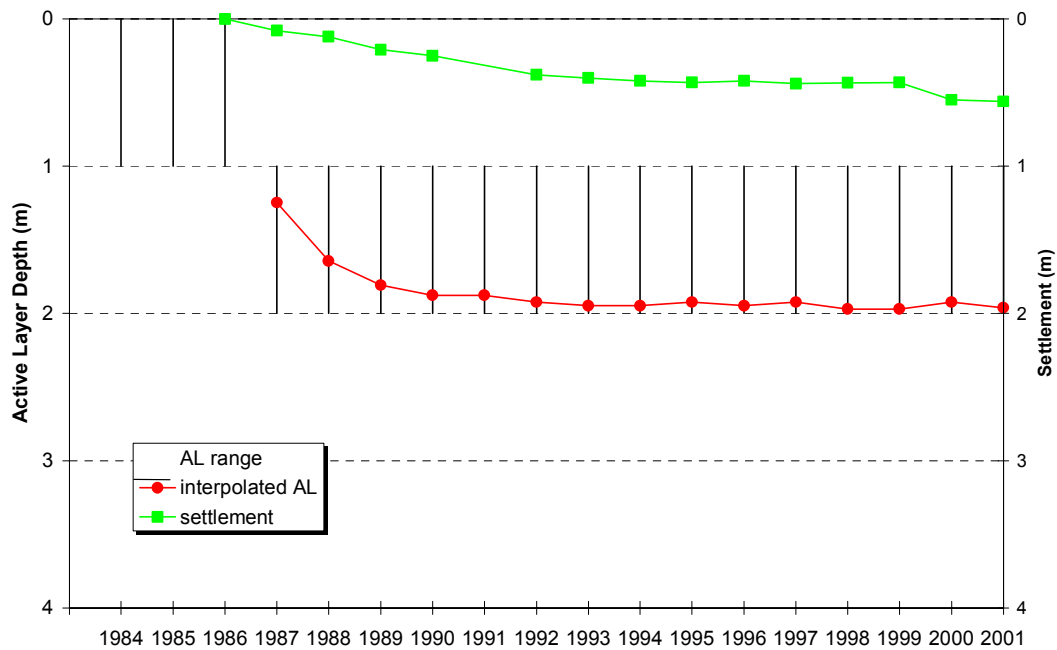
Maximum summer thaw penetration and the position of the ground surface over the monitoring period are shown on the graphs in this section. Active layer depth on the graphs refers to the position of the base of the active layer relative to the fixed reference. AL range refers to the range between the 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.



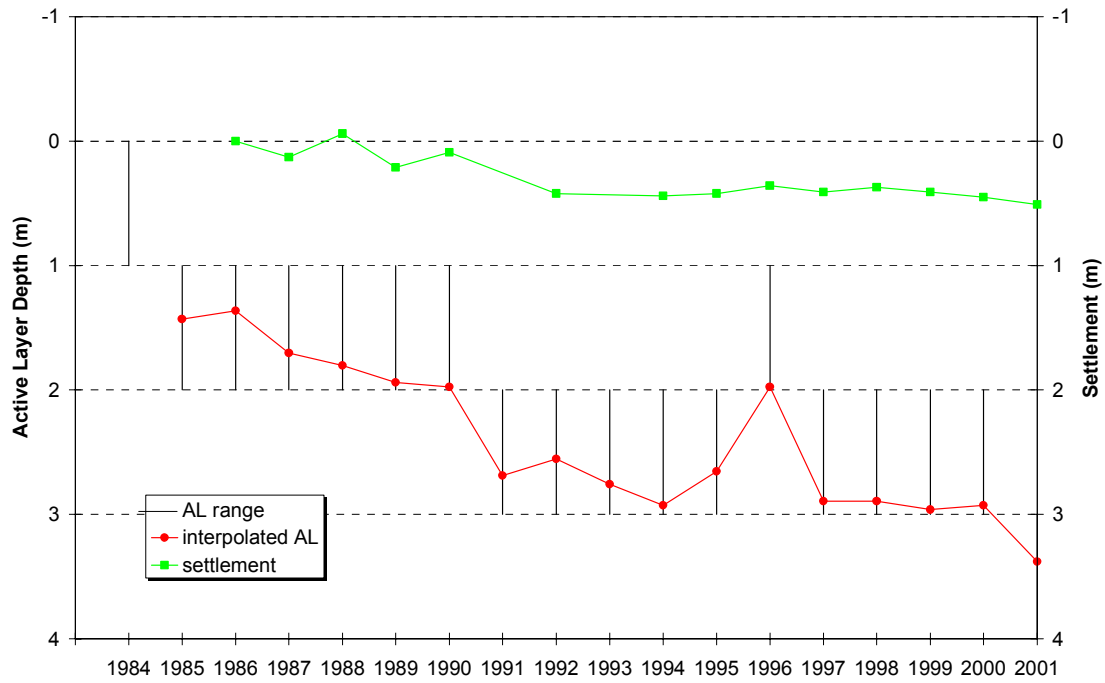
**SITE 84-1 CABLE T3**  
Active Layer and Settlement Over Time



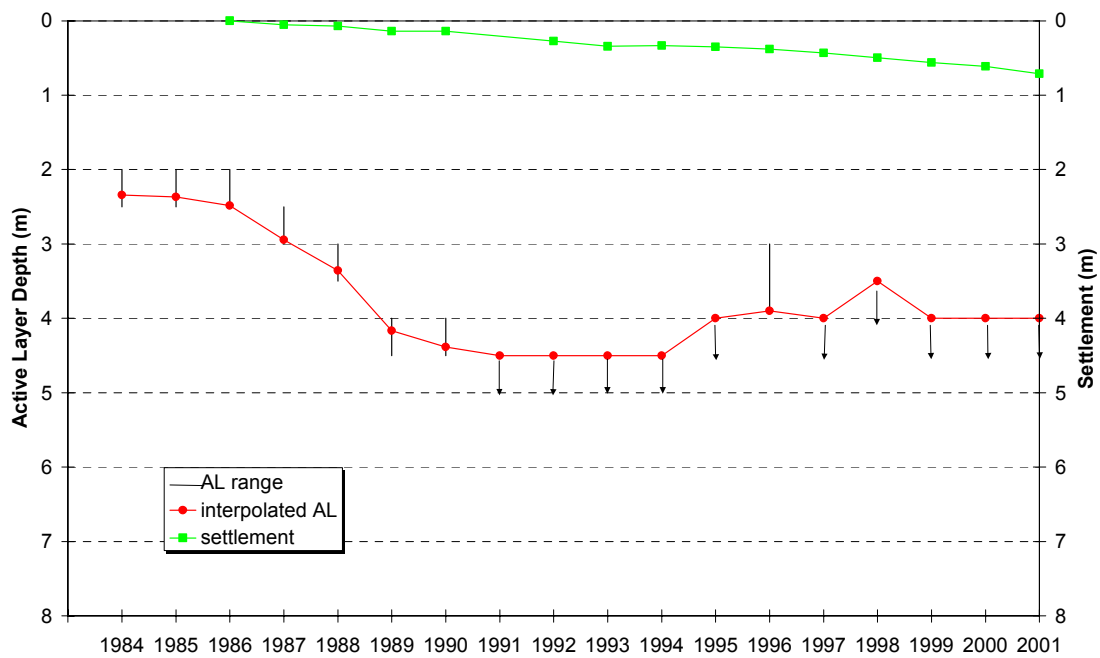
**SITE 84-1 CABLE T4**  
Active Layer and Settlement Over Time



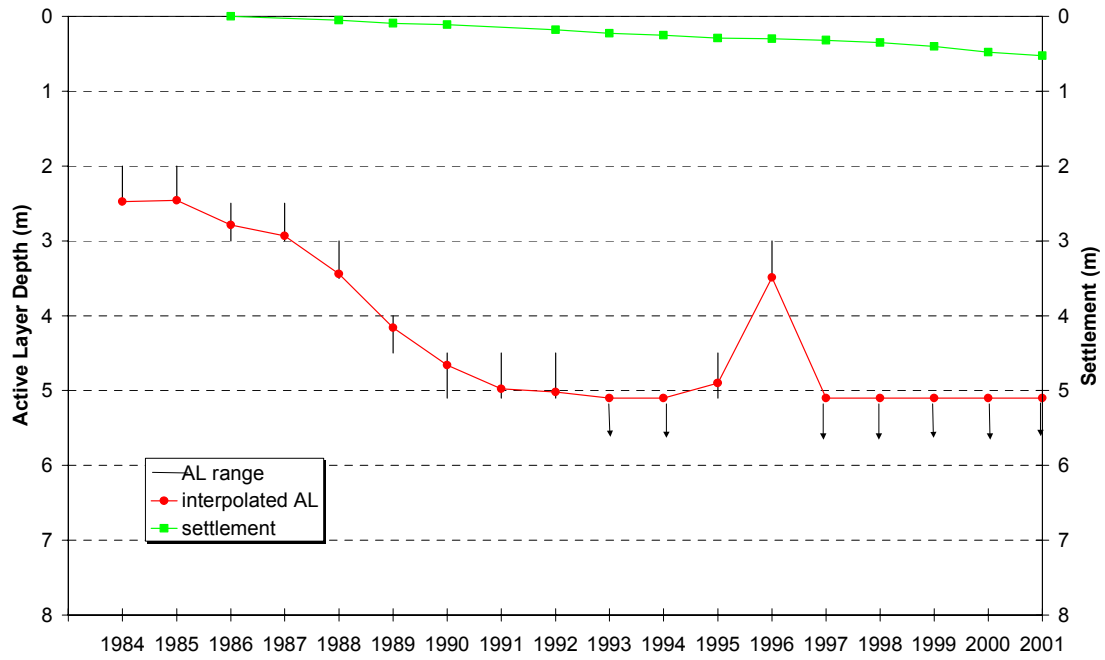
**SITE 84-1 CABLE T5**  
**Active Layer and Settlement Over Time**



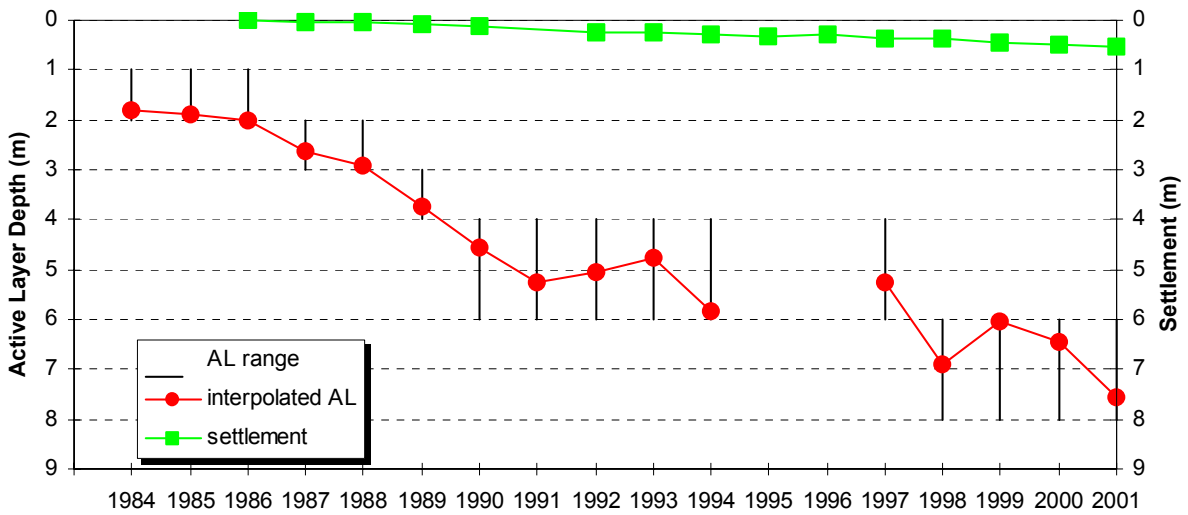
**SITE 84-2A CABLE T1**  
**Active Layer and Settlement Over Time**



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

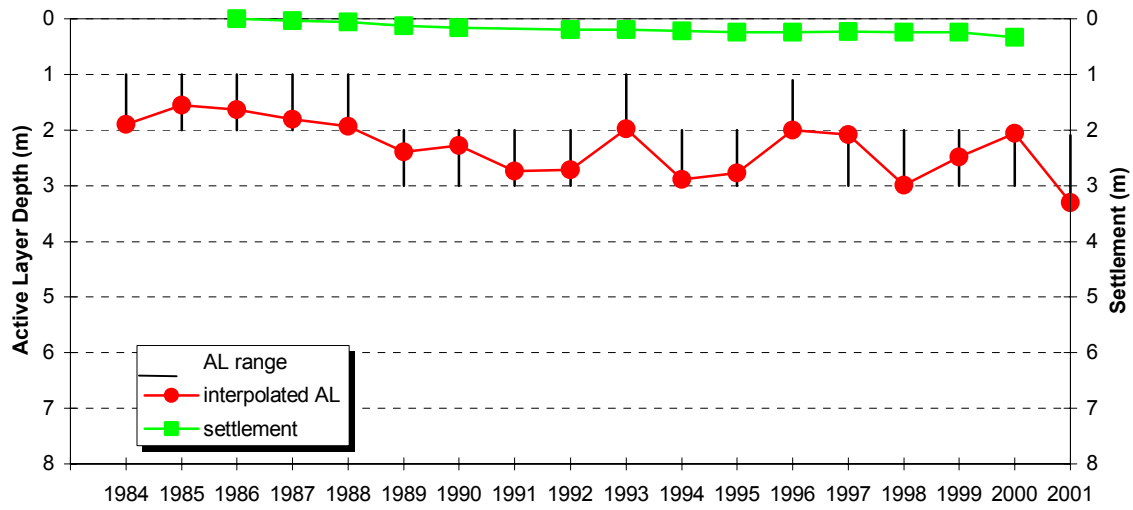


**SITE 84-2A CABLE T3**  
Active Layer and Settlement Over Time

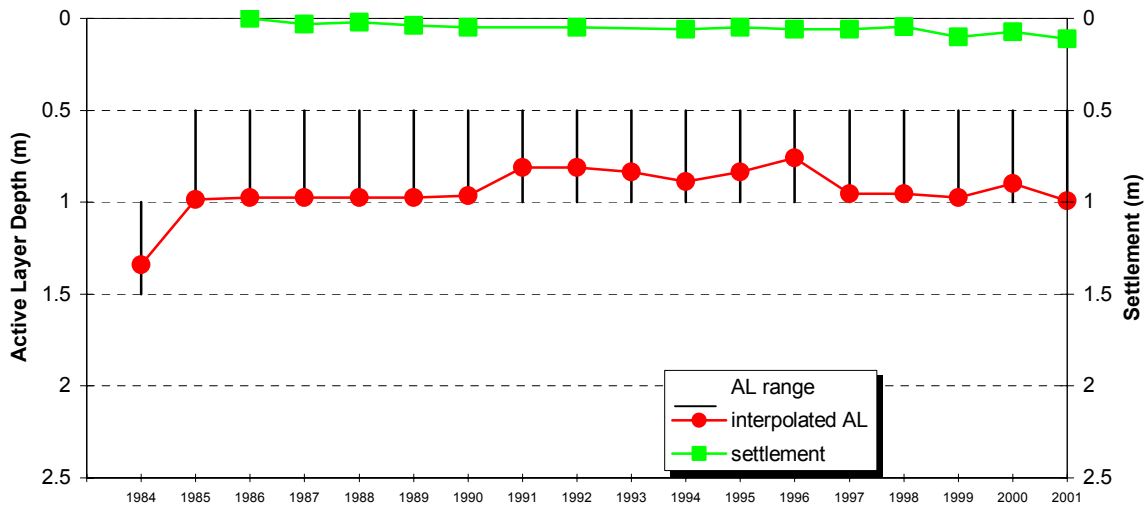




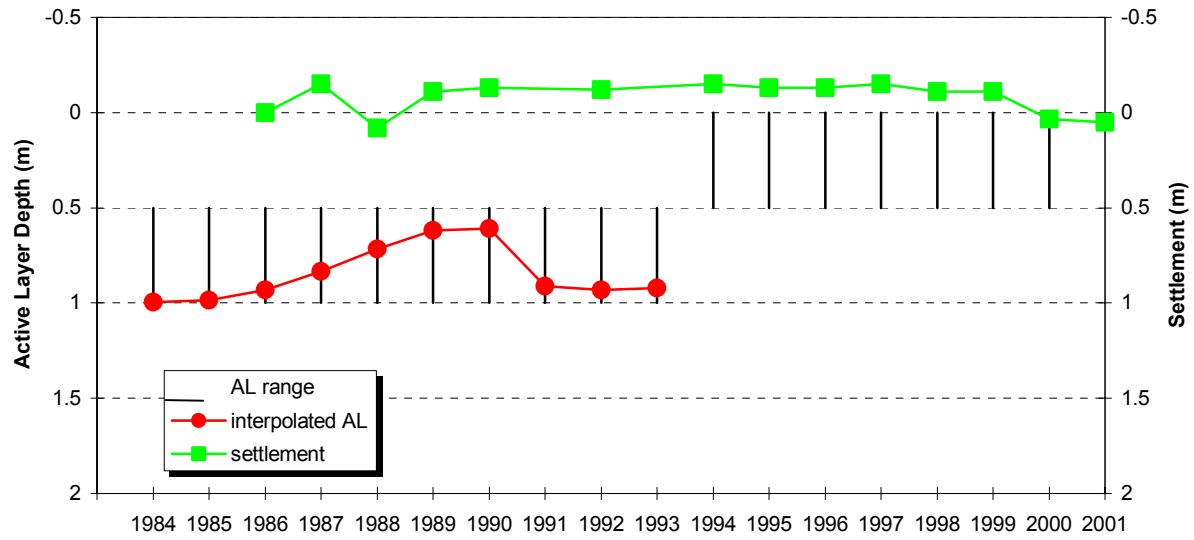
**SITE 84-2A CABLE T4**  
Active Layer and Settlement Over Time



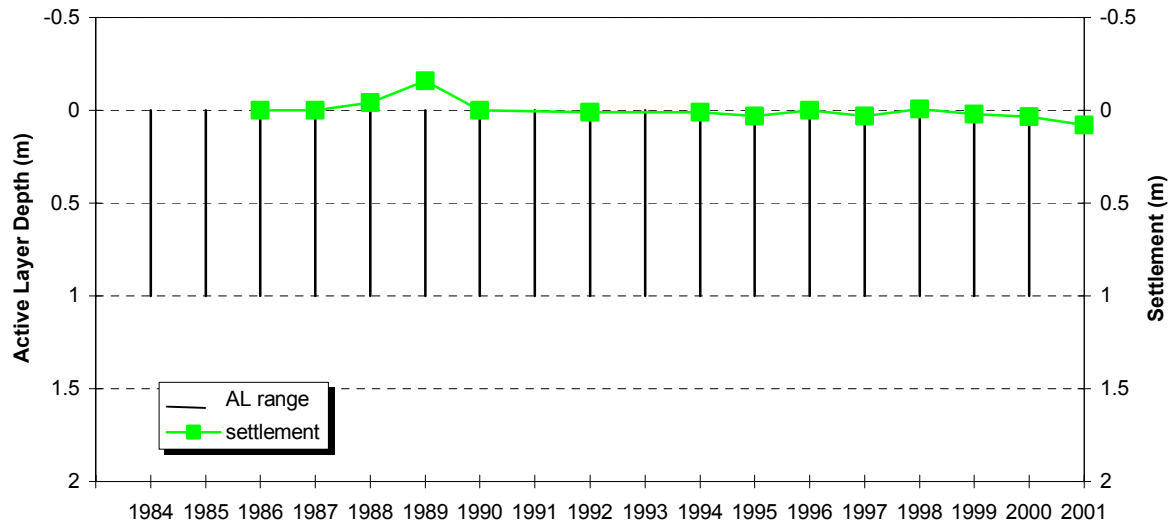
**SITE 84-2B CABLE T1**  
Active Layer and Settlement Over Time



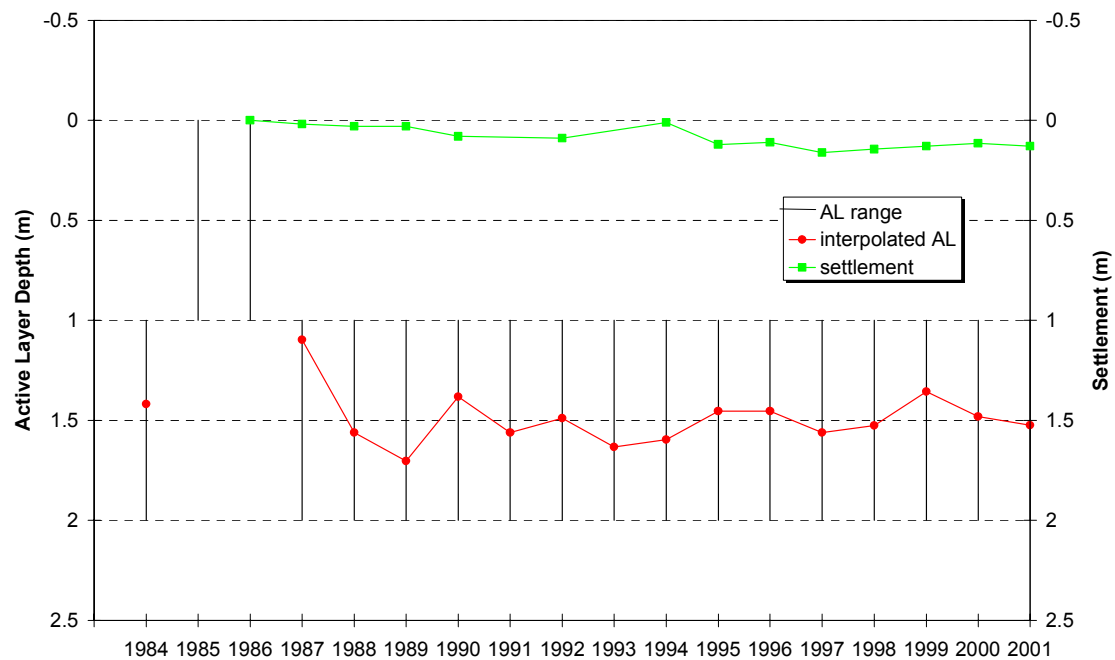
**SITE 84-2B CABLE T2**  
Active Layer and Settlement Over Time



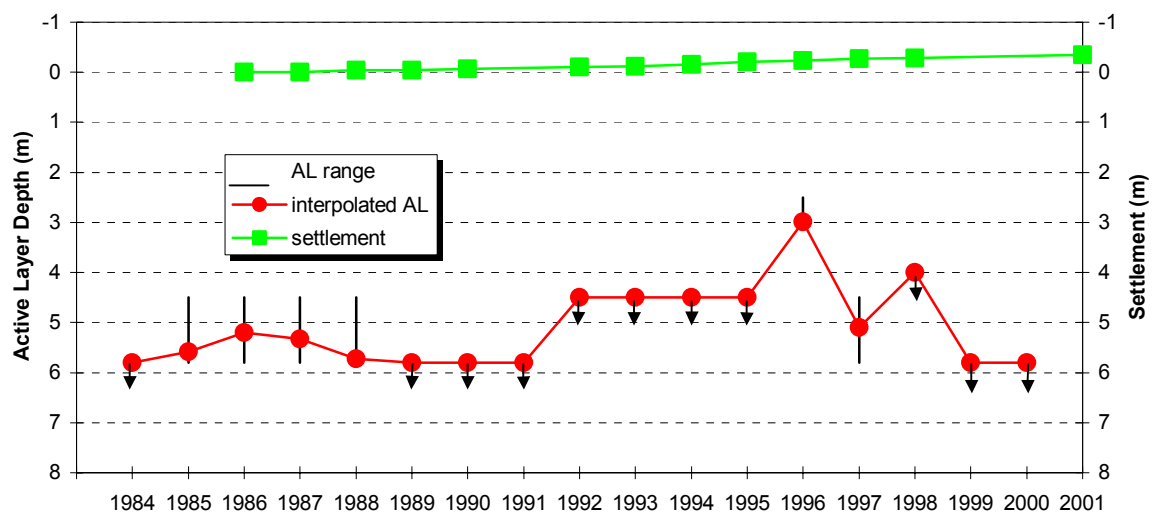
**SITE 84-2B CABLE T3**  
Active Layer and Settlement Over Time



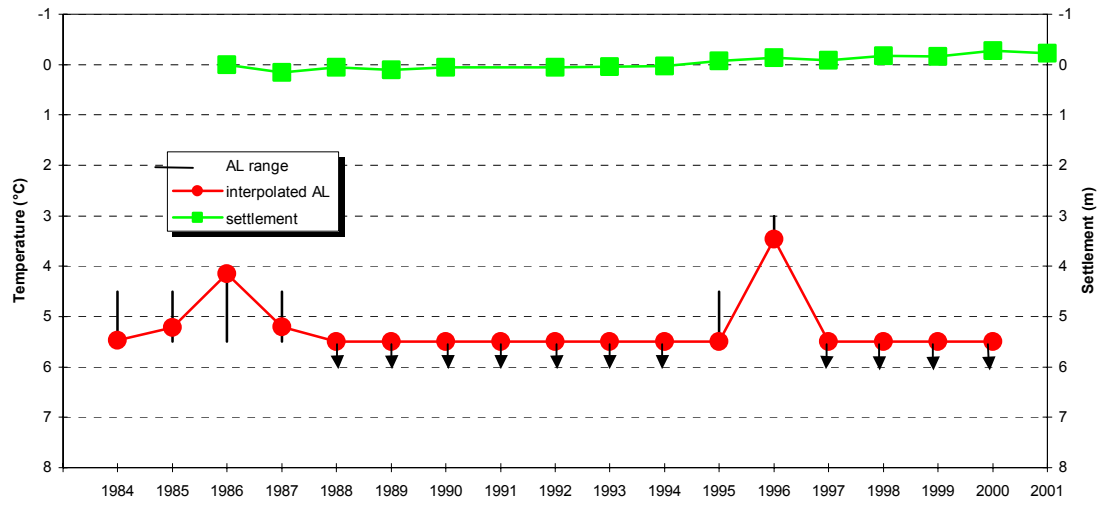
**SITE 84-2B CABLE T4**  
**Active Layer and Settlement Over Time**



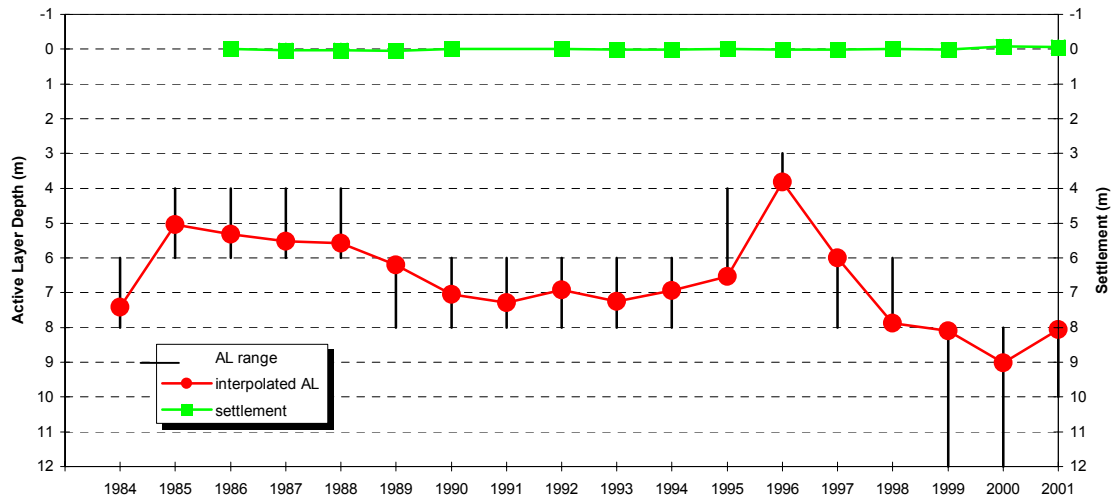
**SITE 84-2C CABLE T1**  
**Active Layer and Settlement Over Time**

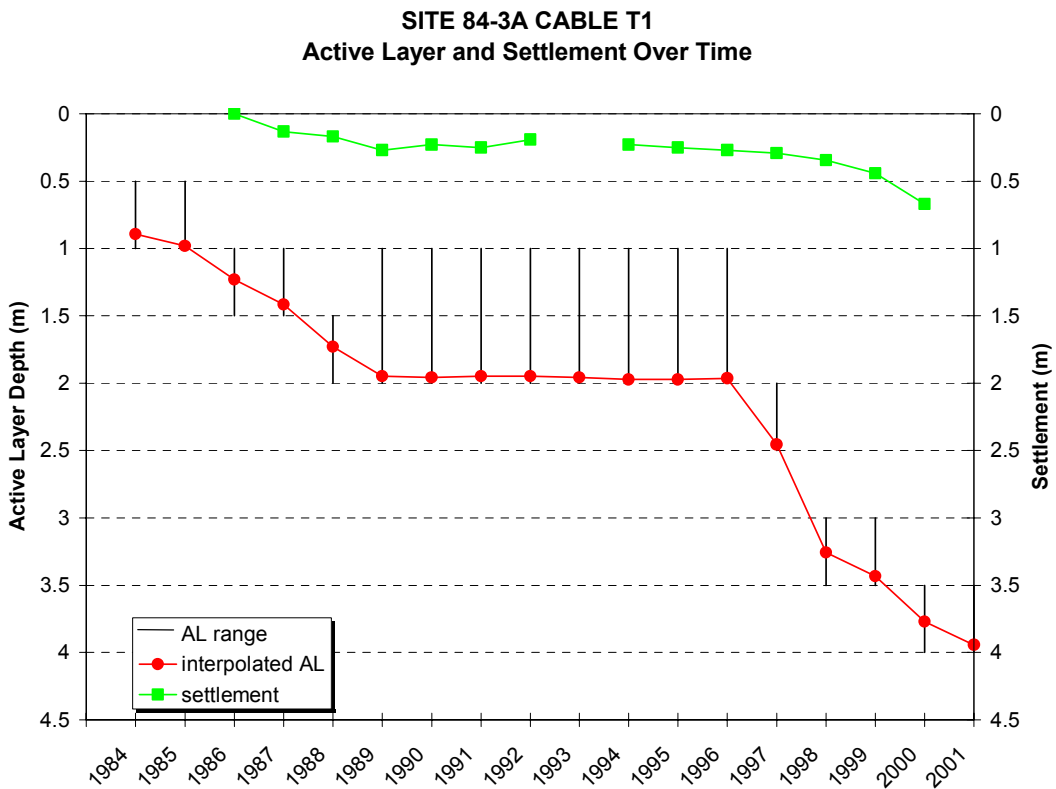
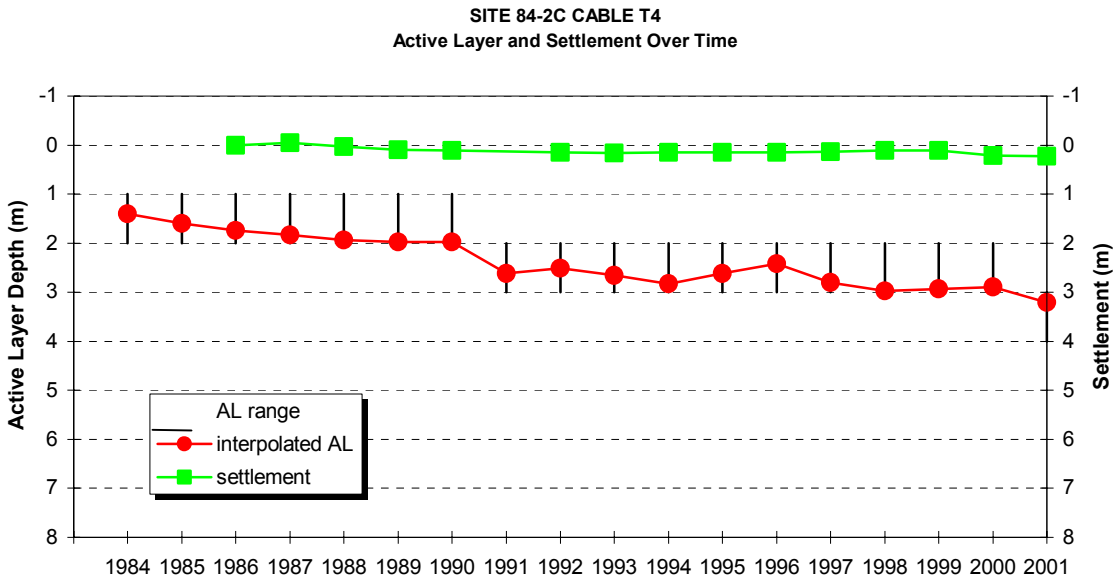


**SITE 84-2C CABLE T2**  
Active Layer and Settlement Over Time

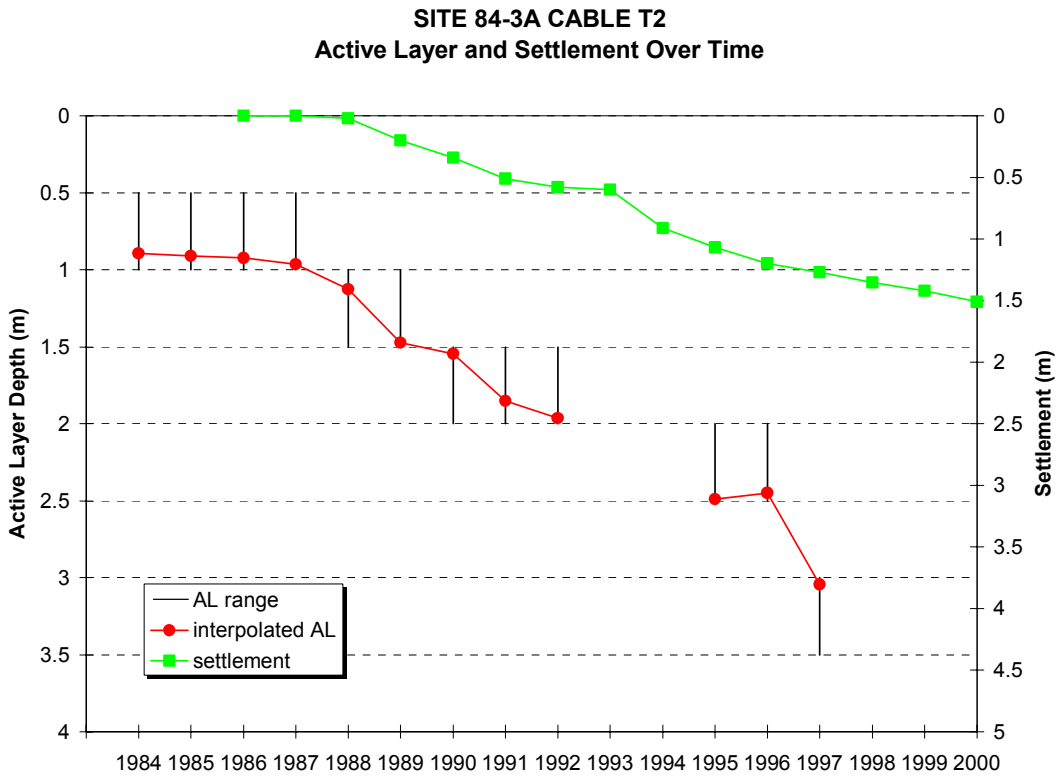


**SITE 84-2C CABLE T3**  
Active Layer and Settlement Over Time

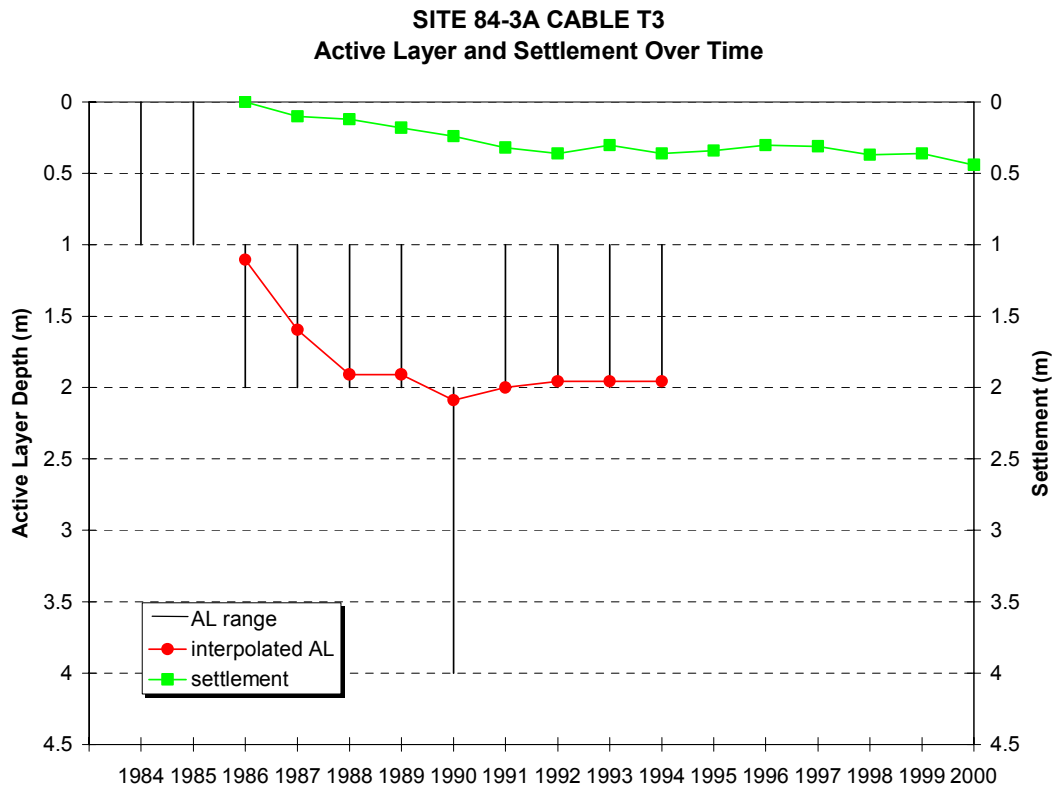




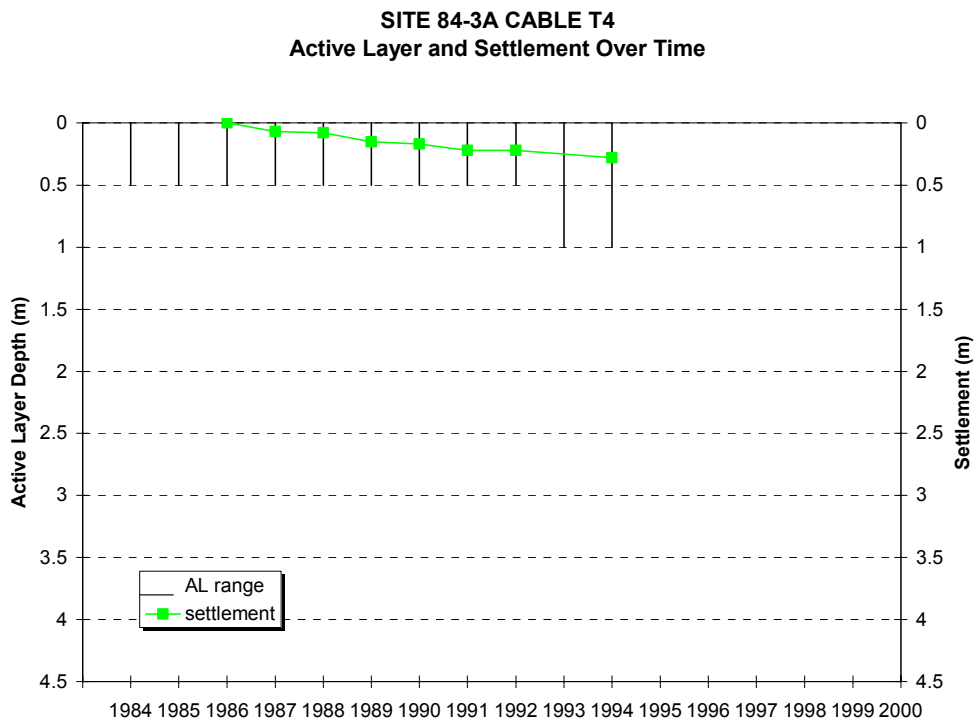
Note: Fire at Great Bear site June 1995



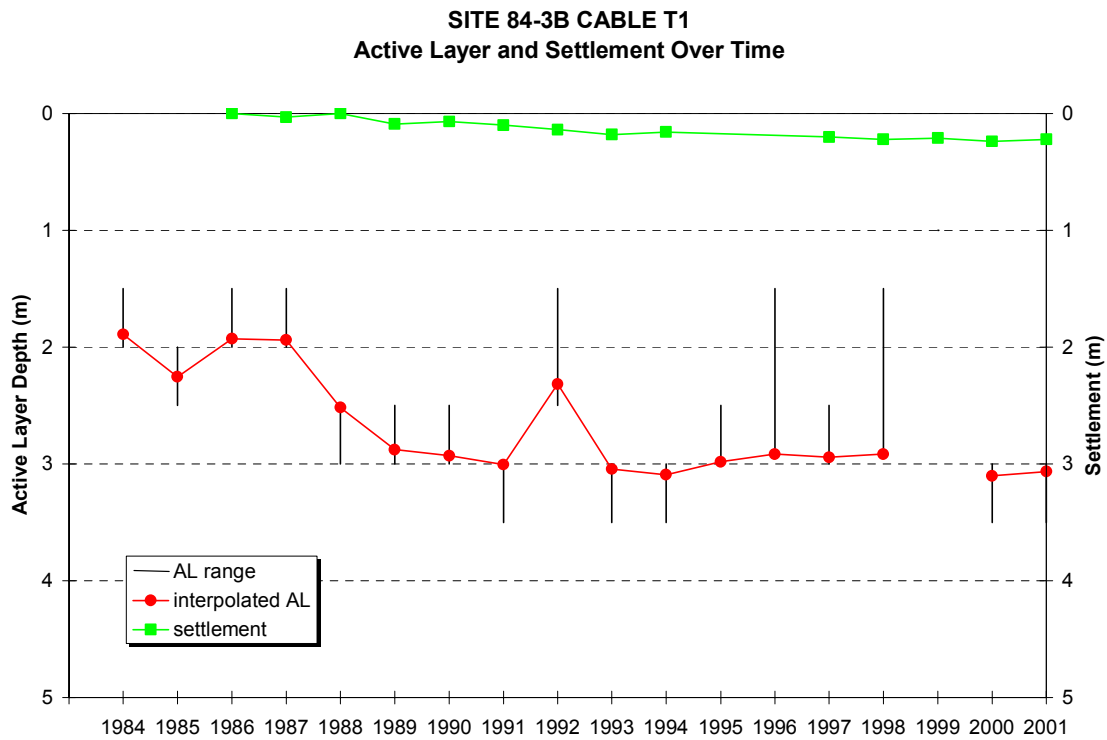
Note: Difficult to estimate thaw depth 1992 onwards – unreliable results



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

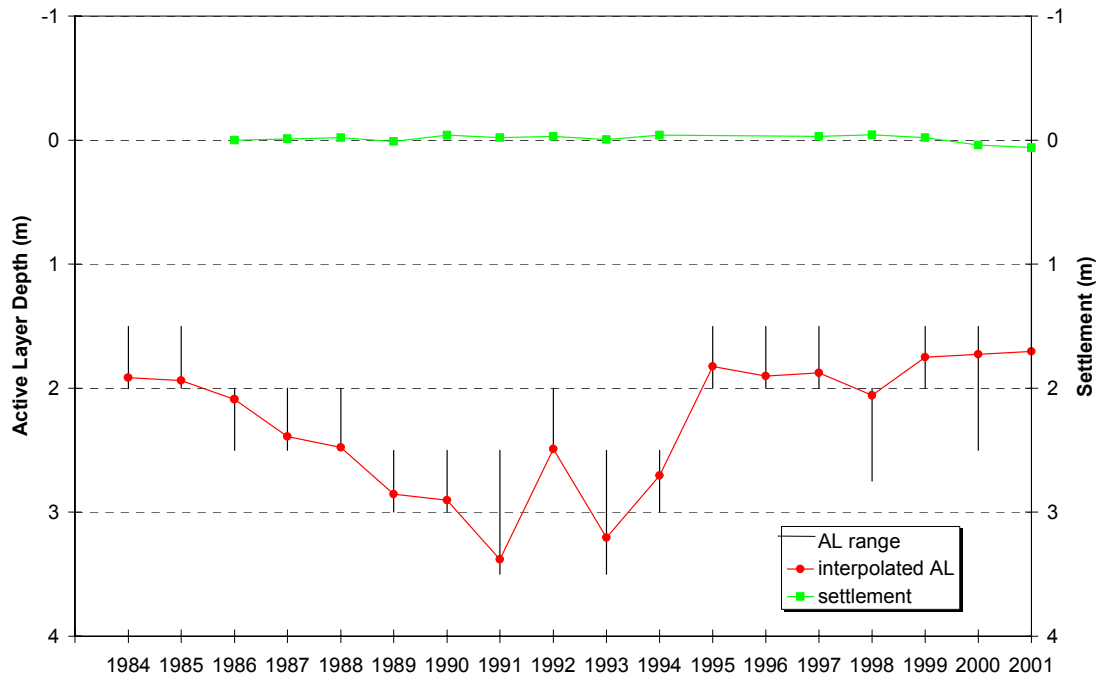


Cable destroyed by fire in 1995

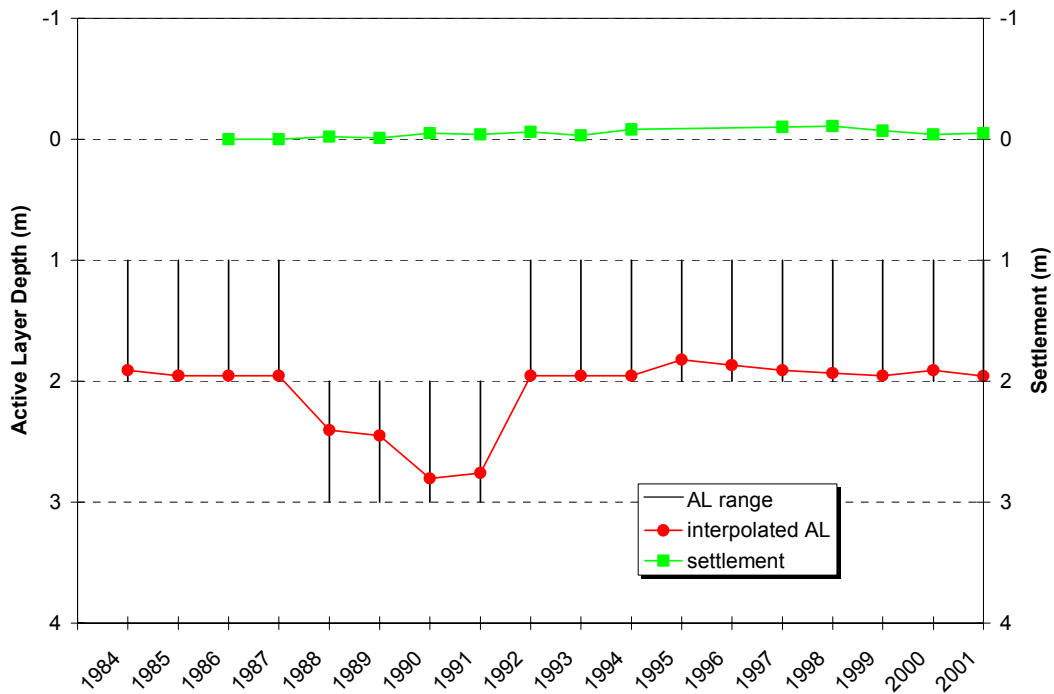




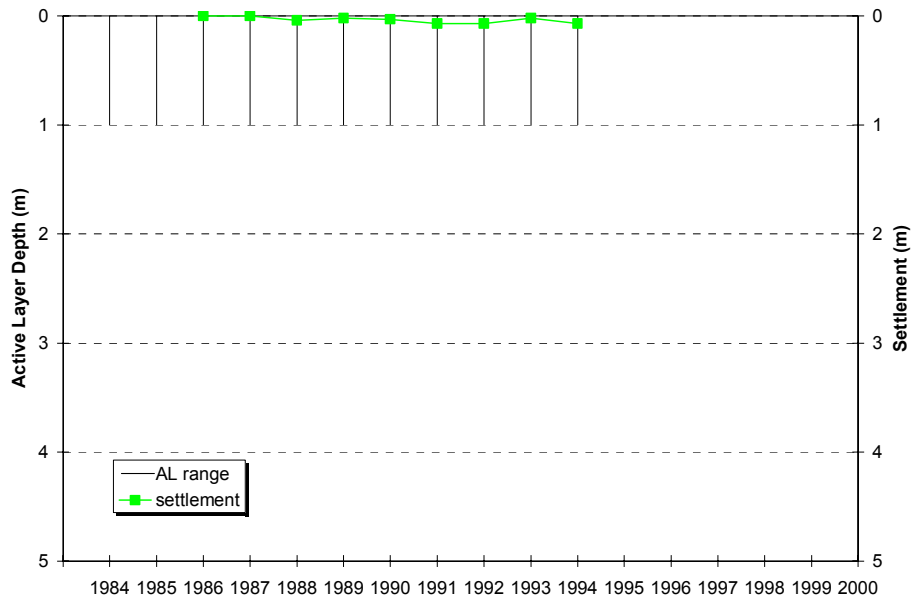
**SITE 84-3B CABLE T2**  
**Active Layer and Settlement Over Time**



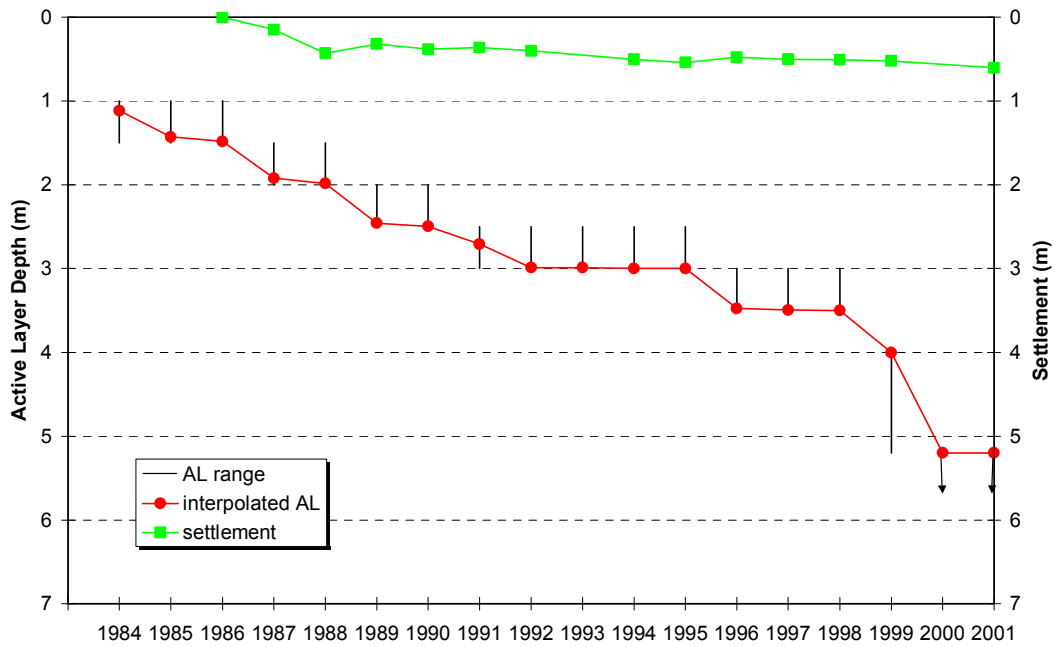
**SITE 84-3B CABLE T3**  
**Active Layer and Settlement Over Time**

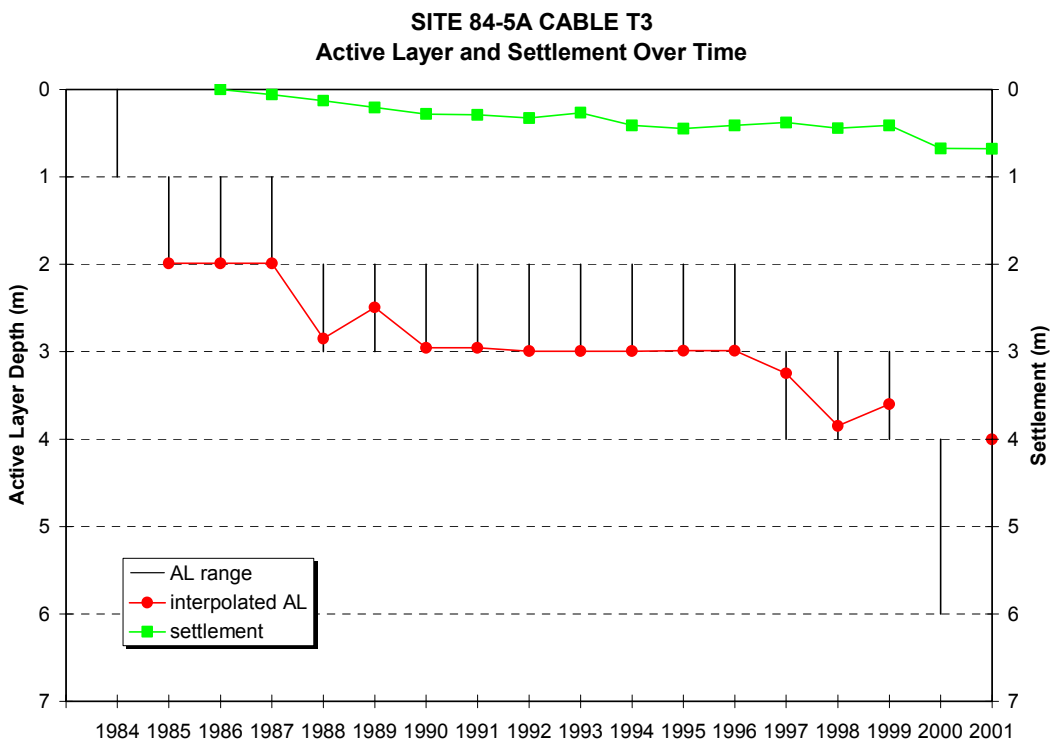
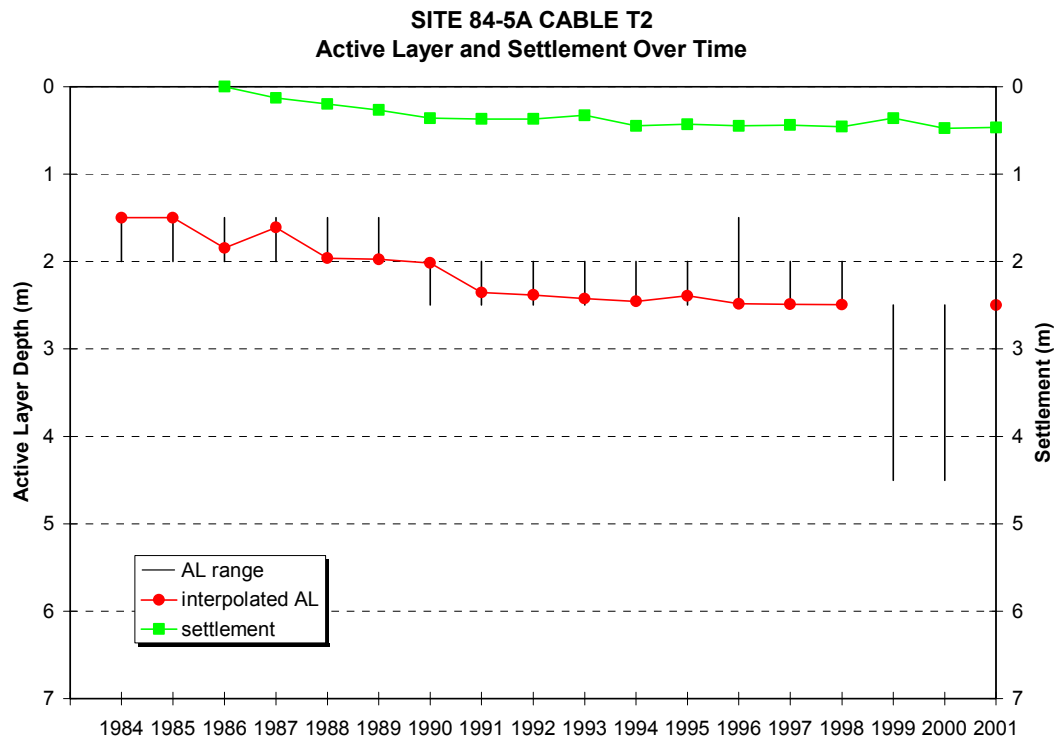


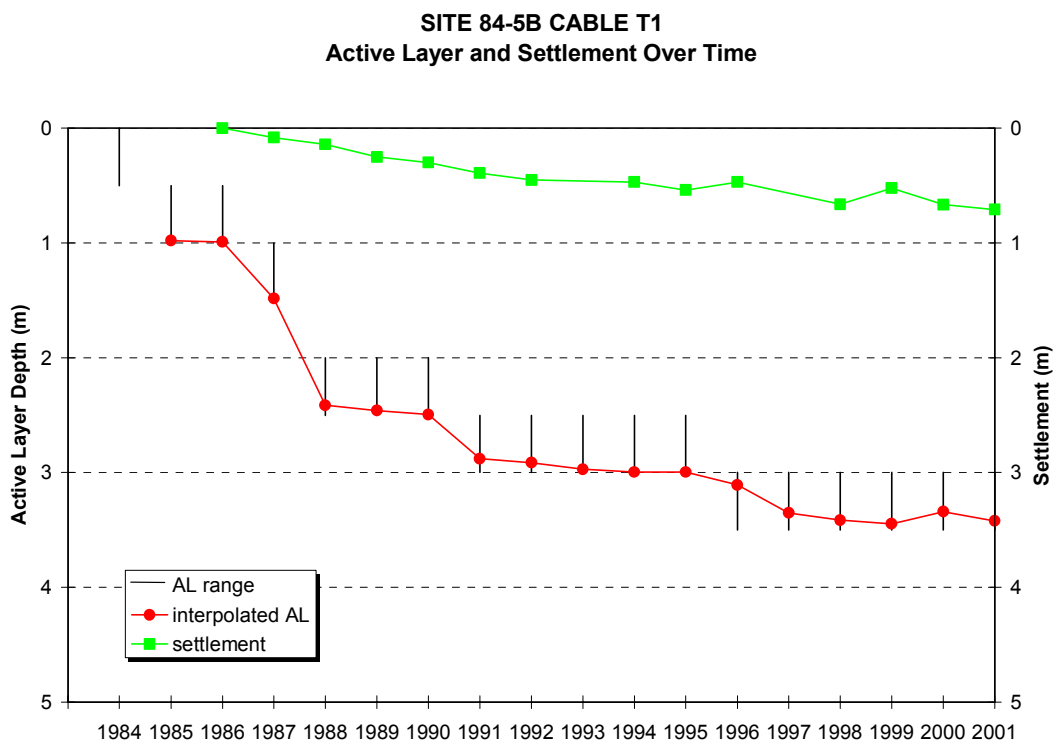
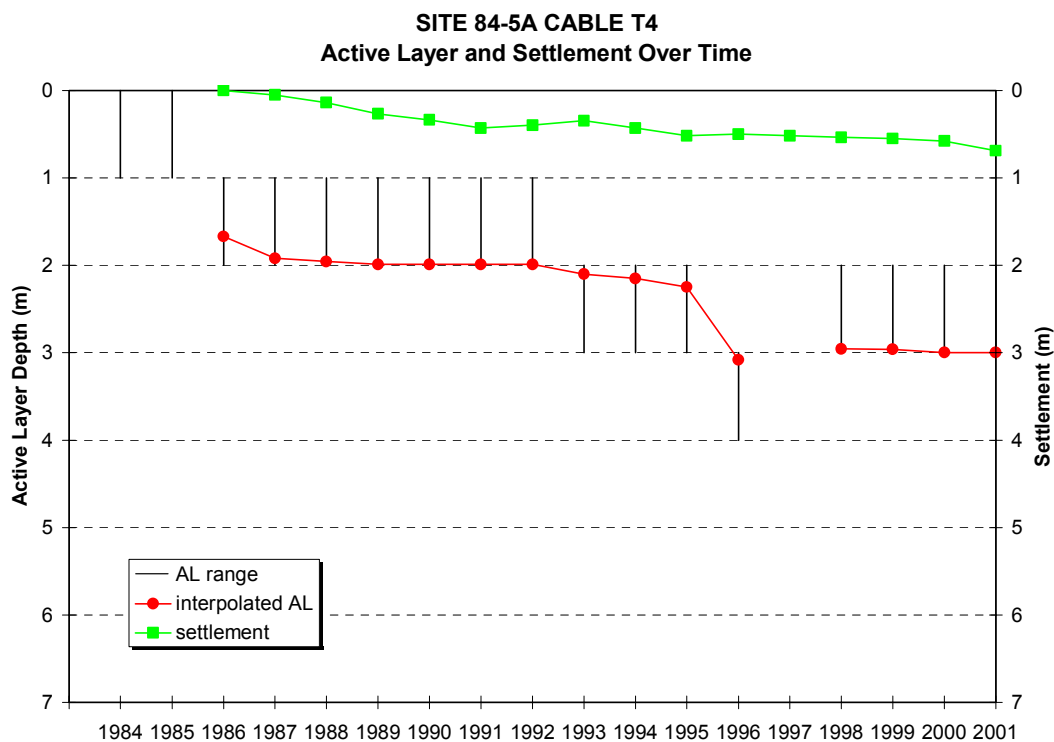
**SITE 84-3B CABLE T4**  
**Active Layer and Settlement Over Time**

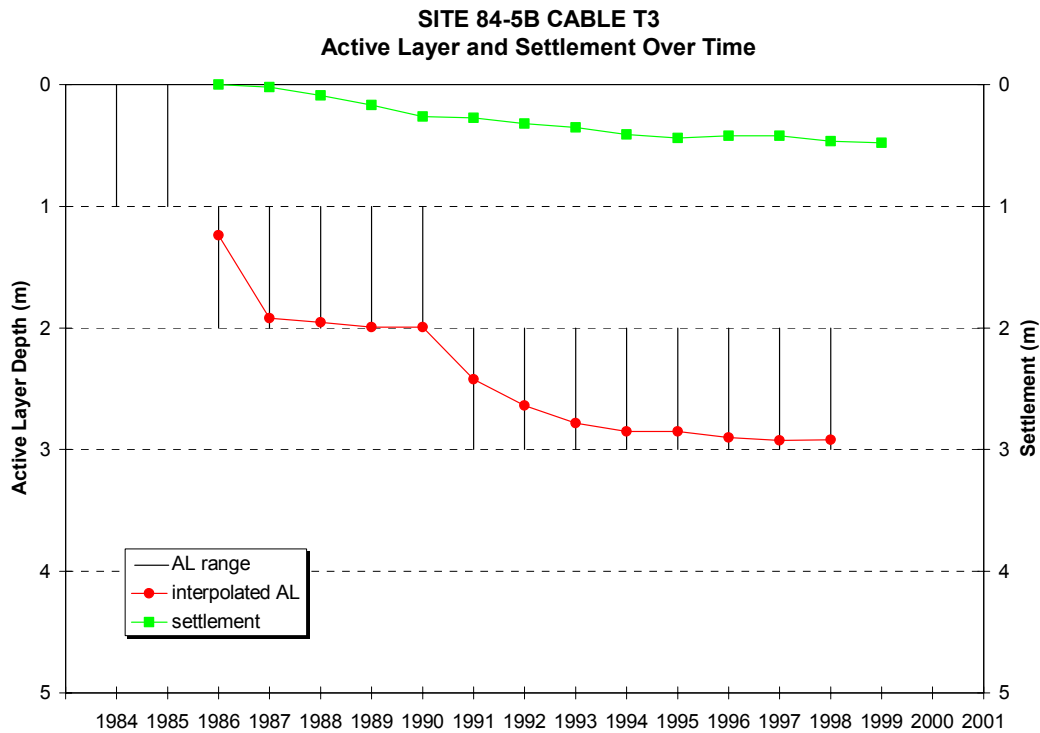
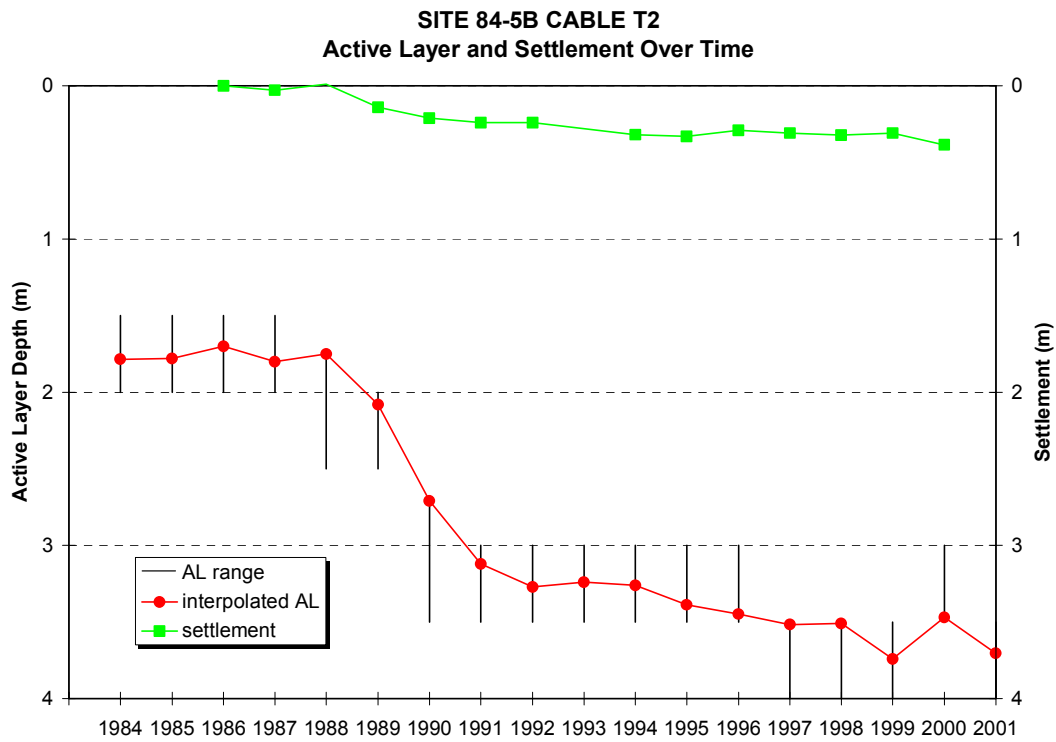


**SITE 84-5A CABLE T1**  
**Active Layer and Settlement Over Time**

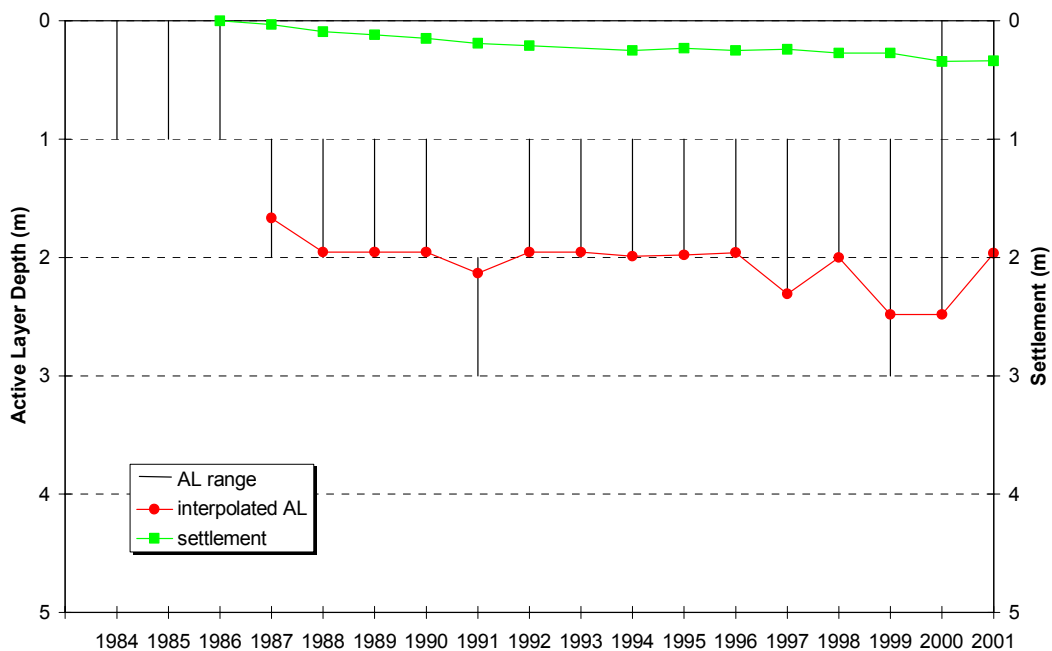




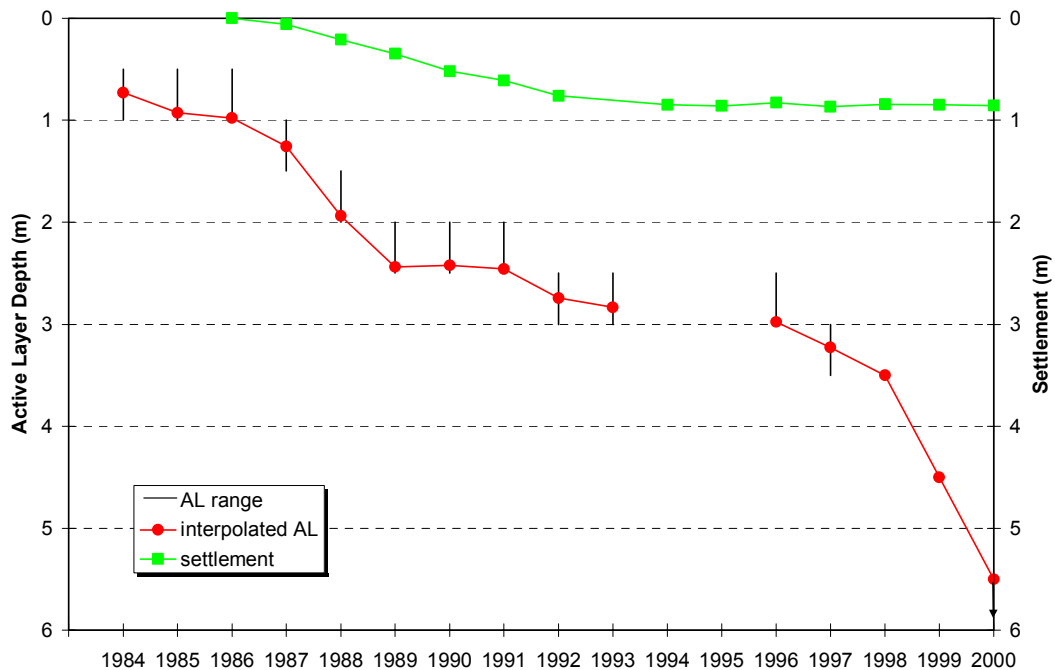


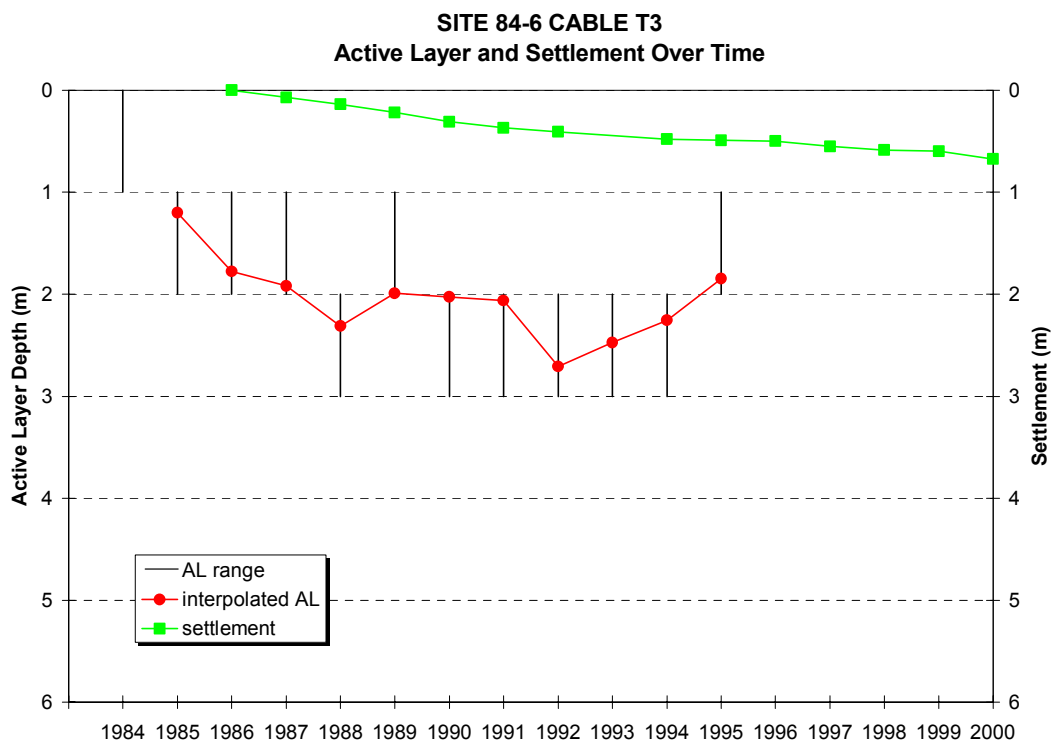
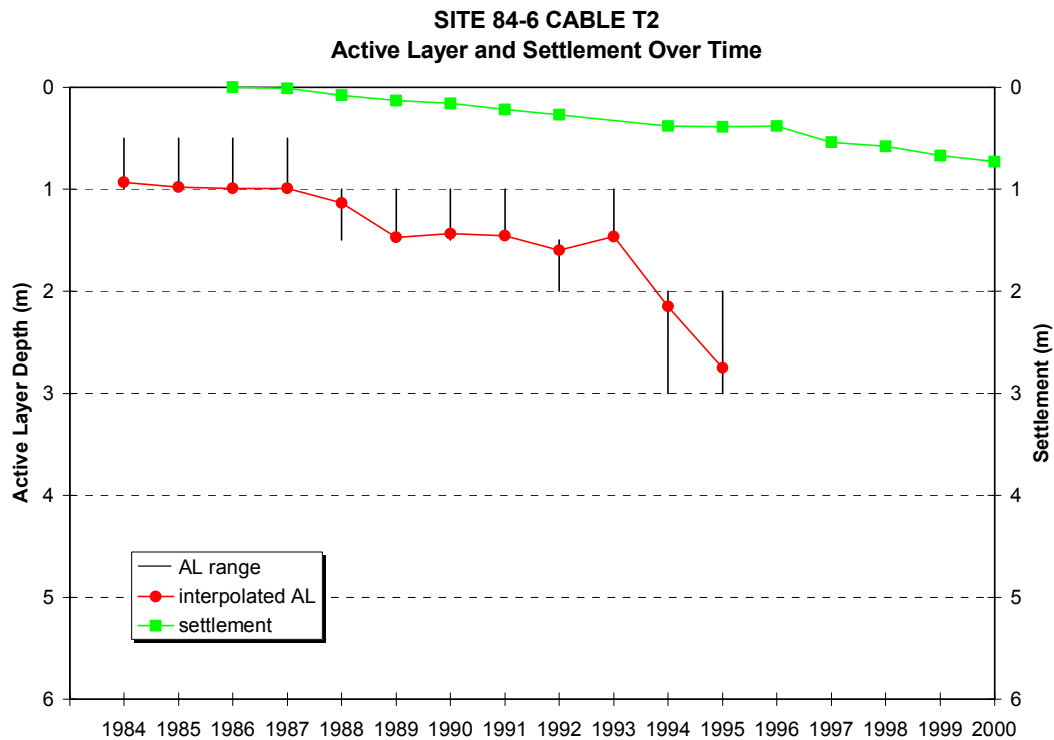


**SITE 84-5B CABLE T4**  
**Active Layer and Settlement Over Time**

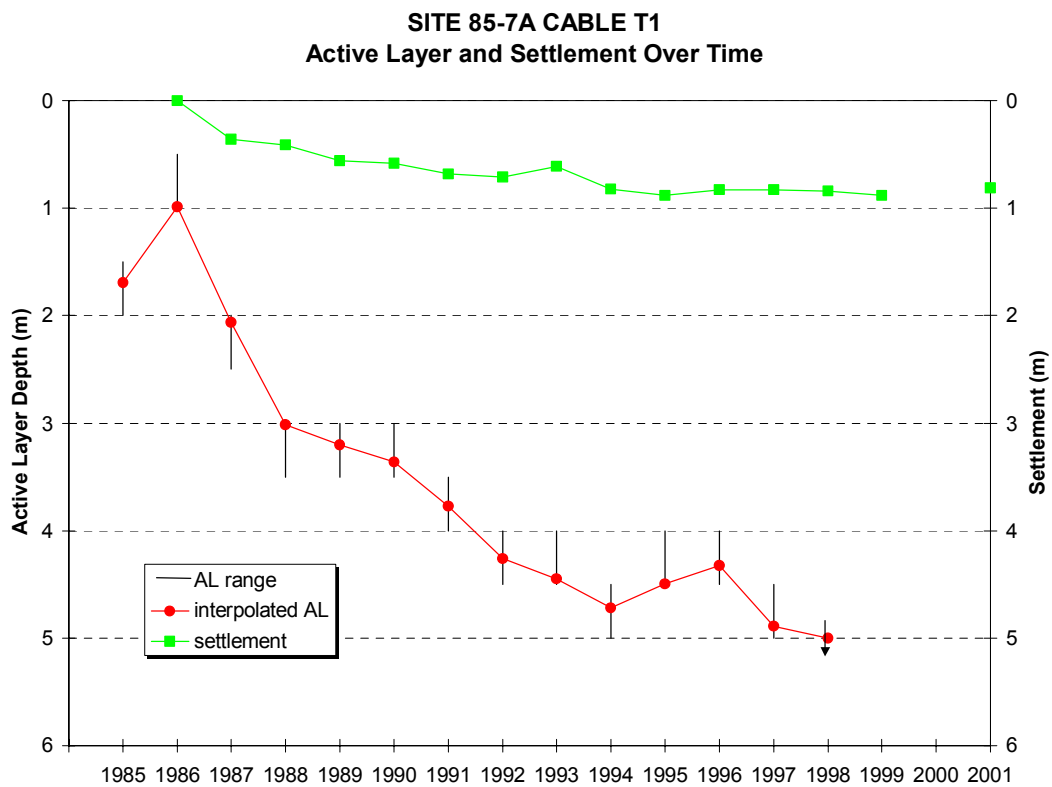
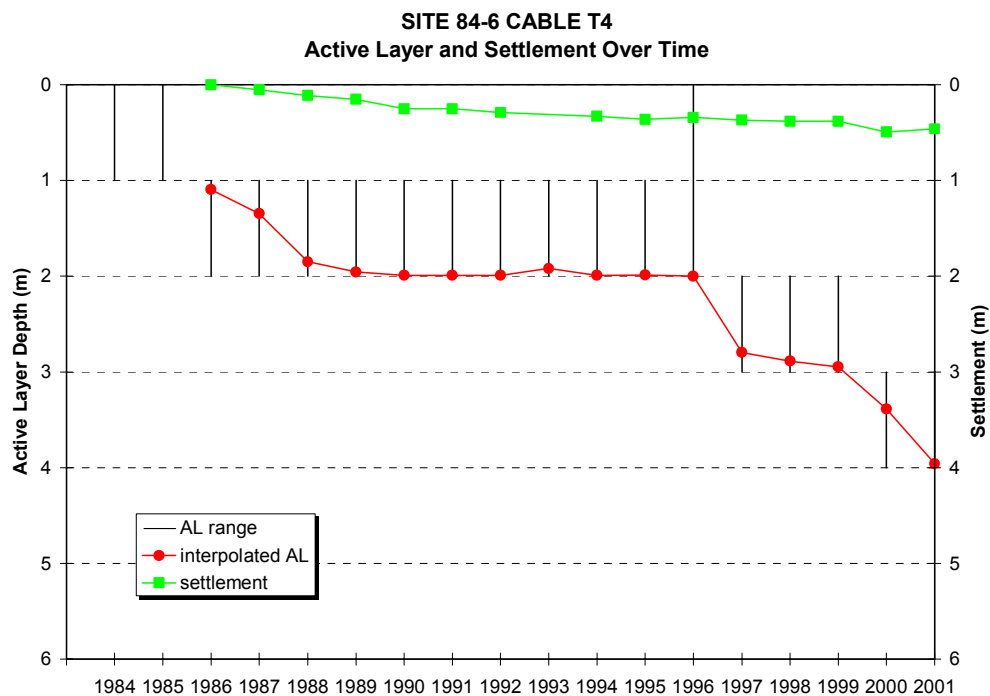


**SITE 84-6 CABLE T1**  
**Active Layer and Settlement Over Time**

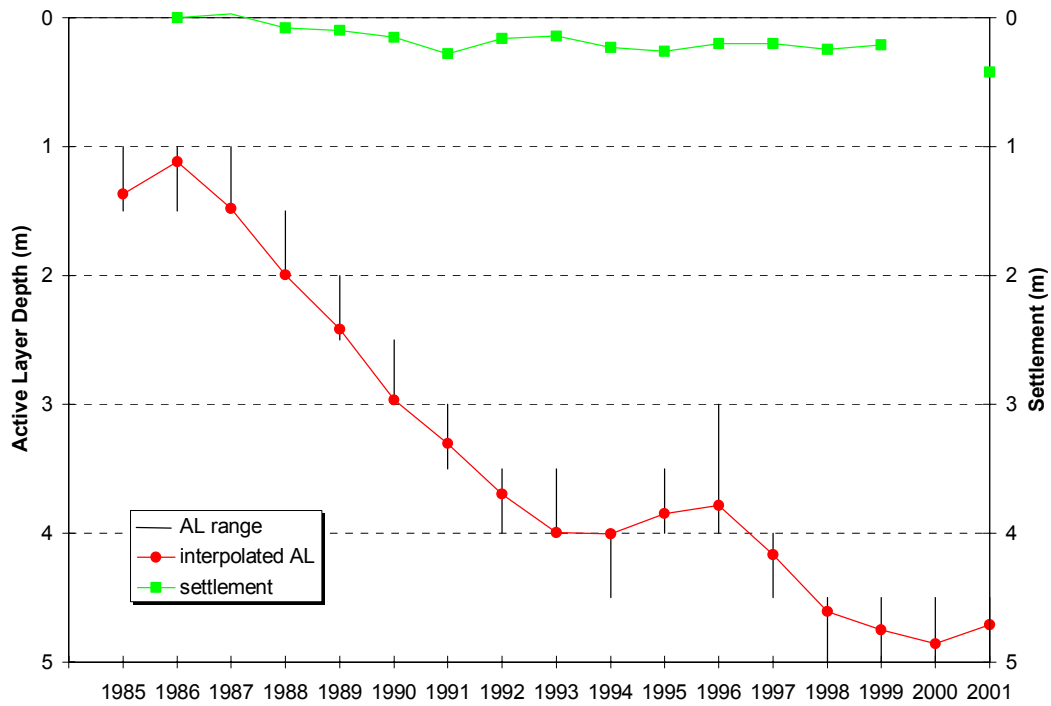




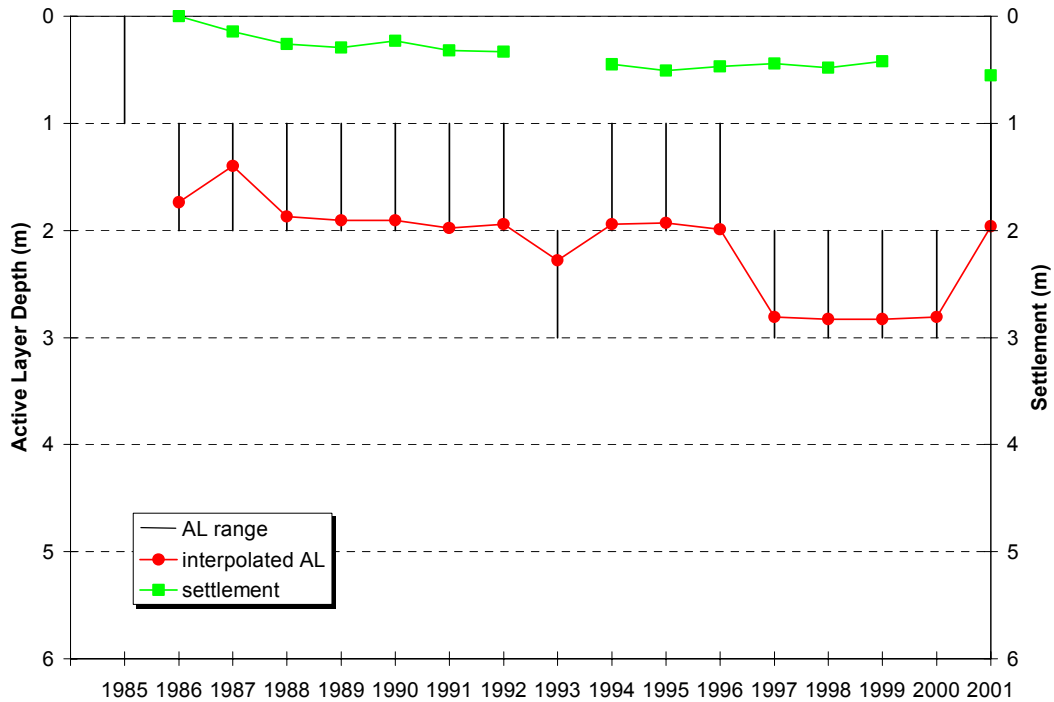




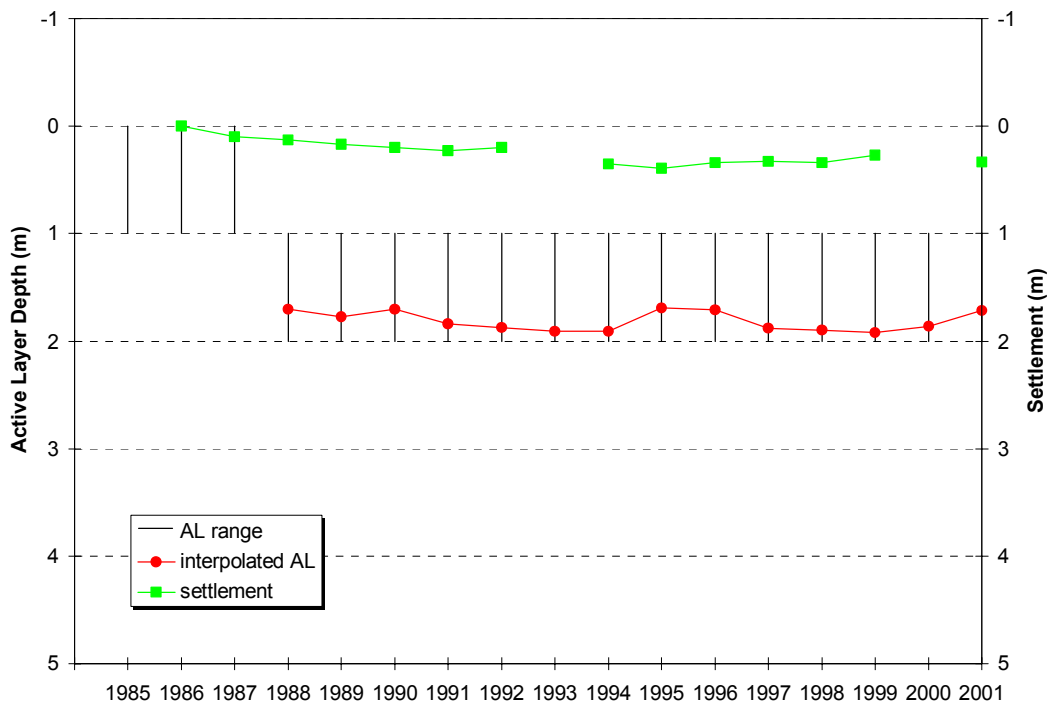
**SITE 85-7A CABLE T2**  
**Active Layer and Settlement Over Time**



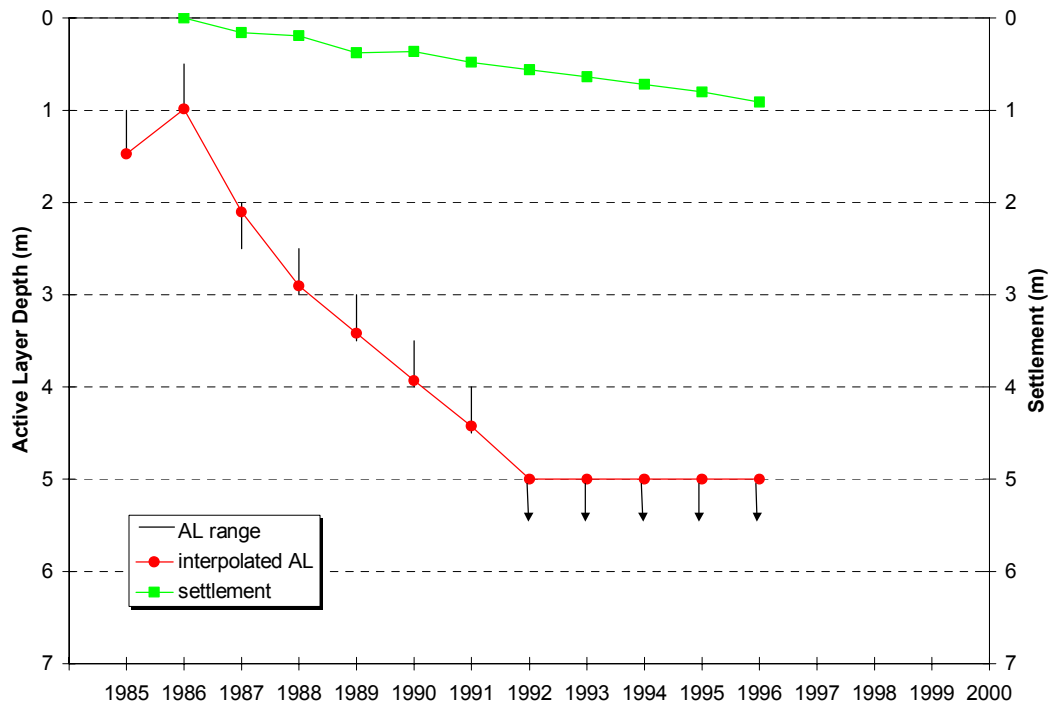
**SITE 85-7A CABLE T3**  
**Active Layer and Settlement Over Time**



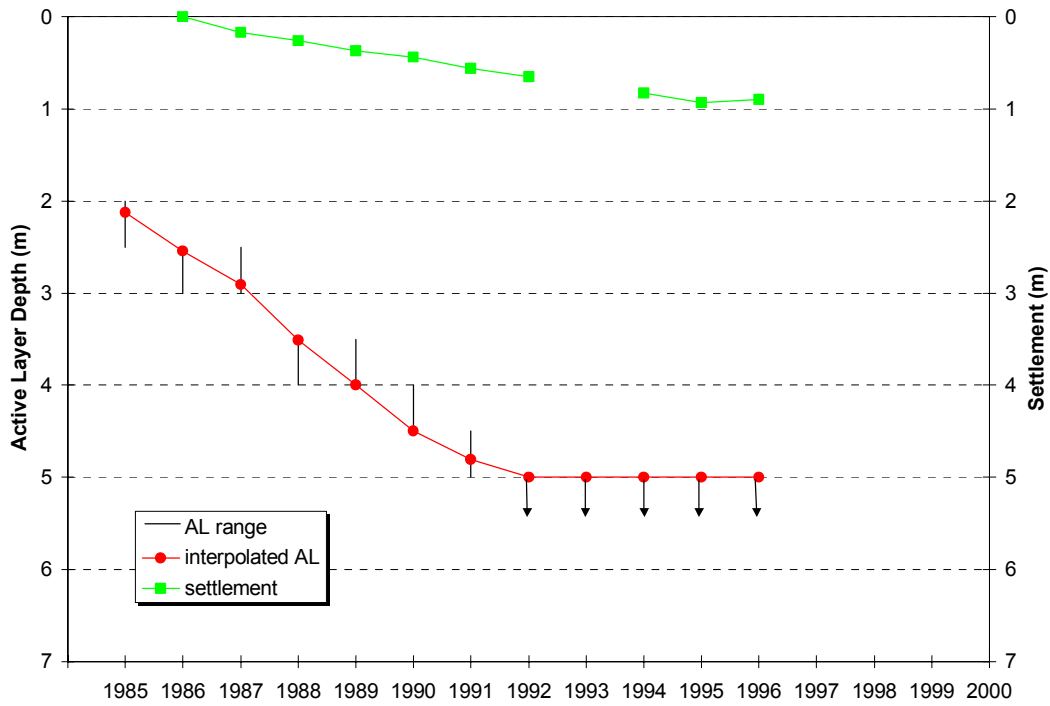
**SITE 85-7A CABLE T4**  
**Active Layer and Settlement Over Time**



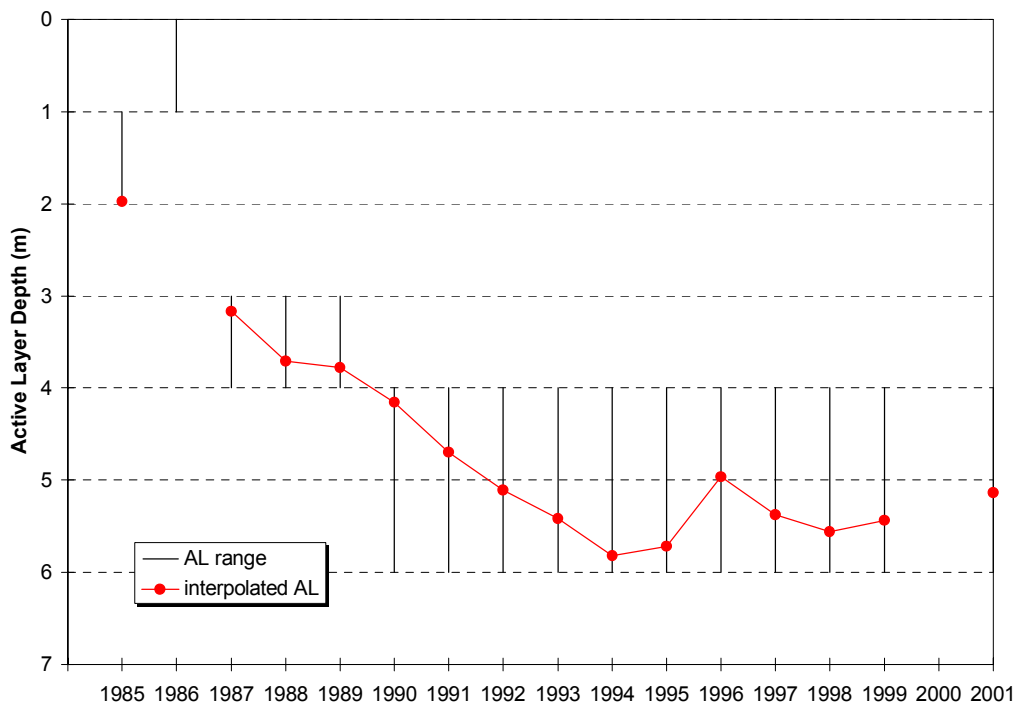
**SITE 85-7B CABLE T1**  
**Active Layer and Settlement Over Time**



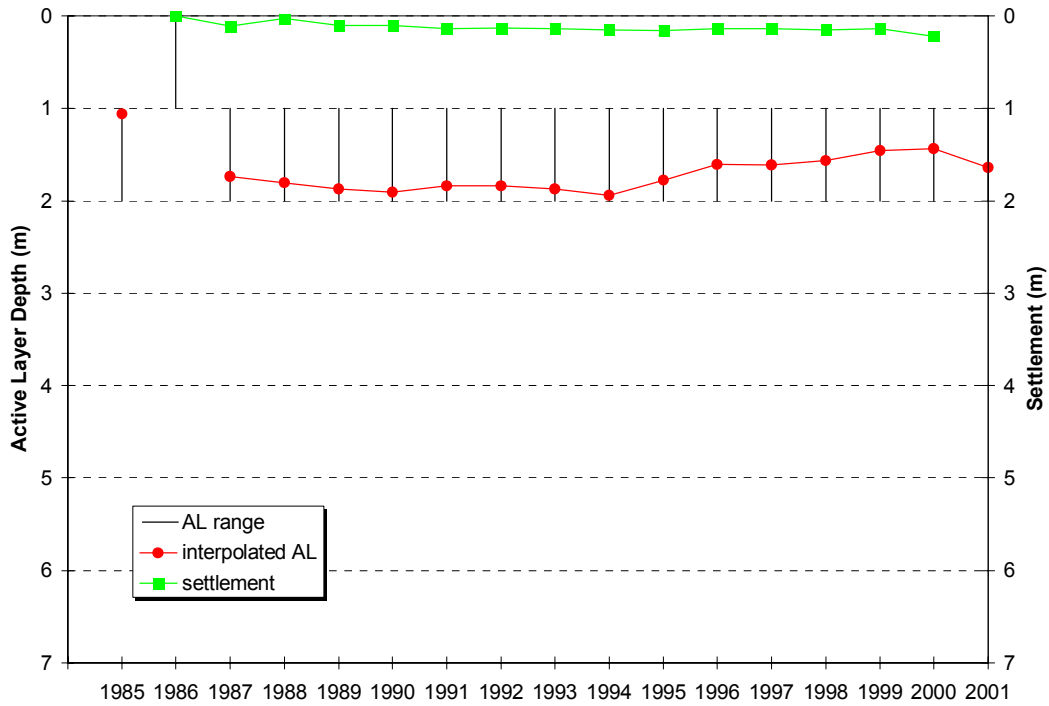
**SITE 85-7B CABLE T2**  
**Active Layer and Settlement Over Time**



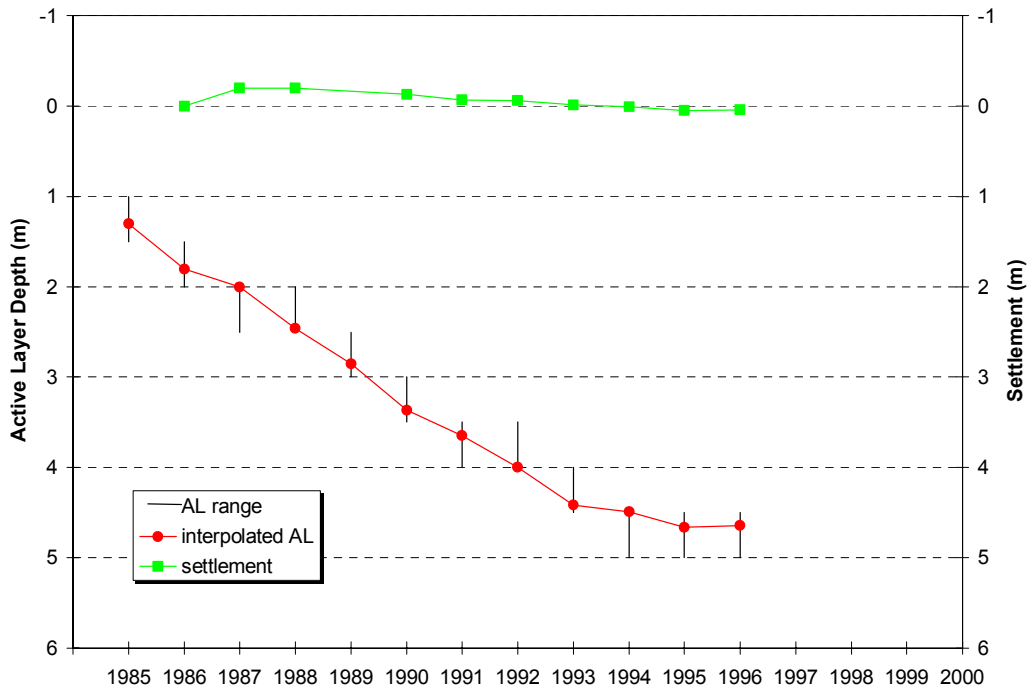
**SITE 85-7B CABLE T3**  
**Active Layer and Settlement Over Time**

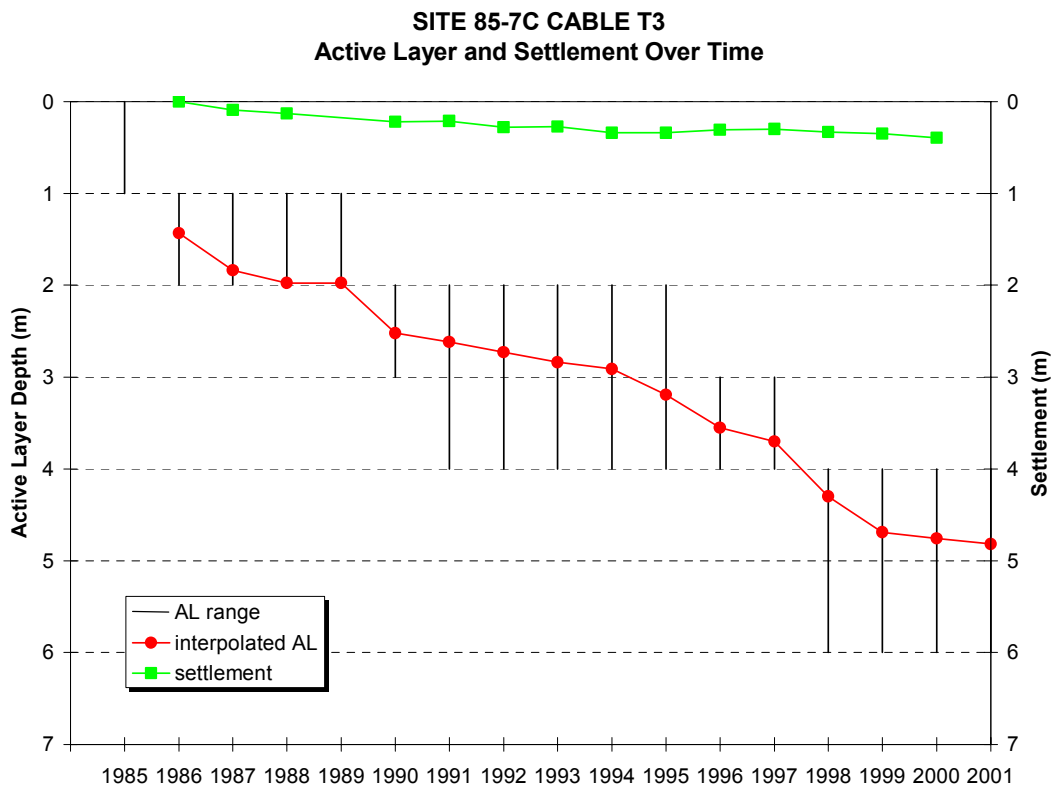
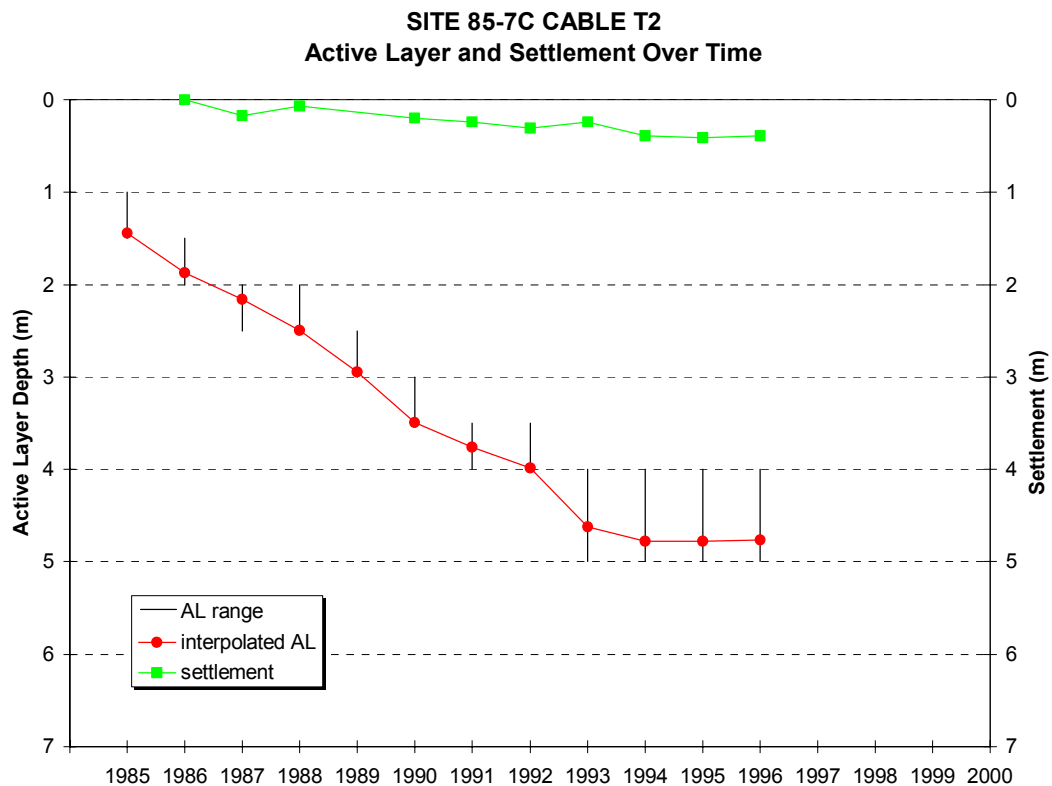


**SITE 85-7B CABLE T4**  
**Active Layer and Settlement Over Time**

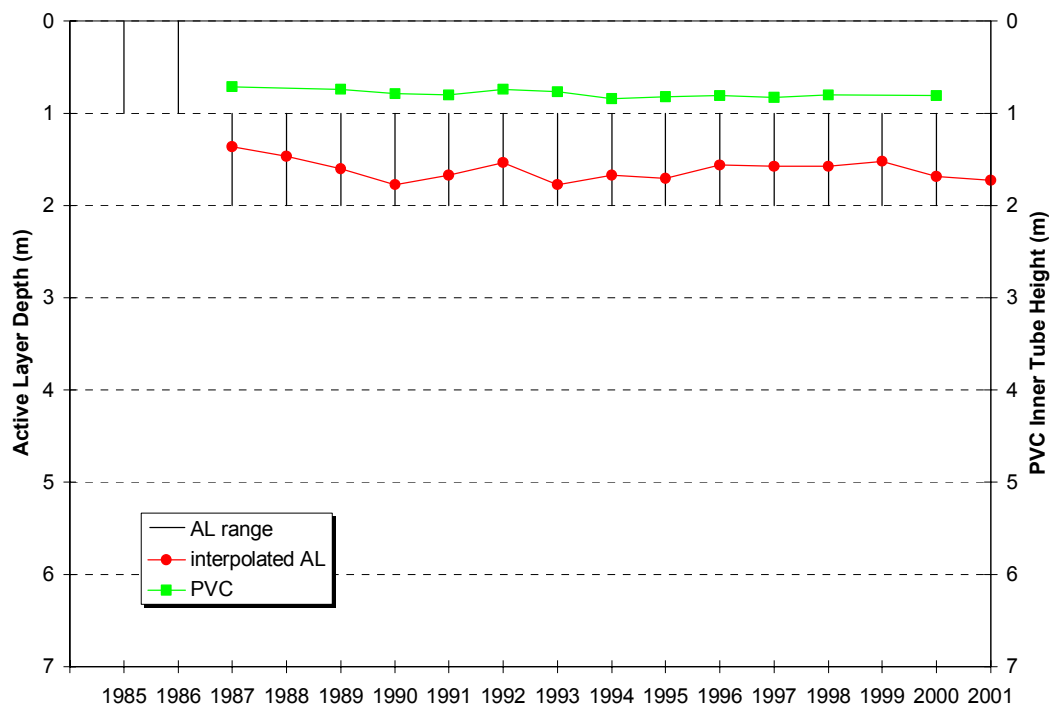


**SITE 85-7C CABLE T1**  
**Active Layer and Settlement Over Time**

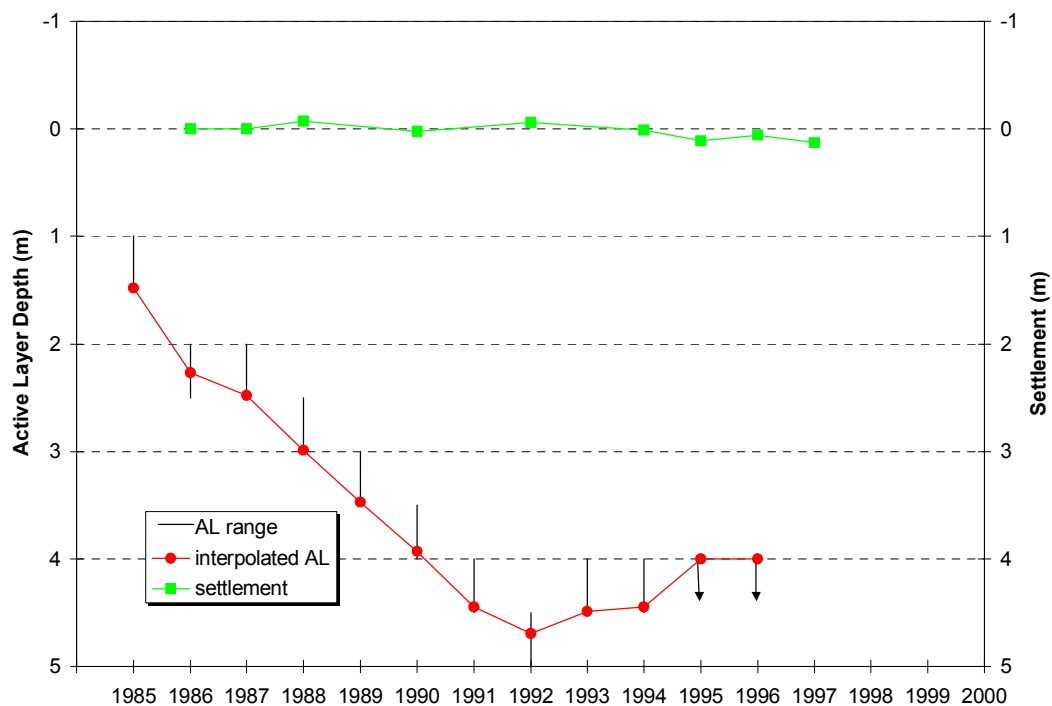




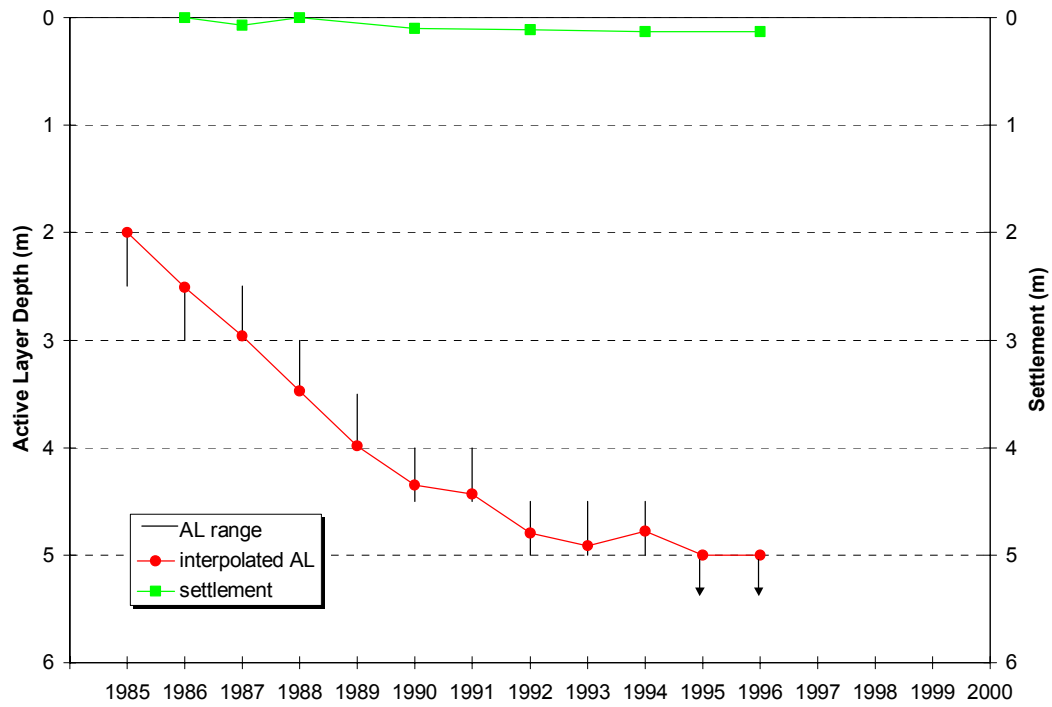
**SITE 85-7C CABLE T4**  
**Active Layer and Settlement Over Time**



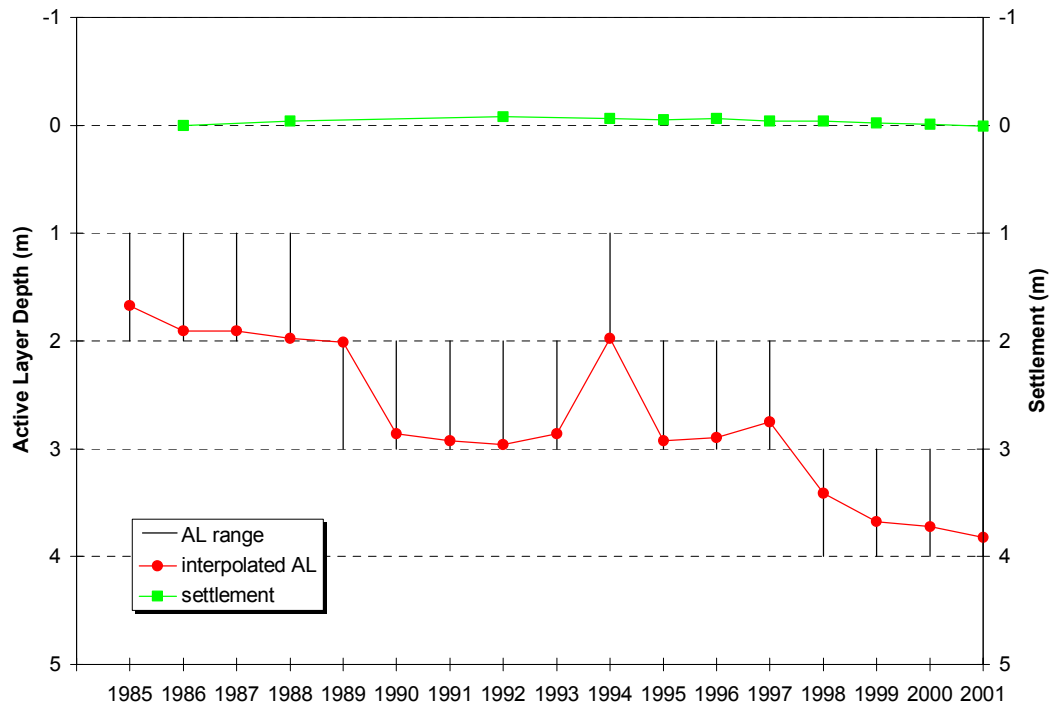
**SITE 85-8A CABLE T1**  
**Active Layer and Settlement Over Time**



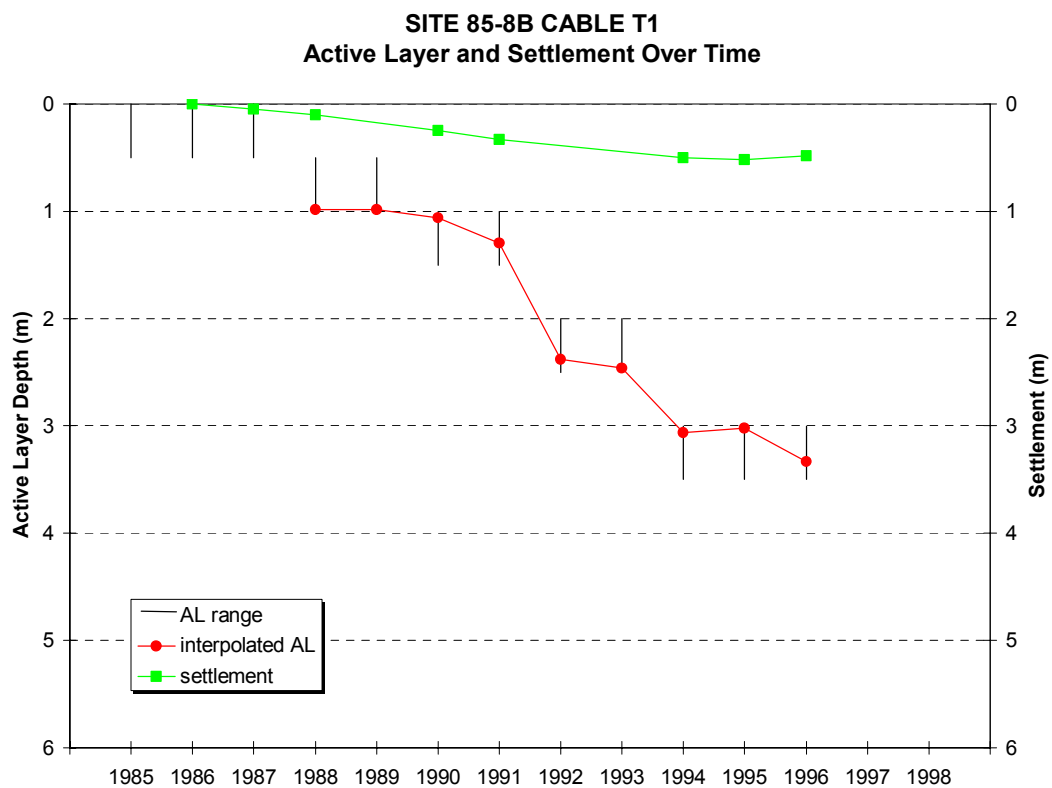
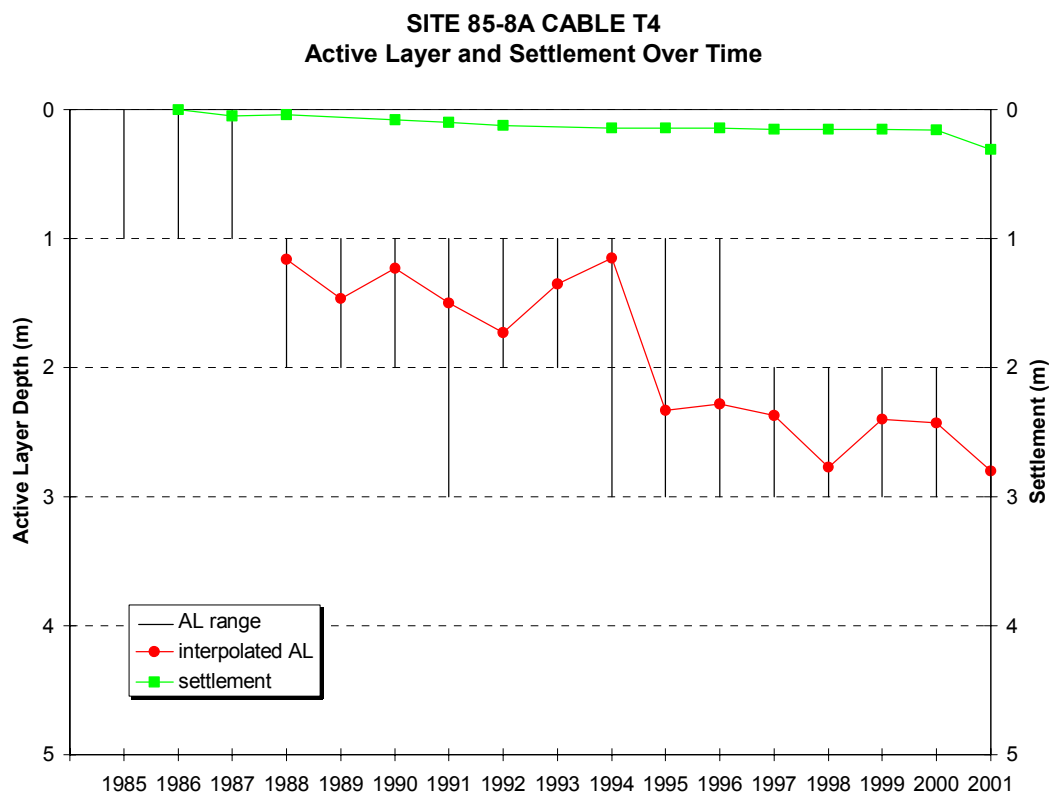
**SITE 85-8A CABLE T2**  
**Active Layer and Settlement Over Time**

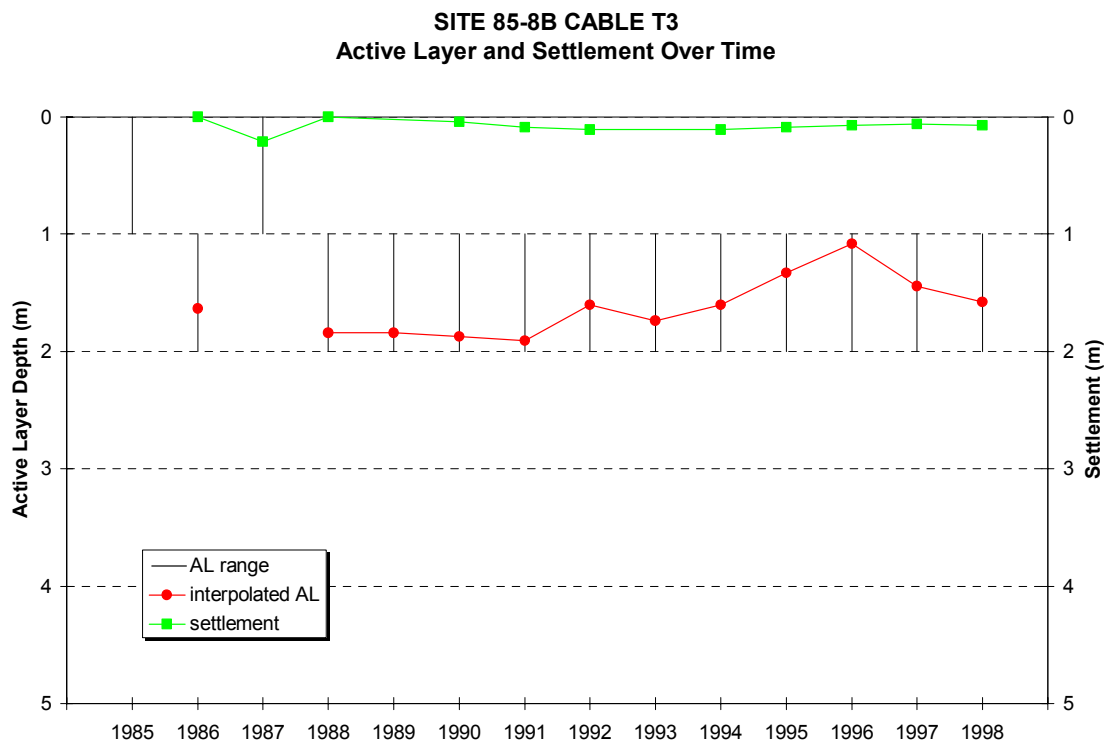
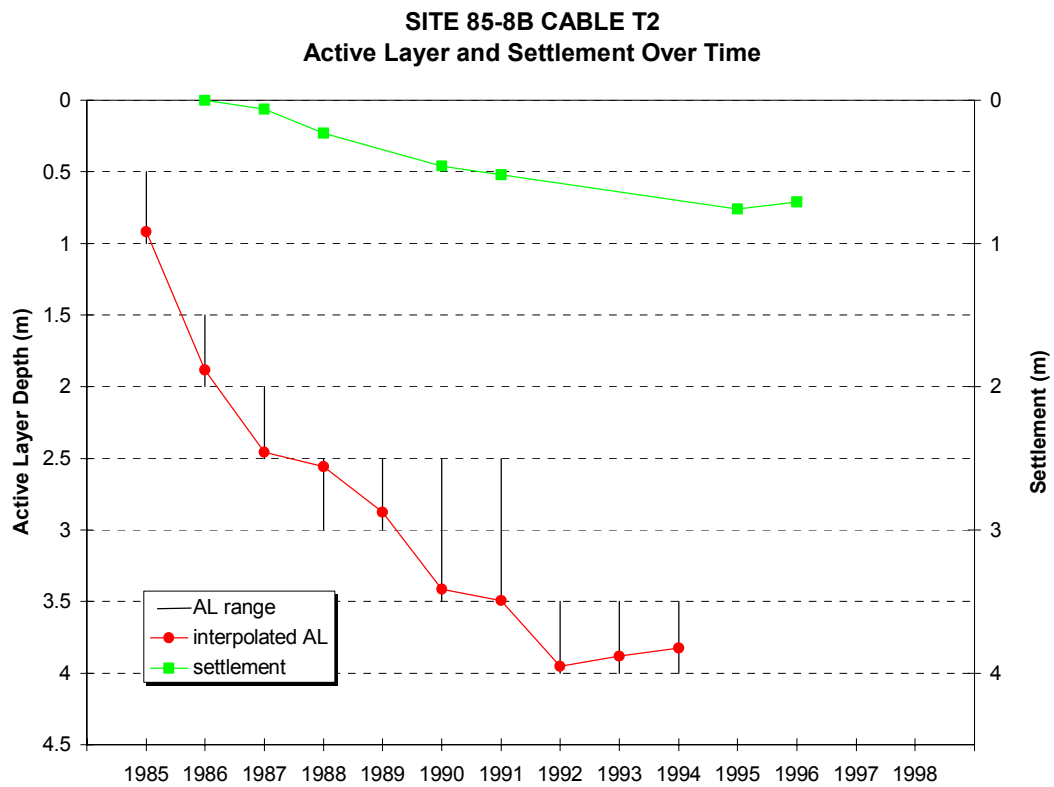


**SITE 85-8A CABLE T3**  
**Active Layer and Settlement Over Time**

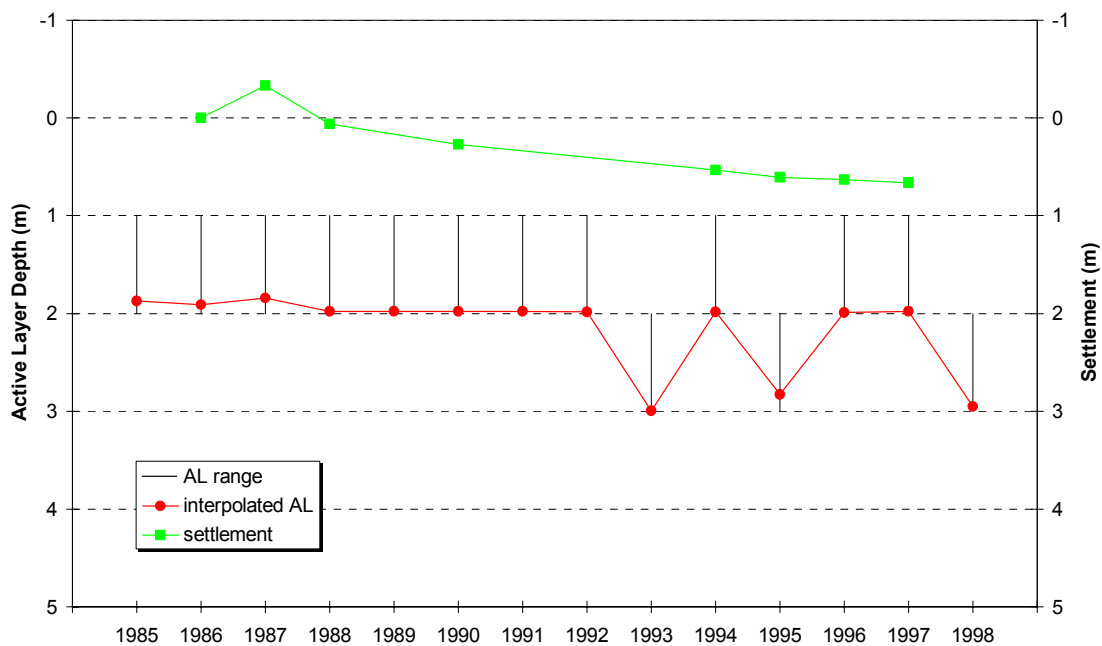




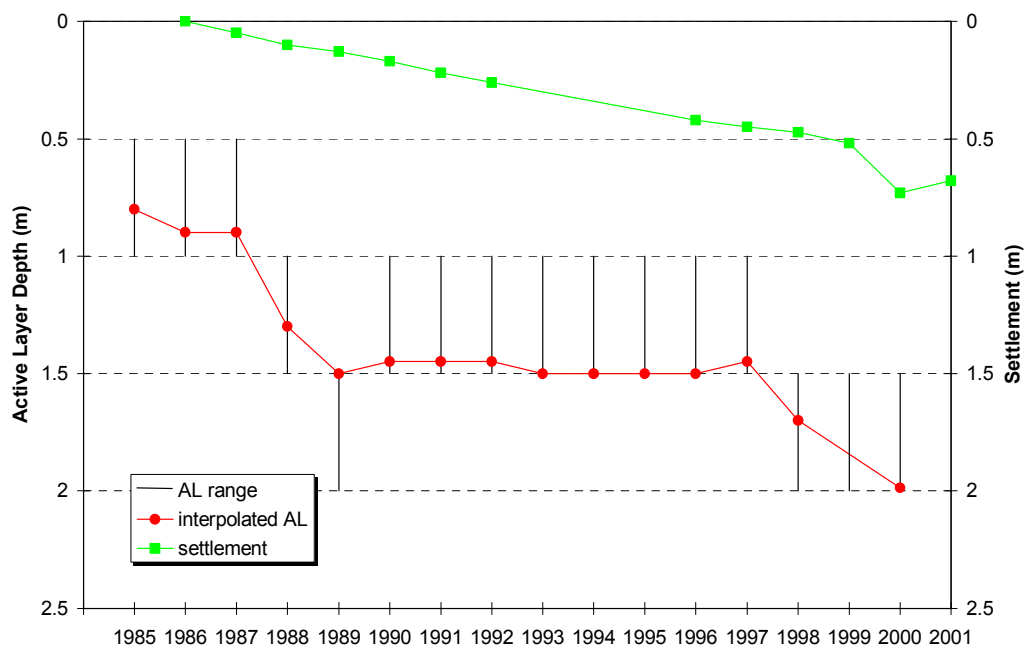




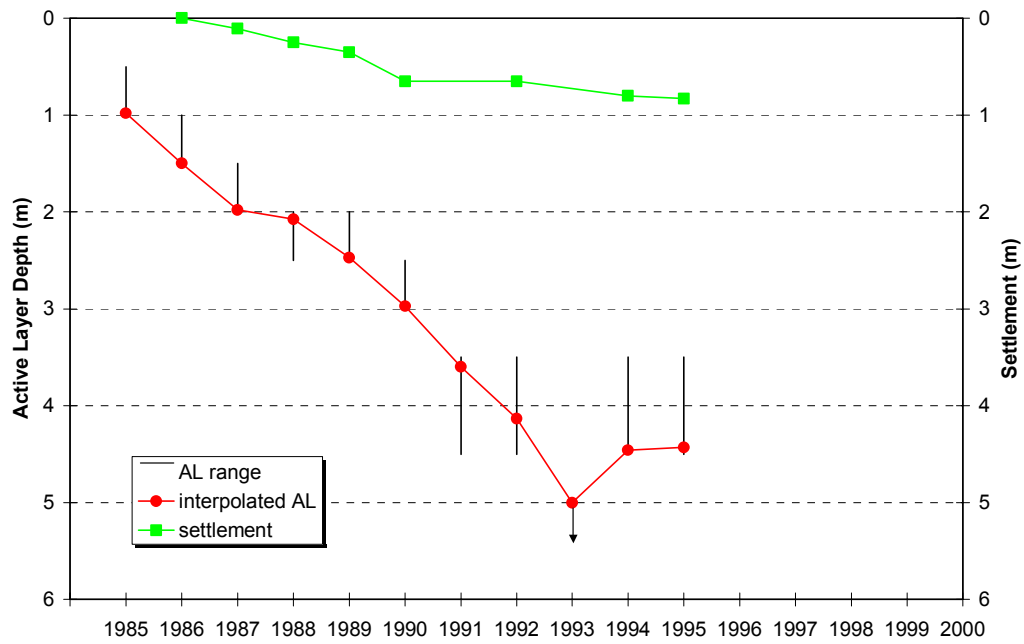
**SITE 85-8B CABLE T4**  
**Active Layer and Settlement Over Time**



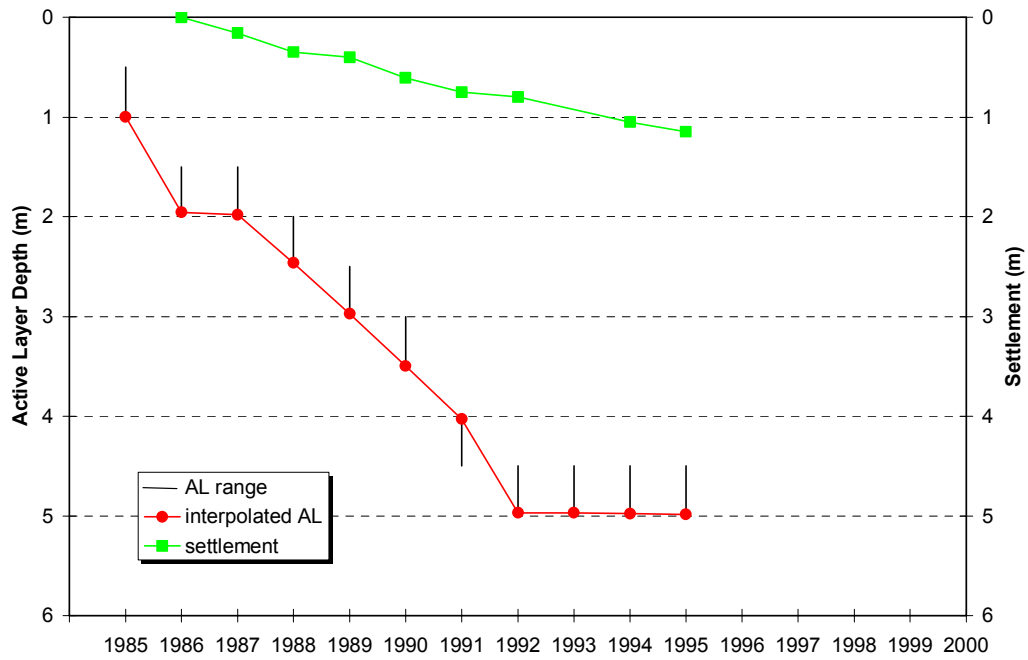
**SITE 85-10B CABLE T4**  
**Active Layer and Settlement Over Time**



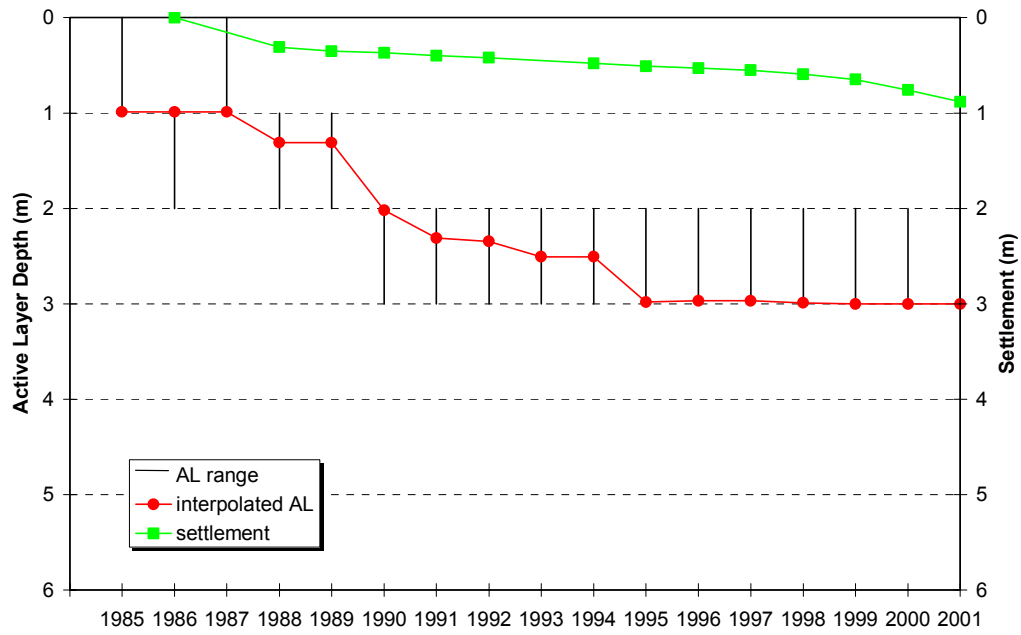
**SITE 85-12B CABLE T1**  
Active Layer and Settlement Over Time



**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**

