# CanZinco Ltd.
# Nanisivik Mine
# Closure and Reclamation Plan

## Volume 2 of 2
## Supporting Documents

A. 2001 Environmental Site Assessment and Proposal for Phase 2 ESA, Gartner Lee Limited, February 28, 2002.
B. Reclamation Cover Design for Nanisivik Mine West Twin Disposal Area Surface Cell, Gartner Lee Limited, March 08, 2002.
C. Pseudostatic Analysis for Seismic Stability of West Twin Lake Dyke, Closure Planning for Nanisivik Mine, NU, BGC Engineering Inc., February 5, 2002.
D. Report on Hydrological Study Nanisivik Spillway Design, Golder Associates Ltd., February 2002.
E. Preliminary Design of the West Twin Dike Spillway for Closure, Nanisivik Mine, NU, BGC Engineering Inc., February 28, 2002.

*Prepared for:*

**CanZinco Ltd.**

*Prepared by:*

**Gartner Lee Limited**

**February 2002**

# Nanisivik Mine

# Reclamation Cover Design for Nanisivik Mine West Twin Disposal Area Surface Cell

*Prepared for*
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*Prepared by:*
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*GLL P21957*

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# 1. Introduction

## 1.1 Background

The Nanisivik Mine, located on the Borden Peninsula of Baffin Island in the Nunavut Territory, is a base metal mine producing zinc and lead concentrates. Construction of the Nanisivik project began in 1974 with the processing of ore following in 1976. The mine life was originally expected to be 12 years, based on known ore reserves. Through continued exploration and underground development however, reserves were consistently replaced and the mine has operated for more than 25 years.

In October 2001 a "new" mine plan was developed to respond to the sustained depression in metal markets. The new plan identified a mining strategy, focusing on the accelerated removal of mine pillars in a "retreating" mine plan scheduled over an 11 month period. Consequently, the permanent closure of the mine is scheduled to occur in September 2002.

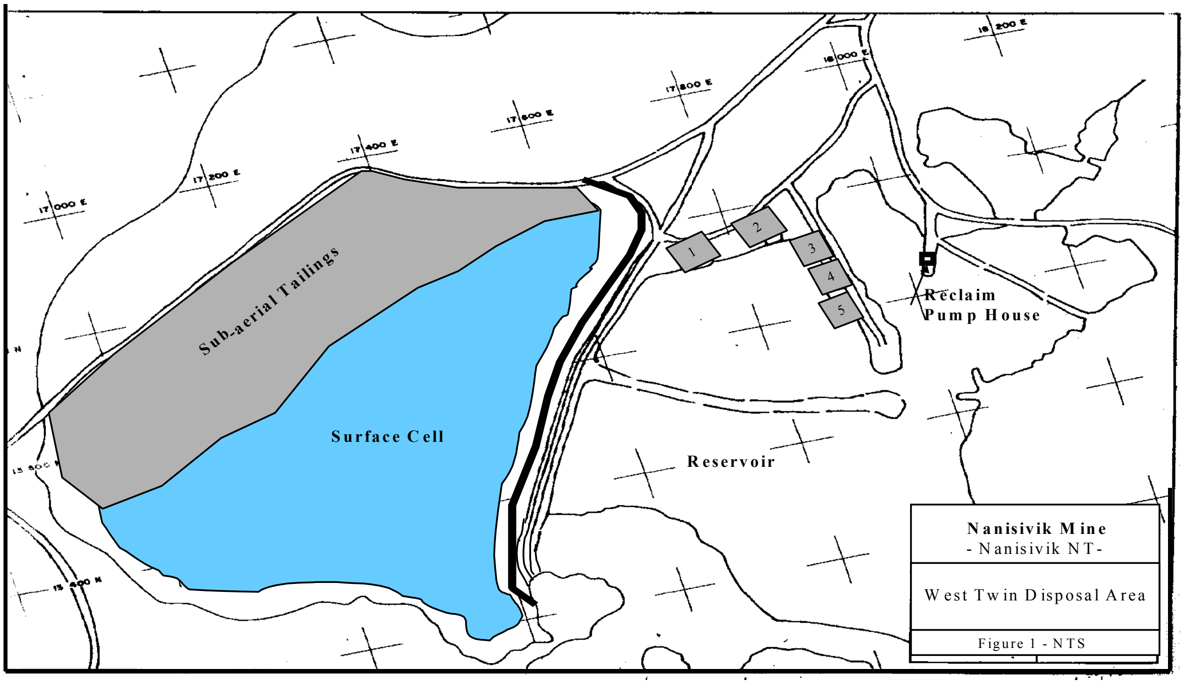
In accordance with reclamation requirements regulated by both the Government of Nunavut and the Department of Indian and Northern Affairs Canada, Nanisivik Mine is preparing a Closure and Reclamation Plan for submission and approval. This report is intended to accompany and complement the Closure and Reclamation Plan as regards reclamation of the surface tailings impoundment (the "Surface Cell").

The Surface Cell tailings impoundment is located in the 55 hectare West Twin Disposal Area (WTDA) approximately four kilometres southeast of the mill. Mine tailings (rejected processed ore) have been deposited exclusively in the WTDA since production began in 1976. The WTDA is comprised of both a surface (subaerial) tailings deposition area (Surface Cell) and a subaqueous tailings deposition area (Reservoir) which was part of the original lake. A site plan showing the WTDA and its components is shown in Figure 1.

The closure concept for the Surface Cell is a cover that will mitigate potential long term impacts from the exposed tailings. The concept that has been developed and pursued to date is a cover of shale either with or without a capping of sand and gravel. Permafrost is known to aggrade rapidly into the tailings after deposition and, therefore, the tailings are expected to be frozen (inclusive of the active layer) prior to placement of the reclamation cover. The cover would need to be thick enough to perpetuate the permafrost that has aggraded into the tailings through thermal insulation and formation of an ice layer at the base of the cover. Nanisivik Mine has conducted a substantial amount of work that has been incorporated into the cover design. This has involved 7 years of field trials of cover materials and laboratory studies.

This report contains the details and rationale for the proposed cover design. Gartner Lee Limited compiled this report with substantial input by CanZinco Ltd. and BGC Engineering Inc.

**Figure 1: West Twin Disposal Area**




## 1.2 Objectives and Scope

The principle closure objectives for the Surface Cell are mitigating the potential long term impacts and providing surface land use compatible to it's natural surroundings. The potential environmental impacts associated with the surface tailings in their current state are related to chemical stability and the potential for metals in solution to exit the containment area, as described in the report "2001 Environmental Site Assessment" prepared by Gartner Lee Limited. The mine tailings have been identified as potentially acid generating over the longer term if exposed to oxidizing conditions (Lorax 1999). The closure concept to manage and minimize these risks is to restrict the transfer of oxygen to the tailings as well as minimize the transport of any available metals.

Reclamation objectives will be achieved by developing a cover system that incorporates the following characteristics:

1. Thermal insulation.
2. Geochemically "inert".
3. Physically stable over the long term.
4. Oxygen diffusive.
5. Aesthetically similar to the local surroundings.

The scope of work required for the development of the cover system is as follows:

1. Review of site data.
2. Determination of surface area and final contours.
3. Consideration and assessment of cover options.
4. Geothermal assessment.
5. Geotechnical assessment.
6. Geochemical assessment.
7. Drainage and hydrological assessment and contouring.
8. Cover construction.
9. Summary report.

# 2. Site Conditions

## 2.1 Physical Setting

The Nanisivik Mine is located in the Canadian Arctic at 73º 03’ north latitude and 84º 35’ west longitude on Borden Peninsula at the northern end of Baffin Island. Strathcona Sound (Arctic Ocean) borders the mine approximately 5 km north of the underground workings.

The mine area consists of a few intermittent planar areas predominately surrounded by relatively steep high-relief hills rising out of Strathcona Sound. The moderately rough landscape and surficial material characteristics reflect marine processes that were accentuated by land rebound after major glaciation.

## 2.2 Geology

A description of the geology of the mine site is provided in *Nanisivik Mine Closure and Reclamation Plan* (CanZinco Ltd., 2002) that is repeated here for reference and context.

The Nanisivik sulphide deposits are hosted in carbonate rocks within a Proterozoic sedimentary sequence. This sequence developed as a Neohelikian intracratonic basin, the Borden Basin, on a peneplaned gneiss complex of Archean-Aphebian age.

The present Borden Basin sequence consists of generally shallow water clastic and carbonate sediments up to 6,100 metres thick, called the Bylot Supergroup. The Supergroup is divided into three Groups, a lower clastic group (the Eqalulik Group), a middle carbonate group (the Uluksan Group) and an upper clastic group (the Nunatsiaq Group).

The Uluksan Group is made up of the lower Society Cliffs Formation and the upper Victor Bay Formation. The Society Cliffs Formation varies in thickness from 260 metres at Arctic Bay to 856 metres at Tremblay Sound. West of Tremblay Sound, it was deposited in a subtidal to intertidal environment. The Society Cliffs Formation is conformably overlain by the Victor Bay Formation, which consists of shales, siltstones, dolostones and coarse carbonate clastics and varies in thickness from 156 metres to 735 metres. The Victor Bay Formation is considered to have acted as a cap rock to mineralization in part of the mine area. All of the economic mineralization at the Nanisivik mine lies within the upper member of the Society Cliffs Formation.

The Nanisivik mine property is up to 7 km wide and up to 15 km long. Rocks cropping out on the property include small exposures of quartzite of the Adams Sound Formation on the southern edge of the lease area. The unit immediately below the Society Cliffs Formation, the Arctic Bay Formation, crops out in the area but is not exposed on the property. The main units exposed are the Society Cliffs Formation and the overlying Victor Bay Formation, together with Paleozoic sandstones of the Gallery Formation.

In the mine area, dips are usually quite shallow and the main structure is faulting. Major structures that are recognized in the mine include the South Boundary Fault, which marks the southern margin of sulfide mineralization, and the Keystone Graben Fault, which defines the southern margin of the Main Ore Zone horst.

The various massive sulphide deposits contain more than 50 million tonnes of which barren massive pyrite bodies occupy most of the area and contain the largest sulphide tonnages. Zones containing sphalerite are present within the massive pyrite bodies, but are confined to a restricted vertical interval. All of the known significant sphalerite deposits are in horsts adjacent to the Keystone Graben.

The South Boundary Zone is wedge-shaped and consists of massive pyrite. It is controlled by the South Boundary Fault. The Main Ore Zone is an elongated, sinuous, lenticular body, hosted in carbonate, with a nearly horizontal upper contact. A number of bodies are irregular subvertical veins, while some other bodies underlie gently dipping shale contacts. These variations in structural style occur both in the massive pyrite and in the sphalerite zones.

Each of the sphalerite-rich ore bodies is confined to a restricted vertical interval that varies in thickness and elevation from zone to zone. Flat sulphide contacts cut at low angles across dolostone bedding and sulphides rarely follow the beds.

The Main Zone deposit is about 3 km long. It is oriented east-west, although it is sinuous in plan. The deposit is broadly 'T' shaped, with a flat-topped upper section that is typically about 100 metres wide and 20 metres high. A remarkable feature of this deposit is the constant elevation of the top of the deposit over its entire length. The keel section of the deposit extends to about 80 metres below the upper section. While it is subvertical, no obvious controlling structures have been recognized to date. In places, flat-lying “wings” of sulfides extend out laterally from the keel zone.

Internal structures in the ore zones tend to be complex, and range from massive and banded to chaotic or brecciated. Banding tends to be subhorizontal in both the upper section of the Main Zone and the keel section of the deposit, but it may be parallel to dipping dolostone contacts in some areas. As well, the ore is porous in places and large irregular zones of ice are present in some faces underground.

The accepted geological model is that the Nanisivik deposits are Mississippi-Valley Type ("MVT"). By definition, these are post-depositional, carbonate hosted deposits. Typically, they are coarse-grained and mineralogically simple. They tend to be sphalerite-rich, may be very large and may contain high base metal grades. However, MVT deposits include quite diverse deposits, different in shape, grade and mineralogy. This diversity appears to result from source fluid chemistry, rocks through which the fluids pass prior to deposition, source fluid temperature and the nature of the depositional environment.

## 2.3 Permafrost Conditions

Nanisivik is located in the permafrost region of the Canadian Arctic Archipelago where permafrost is characterized as “continuous” (i.e. existing over the landscape as a continuous layer).

A description of the local permafrost conditions was provided by Golder Associates Ltd. in the report “Geotechnical Data Review and Stability Assessment of West Twin Dyke” dated October 1999. A summary of the Golder description is provided below.

1. Permafrost at the northern end of Baffin Island has a potential for high amounts (>20%) of ground ice.
2. Permafrost at Nanisivik has been found to be deeper than 430 metres in a borehole drilled from the underground workings;
3. The subsurface rock temperature was noted to range from $-11.7^0$ to $-9.4^0$ C in the project feasibility study;
4. Baseline environmental studies noted that permafrost was encountered in two shallow test pits: at a depth of 25 cm on the north-facing slope of Mt. Fuji and at 60 cm on an exposed dry ridge and that permafrost was not encountered to 85cm depth in another shallow test pit on an exposed dry ridge; and
5. Studies related to the reclamation testing covers indicated that on-land deposition of mine wastes leads to rapid permafrost aggradation into the waste material within a one to two winter timeframe.

## 2.4 Climate

Nanisivik is located in a climatic zone classified as “polar desert”. Meteorological data has been collected by Atmospheric Environmental Services (AES) of Environment Canada since 1976 at the Nanisivik Airport (located approximately 10 km south of the mine site). Over the period of observation, the mean daily temperature is recorded as –15.2ºC. Mean annual precipitation has been recorded at 231 mm, of which, approximately 50 mm is in the form of rain.

Annual evaporation data at the WTDA has been measured at an average of 187 mm during the period 1993 to 2001 (DIAND meteorological station).

The daily rainfall PMP event is estimated to be approximately 140 mm and the daily snowmelt PMP event is estimated to be 155 mm (Golder, 2002). The magnitude of these extreme events is low relative to southern Canada (for example, a daily PMP event in Northern Ontario is approximately 500 mm to 700 mm) which reflects the characterization of the site as a "Polar Desert".

# 3. Ongoing Tailings Disposal Operations

The mine will operate in 2002 with the last shipment of concentrate scheduled for early October. Tailings will continue to be deposited in the WTDA until mill operations cease.

A total volume of 216,600 cubic metres of tailings is scheduled to be produced during 2002 that will be deposited in the Surface Cell. The tailings deposition plan will place tailings in a logical sequence working towards the final contours required for drainage and cover placement. Proactive reclamation is scheduled for the summer of 2002 in areas where final contour elevations have been achieved.

The deposition methodology will be to continue to pour tailings in thin layers as the pipe is moved around the surface cell. This provides conditions amenable to rapid freezing of tailings solids over one winter season, a benefit of which is that placement of the reclamation cover takes place over tailings that are already frozen at depth.

Existing dust control strategies and monitoring will continue during the final operating period and throughout the reclamation period while the cover is being placed. Dust control methods will include: induced ice cover (water cannons), natural and induced snow cover (through fencing) and shale cover. Monitoring will include the continued operation of the high-volume and $PM^{10}$ dust samplers as well as visual observation and photo documentation.

# 4. Evaluation of Surface Cell Cover Materials

An evaluation of three types of covers that may be suitable for the site-specific conditions was conducted based on their ability to meet the general objectives outlined in *Section 1.2* as:

> *The principle closure objectives for the tailings deposit are mitigating the potential long term impacts and returning the area, as nearly as possible, to its natural state.*

The three types of covers evaluated were water cover, geosynthetics and natural materials.

## 4.1 Water Cover

In Canada, the use of water cover has been identified as a proven prevention technology for potentially acid generating mine wastes. Research published by Natural Resource Canada's MEND program (Mine

Environmental Neutral Drainage Program) shows that oxidation of sulphide materials can be inhibited by the presence of a water cover acting as an oxygen diffusive barrier.

MEND also points out that while water covers have been applied at many sites, they are not universally applicable. Related issues such as the design and integrity of the containment structures, plus long term monitoring and maintenance costs, can negate the use of this technology. In fact, this is the case with the Nanisivik Surface Cell.

In order to provide a water cover over tailings in the Surface Cell at the Nanisivik Mine, the existing containment dyke (West Twin Dyke) would need to be raised and an outflow spillway constructed. Given the current elevations of tailings in the Surface Cell (up to 390 m.a.s.l.) and the crest of the dyke (388 m.a.s.l.), it would be necessary to raise the dyke by an estimated six metres in order to provide:

1. A minimum of 1 metre water cover over all tailings.
2. A minimum of 2 metres freeboard on the upstream side of the dyke under the full pond (i.e. flood) condition (assuming a maximum design flood head in the spillway of 1 metre).

Construction of a six metre raise of the dyke and an appropriately sized outflow spillway would likely be possible, although the costs to achieve the required design parameters would likely be very high. Additionally, retention of a surface water pond upstream of the dyke would likely compromise the physical stability of the dyke to the degree where the factor of safety may be marginal and, possibly, below required levels.

Recent stability analyses conducted by BGC Engineering Inc. have shown that the physical stability of the dyke is dependent upon maintaining frozen conditions in the dyke fill and foundation. This is due to the physical properties of the materials used to construct the dyke (i.e. tailings and shale). A water pond on the upstream face of the dyke would act as a heat source that would allow formation of a talik around the pond. This would likely result in: progressive thawing of the dyke and foundation, introduction of pore pressures within the dyke and, as the BGC stability analyses demonstrate, unacceptably low factors of safety.

Modifications to the dyke design to negate the heat sink influence of sustained water retention could possibly be accomplished by installing thermosyphons to extract heat. However, this specific application of thermosyphoning would be unique and, therefore, would introduce larger performance risks than other types of covers. The cumulative costs of dyke raising, installation of thermosyphons (requirement estimated to be in the order of 300+) and increased long term maintenance and monitoring relative to the other options under consideration would be much greater than the costs of other options.

In summary, the primary benefit of a water cover system for the Nanisivik Mine Surface Cell would be a reduction in oxygen diffusion to the tailings. The primary disadvantage of a water cover system would be the likely thawing of the dyke and foundation materials resulting in physical instability of the dyke. Further, a water cover on the Surface Cell would introduce increased requirements for long term monitoring and maintenance associated with the raised, water retaining dyke. Therefore, a water cover system for the Surface Cell is considered unlikely to achieve the project objectives and is given no further consideration.

## 4.2 Geosynthetics

"Dry" cover systems as a closure management and decommissioning option for waste rock and tailings are a common ARD prevention and control technique used at numerous sites around the world. The objectives are to restrict/minimize the influx of water and provide an oxygen diffusion barrier to limit the influx of oxygen.

In many dry cover applications, the question of whether to select geosynthetics over natural materials is a primary consideration. Geosynthetic materials (geotextiles, geomembranes, geonets, and geocomposites) generally offer an economic advantage over natural materials due to their relative light weight and portability, which means they can often be installed in a short construction period using light equipment and this can result in a lower unit cost. At Nanisivik Mine, the costs for mobilization of cover materials to the mine site would be high relative to southern locations and this would reduce the cost advantage of geosynthetics for the Nanisivik site.

An important consideration in the application of some geosynthetics is the life of the geosynthetic material. Some geomembranes have a lifespan limited to the order of 50 to 100 years. These types of covers would not be suitable for the Nanisivik site due to increased costs related to monitoring, maintenance and replacement.

A drawback to the application of a geosynthetic cover on the Surface Cell is the poor thermal insulation properties of geosynthetic materials. An active layer would form in the tailings that could allow oxidation and transport of contaminants. This would be exaggerated by any imperfection or break in the cover that would allow ingress of oxygen and surface water into the tailings.

The installation of a geosynthetic cover is often accompanied by placement of a protective cover of natural material such as sand and gravel. Such a protective cover would be recommended for the Nanisivik Surface Cell in order to protect the cover from damage due to weather/frost action, wildlife or human activities. This would be an important consideration for the Nanisivik Surface Cell application because of the risk of oxidation within the active layer of the tailings if the integrity of the cover were to be compromised.

In summary, the primary benefit of a geosynthetic cover for the Surface Cell would be ease of installation. The primary disadvantage of a geosynthetic cover would be the increased environmental risk related to poor thermal insulation properties and high mobilization costs. This, combined with the potential for tearing, breaking or otherwise compromising the integrity of the cover, introduces a performance risk that is not present for water cover or cover with natural materials. A thin protective cover of natural material would be recommended that would further negate the cost effectiveness of geosynthetic.

A geosynthetic cover system for the Surface Cell is considered unlikely to achieve the project objectives and is given no further consideration.

## 4.3 Natural Materials

A review of local natural materials identified potential cover materials with physical properties appropriate for use as a reclamation cover over the Surface Cell. The natural materials identified provide thermal insulating protection, oxygen diffusion characteristics and durability, which are essential requirements for achieving the reclamation objectives. The materials provide additional reclamation benefits through neutralization potential and light colouration to reflect solar radiation and, thereby, reduce heat absorption.

In continuous permafrost areas, the active layer depth can range from several centimetres to several metres depending on the thermal insulating properties of the ground cover. Generally, fine grained materials or organic type deposits show the least amount of annual thaw depth. Therefore, the investigation of natural materials focused on finer grained local materials because of their generally advantageous thermal properties relative to coarse materials. Each of the materials that were investigated is briefly described below and evaluated for use as a potential reclamation cover material.

### 4.3.1 Marine Silty Clay

A source for this material exists near the Nanisivik beach area (east and west of the dock). Access to the material and “workability” are restricted by the location and fine grained nature of the material. This fine-grained material can not be worked/ripped in the freezing periods because of the high moisture content and resulting ice saturation. In the months of thaw, the active layer thawing restricts access to the area and subsequent significant surface scarring caused by heavy equipment operations. The material can be collected in the spring when sublimation has taken place in the first few centimetres and again in the fall after a frozen crust has developed on the ground surface to allow for traffic movement. This material was excluded from further consideration due to its limited availability relative to the volumes required.

### 4.3.2 Glacial Till

Sources for this material are scattered smaller deposits throughout the area. While the till can be worked over a somewhat longer seasonal period than the marine silty clay (i.e. the “melting season”), accumulating the volume required for the entire cover during the desired reclamation period would not be achievable.

### 4.3.3 Twin Lakes Sand and Gravel

The source for this material is a delta between the East and West Twin lakes. This material is a reworked glacial till deposited by local streams. Site experience in handling this material has shown it to be available during the “melting season” window of time. The Twin Lakes sand and gravel would be especially suited for application as an armouring layer on top of a thermal fill layer due to its high durability rating (recrystalized quartzite and dolostone). Accumulating sufficient volume for an armour cap would be achievable. Finally, the material's light colour (tan to reddish) might provide less heat absorption then the darker materials.

### 4.3.4 Airport Sand

This is local sand produced from surface decomposition of sandstone bedrock. The deposit is located two kilometres south of the WTDA alongside the road to the airport. The Airport sand is not suitable for use as the main portion of the tailings cover due to availability limitations. Unlike the well graded sand and gravel, the Airport sand is predominantly fine grained in nature and, therefore, less attractive as a surface armouring material due to its susceptibility to wind erosion.

### 4.3.5 Shale

The most readily available construction material at Nanisivik is derived from the local shale bedrock. The shale is part of the regional carbonate shelf sequence known as the Bylot Supergroup and is described as "fine carbonaceous clastic sediment forming a friable, relatively weak, recessive unit" (Golder 1998). It is this friable nature that enables the material to be worked/ripped throughout the year, making it available for excavation year round. The shale is produced from the borrow areas as a relatively fine grained material absent of boulders, which is of benefit with regards to increased thermal insulation relative to coarser materials. Additionally, the shale is known to break down further during handling and placement activities, which further increases the fines content and their inherent benefits. A further benefit of the shale material is its high carbonate content, which can provide neutralizing potential against the possibility of acid generation in the tailings.

The review of natural materials in the mine area demonstrated that natural materials are locally available that would be appropriate for use as a cover over the tailings in the Surface Cell and that would achieve the project objectives.

### 4.3.6 Preferred Cover Type

The review of three types of cover systems (water cover, dry cover with geosynthetic material and dry cover with natural material) indicates that a dry cover comprised of natural materials is the most appropriate application for covering tailings in the Nanisivik Mine Surface Cell.

The cover will make use of the beneficial properties of two locally available materials: shale and Twin Lakes sand and gravel. The shale will be used as the base layer of the cover, which takes advantage its availability, grain size and thermal properties. The sand and gravel will form the top, thinner layer of the cover (cap), which takes advantage of its durability and solar reflection capability.

# 5. Cover Design Considerations

## 5.1 Geotechnical Considerations

The following geotechnical considerations were considered in selecting natural cover materials (shale and Twin Lakes sand and gravel):

1. Source/Availability.
2. Permeability.
3. Durability.
4. Slope Stability.

### 5.1.1 Source/Availability

It is likely that the shale material for the thermal fill layer of the cover will come from the four currently permitted borrow areas: East Twin Lake, Mount Fuji, West Twin and Area 14. The grain size specification will be comparable to the design criteria used for the West Twin dyke and the test cells: $D_{50}$ averaging $^{1}/_{4}$ to $^{3}/_{8}$ inch (Terratech 1993). The well-graded shale would be appropriate as a reclamation cover material from a permeability (low) and thermal (insulation) perspective but it would be the material most susceptible to erosion. The indurated sand and gravel from the West Twin delta area would be appropriate as an armour layer, providing better durability, slope stability and erosion properties relative to the shale. Golder Associates (1998) determined the grain size for a sample of the Twin Lakes sand and gravel to have a $D_{50}$ of 19.0 mm (¾ inch).

### 5.1.2 Permeability

In warmer climates (Southern Canada) an engineered cover is required to be constructed of low permeability material in order to prevent leachate generation from infiltration of precipitation (in other words, promote surface runoff). The permeability of the final cover must typically meet regulatory requirements. However, the geothermal regime at Nanisivik provides the opportunity to use a permeable insulating cover, which will keep the waste in a frozen state. Infiltration into the cover material will increase the ice and water saturation level, which will result in a reduction in oxygen diffusion and prevention of the transport of contaminants.

### 5.1.3 Durability

Golder Associates were contracted in 1998 to evaluate the durability of the proposed cover materials. The report entitled “Geotechnical Assessment Of Cover Materials For West Twin Disposal” evaluated the geotechnical durability of the shale from two of the proposed borrow areas known locally as the “Mount Fuji” and “East Twin Lake” quarries. The proposed armouring material, known locally as “Twin Lakes Sand and Gravel”, was also evaluated. Samples of the materials were collected and sent to Golder’s laboratory in Whitby, Ontario where sieve analysis, relative absorption, bulk specific gravity, Los

Angeles abrasion, slake durability index, freeze/thaw durability and petrographic analysis were conducted. A description of the tests as well as a tabular summary and relative comparison as excerpted from the Golder report are provided below.

**Sieve Analysis**
Sieve analyses on all three materials were conducted in accordance with ASTM C 136. The purpose of this test is to determine the relative proportion of various particles sizes in the soil, which serve as a starting point for the description of the engineering properties of soil masses. The soil sample is passed through a series of standard test sieves having successfully smaller mesh sizes. The weight of the soil retained in each sieve is determined and the cumulative percentage by weight passing each sieve is calculated.

**Relative Absorption**
Relative absorption tests were conducted in accordance with ASTM C 127-88. Absorption of water is partially responsible for rock deterioration, and the test is useful in evaluating the weathering vulnerability of rock. Soil samples are oven dried for 48 hours in a ventilated oven at a temperature of 60 ± 2° C and then immersed in water for 48 hours at 20 ± 5° C. The difference in weight is calculated as a percentage of absorption.

**Bulk Specific Gravity**
Bulk specific gravity tests were conducted in accordance with ASTM C 127-88. The specific gravity of a rock is dependent upon the constituent minerals that make up the petrology of that rock type. Similar test procedures are used as for the absorption test except a basket is used to determine the total volume of the sample.

**Los Angeles Abrasion**
Los Angeles Abrasion tests were conducted in accordance with ASTM C 131-89. The purpose of the test is to determine the resistance of rock to abrasion and battering and hence, test both the intact strength and micro-structural features of the sample. The test consists of subjecting the sample to abrading and grinding action in a rotating steel drum containing specified number of steel spheres. The sample is sieved to measure the degradation as percent loss.

**Slake Durability Index**
Slake Durability Index (two cycles) were conducted on the two shale samples in accordance with ASTM D 4644-87. The test is used to estimate qualitative durability of weak “shaley” rocks in the service environment. The test method consists of measuring the dry mass of shale pieces on a 2 mm (No. 10) sieve after two cycles of oven drying and 10 min of soaking in water with a standard tumbling and abrasion action.

**Freeze/Thaw Durability**
Freeze thaw durability tests (25 cycles) were conducted in accordance with ASTM D5312-92. The purpose of the test is to determine the effects of freezing and thawing action on the individual pieces of rock, in order to assess the resistance of the rock to deterioration.

Weathering effects of cold climate are simulated by subjecting the sample to 25 cycles of freeze/thaw in a standard chamber. Five subsamples are actually tested for each sample type.

**Petrographic Analysis**

Petrographic analysis was conducted on the Twin Lake sand and gravel sample in accordance with ASTM C 295. The purpose of the tests is to determine the composition and homogeneity of samples with emphasis on flaws.

**Discussion of Results**

The proposed engineered cover will use shale as the thermal insulation while the sand and gravel will be used for final capping to provide both armouring/erosion protection and light/heat deflection due to its lighter coloration. In order to assign some relativity to the results obtained from the above mentioned tests, it is helpful to compare them to typical or expected criteria for similar materials. More specifically, as it is the durability of the materials that is being evaluated, published literature on armour/rip-rap has been used to provide guidance on some of the relevant parameters. The two papers reviewed were from the ASTM publication on Rock for Erosion Control (Farar 1993; and Lutton and Wong 1993). Table 1 summarizes the testing results and the comparison.

**Table 1: Summary of Test Results and Comparison to Armour Criteria**

| PARAMETERS | SAMPLE A (Mt. Fuji Shale) | SAMPLE B (East Twin Lake Shale) | SAMPLE C (Twin Lakes Sand & Gravel) | Typically Acceptable[1] | Typically Acceptable[2] |
|---|---|---|---|---|---|
| Grain Size ( $D_{50}$) | 18.0 mm | 9.0 mm | 19.0 | n/a | n/a |
| Absorption – maximum (%) | 2.19 | 2.58 | 1.18 | <2 | 2 - 6 |
| Bulk Specific Gravity (saturated surface dry) $Mg/m^3$ | 2.651 | 2.616 | 2.651 | >2.6 | 2.24 - 2.64 |
| Los Angeles Abrasion (% loss) | 34.0 | 32.5 | 29.5 | <10 | 40-60 |
| Slake Durability Index (% loss) | 98.8 (Type I) | 98.3 (Type I) | n/a | not provided | >90 |
| Freeze Thaw (% loss) 25 cycles | 19.7 (6.1) | 2.3 | 0.1 | <25 @ 25 Cycles | 10 - 14 (16-25 Cycles) |
| Petrographic Analysis | n/a | n/a | n/a | n/a | n/a |

Notes: 1) The typical acceptable values from Farar 1993.
2) The typical acceptable values from Lutton and Wong 1993.
n/a means not applicable.

The tabular data indicates that Twin Lake sand and gravel is a relatively competent material for capping and erosion protection. The shale samples have higher abrasion and freeze-thaw losses than the Twin Lake sand and gravel and these materials were not recommended for capping and erosion protection. The shale could be used to provide thermal insulation for the underlying frozen tailings and to restrict infiltration of water/oxygen into the subsurface.

**Slope Stability**

The surface tailings deposit is relatively flat and currently has a slope in the range of 20H:1V (3°) to 30H:1V (2°). The shale and the Twin Lakes sand and gravel would be expected to have frictional values in the range of 20 to 30° and 25 to 33°, respectively, dependent upon the fines content. Therefore, the very shallow angle of the cover will not approach the slope angle at which the cover materials would become unstable and slope stability is not given any further consideration.

## 5.2 Geochemical Considerations

The long term chemical stability of the Surface Cell is required to ensure that the concentrations of metals or other contaminants exiting the containment area are negligible and do not pose an environmental risk to the downstream environment. The following topics are important for the design of the tailings cover:

1. Potential acid generation and acid consuming characteristics of tailings and cover material (shale).
2. Rate of oxidation.
3. Transport mechanism.
4. Heat of exothermic reactions.

### 5.2.1 Potential for Acid Generation and Acid Consumption

Acid generation and acid consumption potentials for tailings and shale have been investigated by Lorax Environmental. A report titled “Acid Generation Potential of Tailings and Shale Cover Material” dated September 1999 describes metals analysis, acid base accounting, mineralogical examination, grain size analysis and humidity cell testing. The samples investigated were tailings collected from the WTDA Surface Cell and shale collected from the West Twin Dyke. A second report titled “Acid Generation Potential of Soil, Waste Rock and Shale” dated April 2001 presents acid base accounting of additional samples of tailings from the WTDA Surface Cell (3), shale from the West Twin Dyke (7), shale from the East Twin Lakes borrow area (10), shale from the Mt. Fuji borrow area (10) and shale from the Area14 borrow area (11).

The determinations of total metals in tailings were: iron (25.2%), zinc (2,610 ppm), lead (406 ppm), cadmium (4.5 ppm) and silver (6 ppm), which were greater than metals in shale and typical concentrations in the earth’s crust.

The acid base accounting analyses confirmed that the tailings are potentially acid generating. The tailings samples contained high concentrations of total sulphur (39.5 to 48.0%) of which most was in the form of sulphides (39.3 to 45.5%). The tailings samples contained some neutralizing potential (79 to 237 kg$CaCO_3$/t) that was primarily in the form of carbonates (72 to 232 kg$CaCO_3$/t). The resulting net neutralization potential for tailings was negative (–997 to –1419 kg$CaCO_3$/t) and the resulting NP/AP ratio was much less than one for all samples (0.05 to 0.19), which demonstrates that their classification as potentially acid generating.

The acid base accounting analyses confirmed that the shale is acid consuming. The shale samples contained low concentrations of total sulphur (0.11 to 2.34%) of which most was in the form of sulphides (0.09 to 2.10%). The shale samples contained large neutralizing potential (315 to 600 kg$CaCO_3$/t) that was primarily in the form of carbonates (224 to 593 kg$CaCO_3$/t). The resulting net neutralization potential for tailings was large and positive (+373 kg$CaCO_3$/t) and the resulting NP/AP ratio was much generally greater than one (4.7 to 49.2), which demonstrates their classification as acid consuming.

The mineralogical analysis indicated that sulphides in the tailings sample consisted primarily of pyrite (80%) with trace amounts of marcasite and sphalerite. Calcite (crystallized carbonate) comprised the majority of the remainder of the sample with minor quartz grains. The shale sample consisted primarily (>90%) of carbonate rock that was considered to probably be dolomite. The remainder of the shale sample consisted of bituminous material (2.5%), quartz (2%), microdiorite (1%) and sulphides (0.5%).

Grain size analyses demonstrated that the shale was generally within the size ranges for sand and gravel with approximately 45% finer than 2 mm (i.e. coarse sand and finer) and approximately 90% finer than 6mm (i.e. pebble and finer). The sample of tailings was generally within the size ranges for silt and sand with approximately 81% finer than 0.2 mm (i.e. fine sand and silt) and 100% finer than 2mm (i.e. coarse sand and finer).

Humidity cell tests were conducted for 35/37 weeks for one sample each of tailings/shale. The tests were run at 20°C for 26/28 weeks and then at 2°C for the remainder of the test to determine the effect of colder temperatures. The primary observations of the tests are as follows:

1. Leachate remained neutral (pH>7.5) throughout the test for both samples.
2. Sulphate production rates from the tailings sample were generally steady throughout the test but became reduced by approximately 50% at the time of switching to the colder temperature; the calculated rate of carbonate depletion did not vary with temperature.
3. Sulphate production rates from the shale generally decreased throughout the test and were not clearly affected by the decrease in temperature; the calculated rate of carbonate depletion increased slightly throughout the test and was not clearly affected by the reduction in temperature.
4. Calcium and magnesium were released at rates of at least two orders of magnitude greater than other metals in both the tailings and the shale sample.
5. Zinc was released at the greatest rate from tailings sample, which was approximately 2 orders of magnitude greater than other heavy metals.

The general conclusions of the humidity cell tests were:

1. The tailings sample was confirmed to be potentially acid generating (neutralization depletion rate faster than acidity).
2. The shale sample was confirmed to be acid consuming (sulphate depletion faster than neutralization).
3. Zinc is the most mobile metal in the tailings.
4. Both samples were confirmed to have neutralizing potential present primarily in the form of carbonates.

### 5.2.2 Rate of Oxidation

Given that the tailings are confirmed to be potentially acid generating, the rate of oxidation is an important consideration. The rate of oxidation in Nanisivik tailings will be controlled by two key factors: temperature and oxygen availability.

A common reference regarding sulphide oxidation in the north is the MEND report "Acid Mine Drainage in Permafrost Regions: Issues, Control Strategies and Research Requirements" by Dawson and Morin, 1996. This text demonstrates that the rate of sulphide oxidation decreases at low temperatures but may not be eliminated completely at freezing temperatures. This text also confirms that the cold arctic climate substantially limits the rate of oxidation by maintaining frozen conditions through most of the year. This is especially applicable to the Nanisivik site because of the extremely cold daily temperatures (average –15 degrees C) at the high latitude of the minesite (approximately 73 degrees north).

The site specific effects of temperature on the rate of sulphide oxidation in Nanisivik tailings were measured by Dr. Bo Elberling of the University of Copenhagen in 1998 as part of a multi-year research program. The tests were conducted on columns loaded with undisturbed tailings. One of the test columns consisted of older, well-drained tailings from the Surface Cell. The measurements from that column confirmed that the rate of oxidation decreased with decreasing temperature. At 2 degrees C, the rate of oxidation was reduced by a factor of 30% relative to the rate at 20 degrees C. Oxidation was observed to continue at a decreasing rate to as cold as zero degrees C. Although the temperature at which oxidation would cease completely was not determined and could not be accurately extrapolated.

Dr. Elberling's testwork also demonstrated that the sulphide oxidation rate was controlled by oxygen diffusivity and not by reaction kinetics. The testwork went on to demonstrate that application of a saturated diffusive barrier layer would reduce oxygen diffusivity and, therefore, the oxidation rate by several orders of magnitude. This is analogous to the proposed application of shale on the Surface Cell and the anticipated frozen, saturated zone at the base of the cover. The frozen, saturated zone will provide the same beneficial effect of a water saturated diffusive barrier layer due to the reduced oxygen diffusivity in ice relative to air.

### 5.2.3 Transport Mechanism

The MEND study referenced above from Dawson and Morin, 1996, confirms that the cold arctic climate substantially restricts the primary contaminant transport mechanism by maintaining frozen conditions through most of the year when surface water is immobile.

This is especially applicable to the Nanisivik site because of the extremely cold temperatures (average –15°C) and the high latitude of the minesite. In the winter season, the ground (including the tailings cover) at Nanisivik will be frozen to the surface of the cover and, therefore, transport of contaminants will be prevented.

The Nanisivik cover is designed to maintain frozen conditions within the tailings cover materials even during the short summer season. It is anticipated that an ice layer will form at the base of the active layer in the cover, as a result of the recurring infiltration of snow melt, runoff and precipitation water. The ice layer will prevent the contact of surface run off water with tailings and, therefore, will prevent the transport of contaminants to surface water.

### 5.2.4 Heat of Exothermic Reactions

The exothermic chemical reactions that occur as part of the acid generation process generate heat. Even in the sub-zero temperatures that will exist in the tailings (post reclamation), the reactions may continue at slow rates and may generate a small amount of heat on a local or even microscopic level. It is likely that this heat of reaction will be relatively small and will dissipate quickly with respect to the energy required to melt pore ice and the surrounding tailings particles.

### 5.2.5 Summary of Geochemical Considerations

A review of geochemical considerations provides the following conclusions:

1. Nanisivik tailings are confirmed to be potentially acid generating.
2. The proposed cover material (shale) is confirmed to be acid consuming.
3. The cover design objective is to maintain freezing conditions (less than zero degrees C) in the base of the cover material.
4. The freezing conditions will substantially reduce the rate of oxidation by maintaining cold temperatures and by providing an oxygen diffusion barrier layer (frozen saturated zone at the base of the shale).
5. The freezing conditions will prevent the transport of contaminants to surface water by maintaining a frozen, saturated zone at the base of the cover materials.
6. The heat generated by exothermic reactions within the frozen tailings is anticipated to be small relative to the heat required to melt ice and thaw the ground.

# 6. Geothermal Assessment

In order to estimate the active layer thickness both now and into the future, a geothermal assessment was completed and is described in the following sections.

## 6.1 On-Site Field Tests (CanZinco Ltd.)

A critical component of geothermal modelling is the calibration of the model based on field observations. MEND recommends direct measurement of field performance as the best method for demonstrating that a cover system will perform as designed. Part of Nanisivik's reclamation planning process has included a field program that was initiated in 1990 through consultation with Terratech (a division of SNC).

Terratech was contracted to supervise and report on the drilling of eight boreholes to clarify permafrost aggradation processes that were observed in man made fills in the Nanisivik area. The resultant report "Geotechnical Investigation of Permafrost Aggradation – Nanisivik Mine" showed that permafrost aggradation had occurred in tailings deposited in West Twin lake as foundations for internal causeways. Both drill core logging and thermocouple installations confirmed that permafrost had aggraded into the tailings areas after several years, to depths exceeding 12 metres (despite the presence of the lake as a heat sink).

It was also pointed out in the discussion section of the report that where frozen ground included a high ice content, the time to thaw such material is much greater than that of a free draining gravel or mine waste. Generally fine grained materials retain a higher moisture content and when frozen, much more heat is required to thaw than a relatively dry material. (The *specific heat* of water is 1 calorie to raise 1 gram by $1^{o}$C, the *latent heat* required to melt 1 gram of ice is 79.7 calories.)

This information indicated that it would be possible to manipulate the local permafrost table and induce aggradation into a cover material thereby protecting the underlying tailings from thaw. Further fieldwork to qualify the natural freeze/thaw process and potential anthropogenic influences were planned, carried out, and are described in the following sections.

### 6.1.1 Test Cell Construction

Under the continued supervision and direction of Terratech, field testing of various tailings cover materials began in 1991. Five "test pads" were constructed in the WTDA, along the north shore of the West Twin reservoir. The test pads were place on exposed tailings having a surface elevation of 370 to 371 (m.a.s.l.). The locations of the test pads are shown on Figure 1.

In the fall of 1991, The first test pad (No.1) was built entirely out of shale. The pad had a surface platform of 30 x 30 m, and the western half of this pad was covered with 5 to 10 cm of "Airport Sand". The pad was constructed without saturation or controlled compaction (other than the compaction supplied by the haulage and placement equipment). This pad had a nominal shale fill thickness of 2 m and would be typical of an area where little or no construction control is applied.

In May 1992, test pad No. 2 was constructed to a height of 1.7 m with saturated and compacted shale. The placement method of the shale was in controlled lifts of 30 cm each. A 0.3 m cap of Twin Lakes sand and gravel covered the 16 x 16 m pad.

In June 1992, test pads Nos. 3, 4 and 5 were constructed; each having a surface dimension of 16 x 16 m.

Test pad No. 3 was built of compacted shale to a height of 1.0 m. This pad was left unfinished until 1995 when it received a further 1.0 m lift of shale.

Test pad No. 4 was constructed of compacted shale with a 0.3 m "sandwich" layer of glacial till to a height of 1.7 metres. A 0.3 m cap layer of Twin lakes sand and gravel completed the 2.0 m thick pad.

Test pad No.5 was constructed similarly to No. 4 with the exception that the sandwich layer was comprised of compacted Airport sand.

piezometers and frost indicators ("frost gauges") were incorporated into each of the test pads as the construction proceeded in 20 to 30 cm compacted lifts. In test pad No. 5 a thermocouple string (NML T4) was installed in a drill hole which was put down after the test pad was completed.

Although water was added to the fill in test cells 3, 4 and 5, saturation could not be obtained because of low air temperatures during the construction period.

A construction report with preliminary results was issued in a 1993 Terratech report - "Geotechnical Test Program – West Twin Test Cells". First year results (1992 data) were expected to be of little value as it was the first thawing season. Results were described in the report and as erratic and inconclusive. However, several notable observations were included:

1. Areas with lighter coloured surface material on test pad 1 experienced approximately 30% less thaw than proximate areas with (darker) shale cover.
2. Susceptibility of the Airport sand to wind erosion was evident from the significant reduction in the sand capped areas after one year.

### 6.1.2 Geothermal Instrumentation

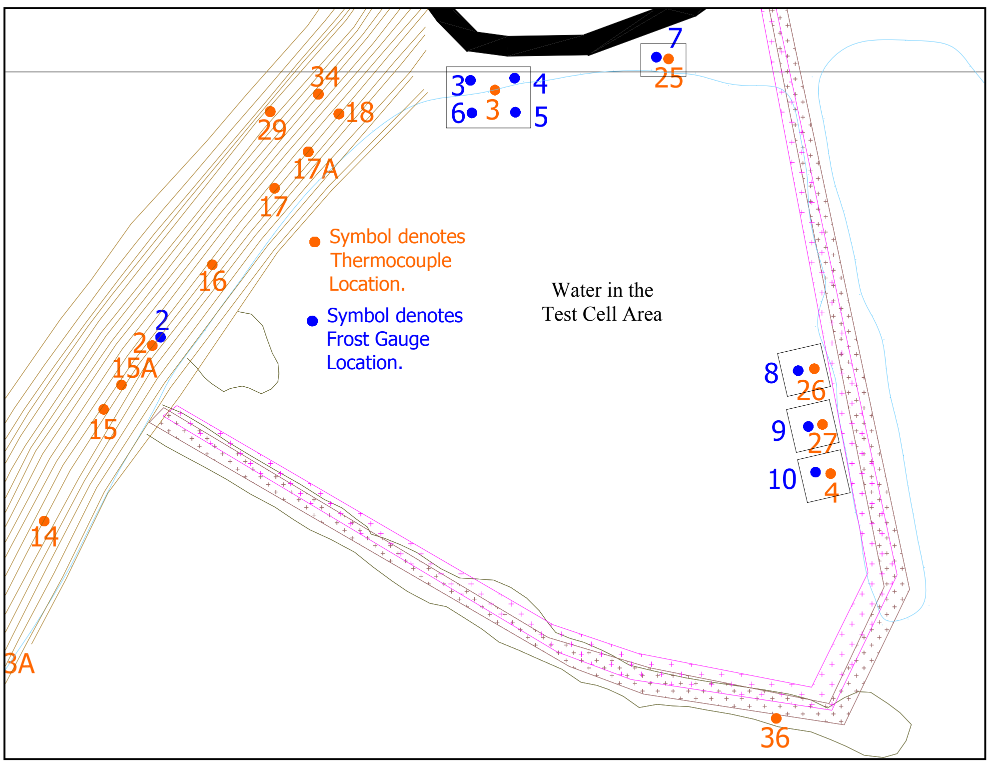
Geothermal monitoring in the mine area was initiated in 1989 with two boreholes drilled in the WTDA. The boreholes were part of Terratech's "Geotechnical Investigation, Proposed Tailings Containment Scheme" (1989) and were drilled through the tailings deposit and terminated in the bedrock beneath the lake. The installation methodology as detailed in the report follows:

*The boreholes were put down with a Diamec 250 diamond drill. They were generally sampled and logged by coring in BQ sizes with some split spoon sampling carried out where unconglomerated material was encountered. The BQ coring technique provided good recovery in all boreholes where permafrost was present, through the use of a suppressed freezing point drilling fluid.*

*Following completion of the boreholes a closed bottom end plastic tube with a 25 mm inside diameter was placed in each borehole, and a thermocouple string was inserted with thermistor spacings generally ranging from 1 to 3 metres. The thermocouple wire used was T-Type 20 gauge wire and the read-out unit* *was a Fluke 2190A digital thermometer. To prevent air convection currents within the plastic tube and to minimize damage to the thermocouple wires by potentially aggressive oxidation reactions, the plastic tube was filled with edible oil.*

Following the successful installation of the first two units, thermocouples were installed at more than 40 locations around the mine. The existing installations are illustrated on Figure 2 and listed in Table 2 (several installations have been abandoned or recovered during continuing mining operations). Installation methodology of the thermistor strings remained consistent with the "prototypes" described above. The principle function of the thermistors was to monitor subsurface temperatures at depths, generally exceeding the active layer (+1.0 m). More precise near surface thermal monitoring was accomplished through the installation of frost gauges.

**Figure 2: Test Cell Detail**




The frost gauges used at Nanisivik are 270 cm lengths of clear tygon tubing with an outside diameter of 20 mm. The tubing is filled with water and "methlyene blue" dye mixture and sealed at both ends. Methlyene blue dye has chemical properties which enable it to be used as an indicator of water solidification (freezing). The blue dye becomes transparent when frozen. The water/methlylene mixture maintains the freezing properties of water but turns clear to indicate frozen conditions. The gauge is inserted into the borehole, inside which is a 25 mm diameter plastic casing (liner). The top 20 centimetres of the gauge remain above ground as the "stick-up".

## Table 2: Thermocouple Installations

| Station | Location | Thermistors | Frequency |
|---|---|---|---|
| T1 | South dyke, chainage 00+75 | 4 | Monthly |
| T2 | North dyke, chainage 03+25 | 6 | Monthly |
| T3 | Test Pad #1 | 4 | Monthly |
| T4 | Test Pad #5 | 8 | Monthly |
| T6 | West Twin Lake - East shore | 2 | Monthly |
| T7 | Area 14 – shale pad | 3 | Monthly |
| T8 | Area 14 – shale pad | 4 | Monthly |
| T9 | 09 South Portal | 6 | Monthly |
| T10 | 09 South Portal | 7 | Monthly |
| T11 | East Adit waste pile | 6 | Monthly |
| T12 | South dyke, chainage 01+30 | 7 | Monthly |
| T13 | South dyke, chainage 01+50 | 6 | Bi-Weekly |
| T14 | South dyke, chainage 02+25 | 7 | Monthly |
| T15 | South dyke, chainage 02+88 | 7 | Monthly |
| T16 | North dyke, chainage 03+75 | 7 | Monthly |
| T17a | North dyke, chainage 04+50 | 7 | Monthly |
| T18 | North dyke, chainage 04+75 | 4 | Monthly |
| T19 | Downstream dyke, chainage 01+25 | 5 | Monthly |
| T20 | Downstream dyke, chainage 03+75 | 5 | Monthly |
| T21 | Surface Cell – 13,730 N, 17,340 E | 4 | Monthly |
| T22 | Southern Delta Fan | 6 | Monthly |
| T23 | Central Delta Fan | 8 | Monthly |
| T24 | Northern Delta Fan | 8 | Monthly |
| T25 | Test Pad #2 | 7 | Monthly |
| T26 | Test Pad #3 | 8 | Monthly |
| T27 | Test Pad #4 | 8 | Monthly |
| T28 | South dyke, chainage 02+25 | 6 | Monthly |
| T29 | North dyke, chainage 04+25 | 7 | Monthly |
| T31 | South dyke, 01+50, 378 m elev. | 5 | Bi-Weekly |
| T32 | South dyke, 01+50, 382 m elev. | 6 | Bi-Weekly |
| T33 | South dyke, 01+50, 386 m elev. | 7 | Bi-Weekly |
| T34 | North dyke, 04+75, 386 m elev. | 6 | Monthly |
| T35 | Upstream @ 01+50 m in Tailings | 8 | Bi-Weekly |
| T36 | Upstream @ 01+50 m in Tailings | 8 | Bi-Weekly |
| T37 | Upstream @ 03+75 m in Tailings | 7 | Monthly |

Frost gauges are read visually. The gauge is removed from the borehole and the frozen (or thawed) areas are manually measured and recorded. Frost gauges have a distinct advantage over thermistor strings, in terms of the detailed monitoring of the active layer. Thermistor strings must have separate thermocouple contacts with dedicated wiring for each depth monitored. While thermistors will provide accurate temperature records, they are generally placed at intervals greater than 0.25 metres. Frost gauges are capable of providing freeze/thaw determinations at increments of 1 – 2 cm. For active layer behaviour this level of detail is more informative.

**Table 3: Frost Gauge Locations**

| Station | Location | Frequency |
|---|---|---|
| F1 | South dyke, chainage 00+75 | Twice weekly during periods of thaw |
| F2 | North dyke, chainage 03+25 | |
| F3 | Test Pad No. 1 | |
| F4 | Test Pad No. 1 | |
| F5 | Test Pad No. 1 | |
| F6 | Test Pad No. 1 | |
| F7 | Test Pad No. 2 | |
| F8 | Test Pad No. 3 | |
| F9 | Test Pad No. 4 | |
| F10 | Test Pad No. 5 | |

Ten frost gauges were installed in boreholes in the WTDA area in 1991/92. The locations of these are listed in Table 3.

### 6.1.3 Field Observations

The frost gauge network was used to monitor the active layer on both the West Twin Dyke and the Test Pad covers. Monitoring consisted of visual readings/measurements twice per week during periods of thaw (typically June through September). Systematic monitoring began in 1993 and continued until 2000.

It should be noted that the data from 1998 – 2000 is not considered in this interpretation because, during these years, tailings were poured in the Test Cell area, in the immediate vicinity of the test pads. Tailings are discharged at +11$^{o}$C and at an approximate rate of 120,000 m$^3$/month (as a relative comparison the test cover volumes range from 500 to 1,800 m$^3$). The tailings volume introduced a heat sink which biased the thermal monitoring.

Data from 1993 to 1997 has been used to assess the performances of the different test covers described in Section 7.3.1. A summary of the maximum annual penetration of thaw is shown in Table 4.

**Table 4: Annual Maximum Thaw**

| (metres below ground level) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Frost Gauge No.** | **Location** | **Thaw depth at installation** | **1993** | **1994** | **1995** | **1996** | **1997** |
| **F1** | South dyke | >2.00 | -1.43 | -1.18 | -1.11 | -1.06 | -1.02 |
| **F2** | North dyke | >2.00 | -1.42 | -1.26 | -1.29 | -1.18 | -1.19 |
| **F3** | Test Pad 1 | >2.00 | -0.99 | -0.82 | -0.73 | -0.73 | -0.73 |
| **F4** | Test Pad 1 | >2.00 | -1.26 | -1.09 | -0.93 | -0.90 | -0.95 |
| **F5** | Test Pad 1 | >2.00 | -2.09 | -1.86 | -1.38 | -1.24 | -1.05 |
| **F6** | Test Pad 1 | >2.00 | -1.66 | -1.29 | -1.08 | -1.03 | -0.97 |
| **F7** | Test Pad 2 | >2.00 | -0.95 | -0.90 | -0.94 | -0.98 | -0.87 |
| **F8*** | Test Pad 3 | >2.00 | * | * | * | -1.27 | -1.24 |
| **F9** | Test Pad 4 | >2.00 | -1.55 | -1.45 | -1.46 | -1.35 | -1.33 |
| **F10** | Test Pad 5 | >2.00 | -1.63 | -1.63 | -1.59 | -1.50 | -1.40 |

*Test Pad 3 remained unfinished until 1995 when the final metre of shale was added.

### Maximum/Minimum Depth of Thaw

The maximum thaw recorded in 1993 (first year monitored after installation) ranged between 0.95 and 1.63 metres below ground level. The best results (minimum thaw) in 1993 occurred in F3 and F7 (Test Pads 1 and 2) with thaws of <1.0 metres.

In 1997 (the last year monitored) the maximum thaw had decreased to a range 0.73 and 1.40 metres. Thaw depths of <1.0 metres were recorded in F3, F4, F6 and F7. Thaw depths of <1.25 metres were recorded on all gauges except F9 and F10. Again the best results occurred in F3 and F7 (Test Pads 1 and 2) with thaw of 0.73 and 0.87 metres respectively.

### Temporal Trends

Temporal trends will be referred to in this document as either "annual" or "life of project". Annual trends refer to behaviour that can be observed over the course of one melting season. Life of project (LOP) trends refer to observations made over the entire construction and monitoring period (1991 – 1997). The graphed data for the frost gauge readings is provided in Appendix A.

In the evaluation of **annual trends**, three distinct thaw behaviours occur:

1. Each melt season begins with a steep migration of permafrost out of the surficial cover layer. During the first few weeks of the 12 to 18 week melting season approximately 80% of the active layer thaw occurs.
2. Following the initial steep frost migration period, the rate of thaw slows to a very gradual scale. Generally less than 20% of the annual thaw occurs during this longest (and warmest) portion of the melt period.
3. As the cold air temperatures return in the fall, there is a very steep frost aggradation period. Generally, from the time the first indication of frost aggradation is observed, until complete freeze-up, is 1 – 3 weeks.

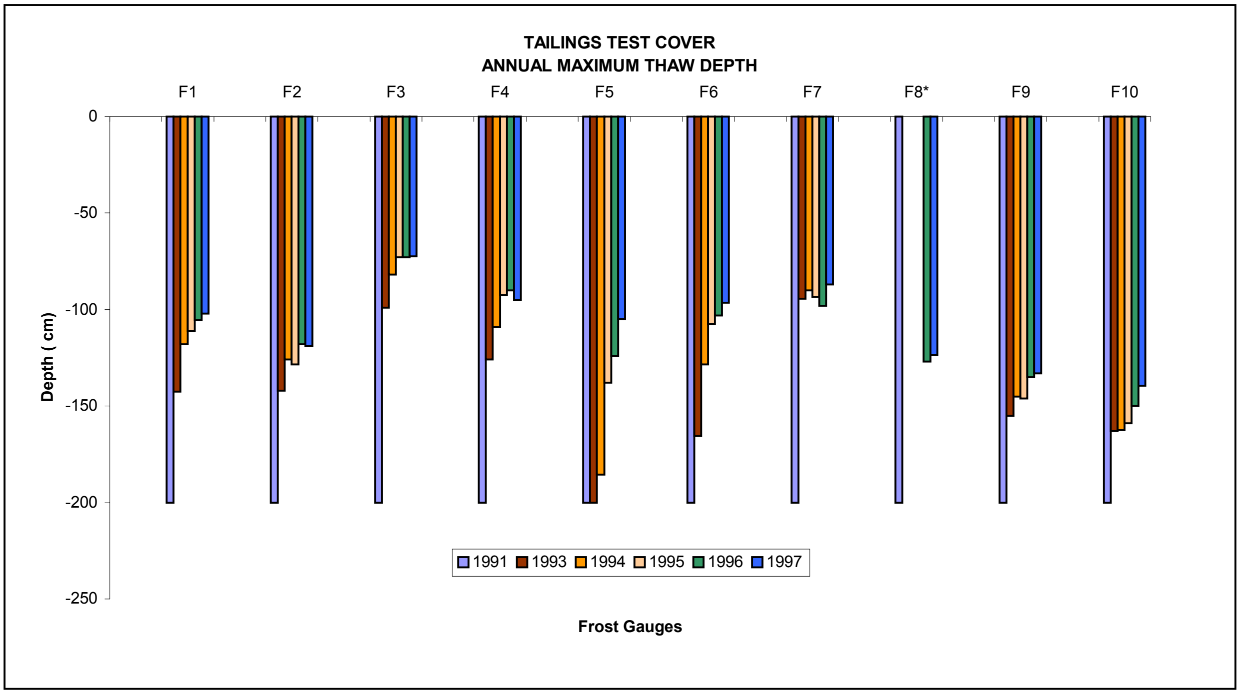
The following **life of project trends** were observed:

1. The depth of thaw for all locations decreased by an average of 28% between the installation date and the first year of readings in 1993 (i.e. the depth of thaw for F1 was 2.00 metres in 1991 and had decreased to 1.43 metres in 1993).
2. The depth of thaw for all locations decreased by an average of 47% between the installation date and the last year of readings in 1997.
3. The maximum depth of thaw, averaged for all locations, continued to decrease by a diminishing percentage each successive year. This is to say that between successive years (i.e. 1991/2 and 1993, 1993 and 1994, 1994 and 1995, etc) depth of thaw decreased by 28%, 11%, 8%, 4%, and 4% respectively.
4. In 8 of the 10 frost gauges the thaw depth was continuing to diminish annually when the program was terminated (as shown in Figure 3).

A direct comparison between pairs of frost gauges in Test Pad 1 was made to evaluate the influence of the water reservoir in the Test Cell as a heat sink. As shown in Figure 2, F5 and F6 were located on the south end of the pad. Results from F3 are compared with results from F6 as both instruments were in the area with the lighter coloured surface material. This comparison shows that F6 (which was closer to the water) thawed an average of 0.40 metres deeper than F3. Similarly, F5 thawed an average of 0.48 metres deeper than F4.

Another direct comparison between pairs of frost gauges in Test Pad 1 was made to evaluate the effects of the lighter coloured surface material. The west half of the surface area of Test Pad 1 (containing F3 and F6) was covered with a 15 cm layer of light coloured material (sand). The results show that the gauges in the area with light coloured surface cover (F3 and F6) experienced an average of 0.26 m less thaw depth than their darker coloured counter parts (F4 and F5).

**Figure 3: Annual Maximum Thaw**

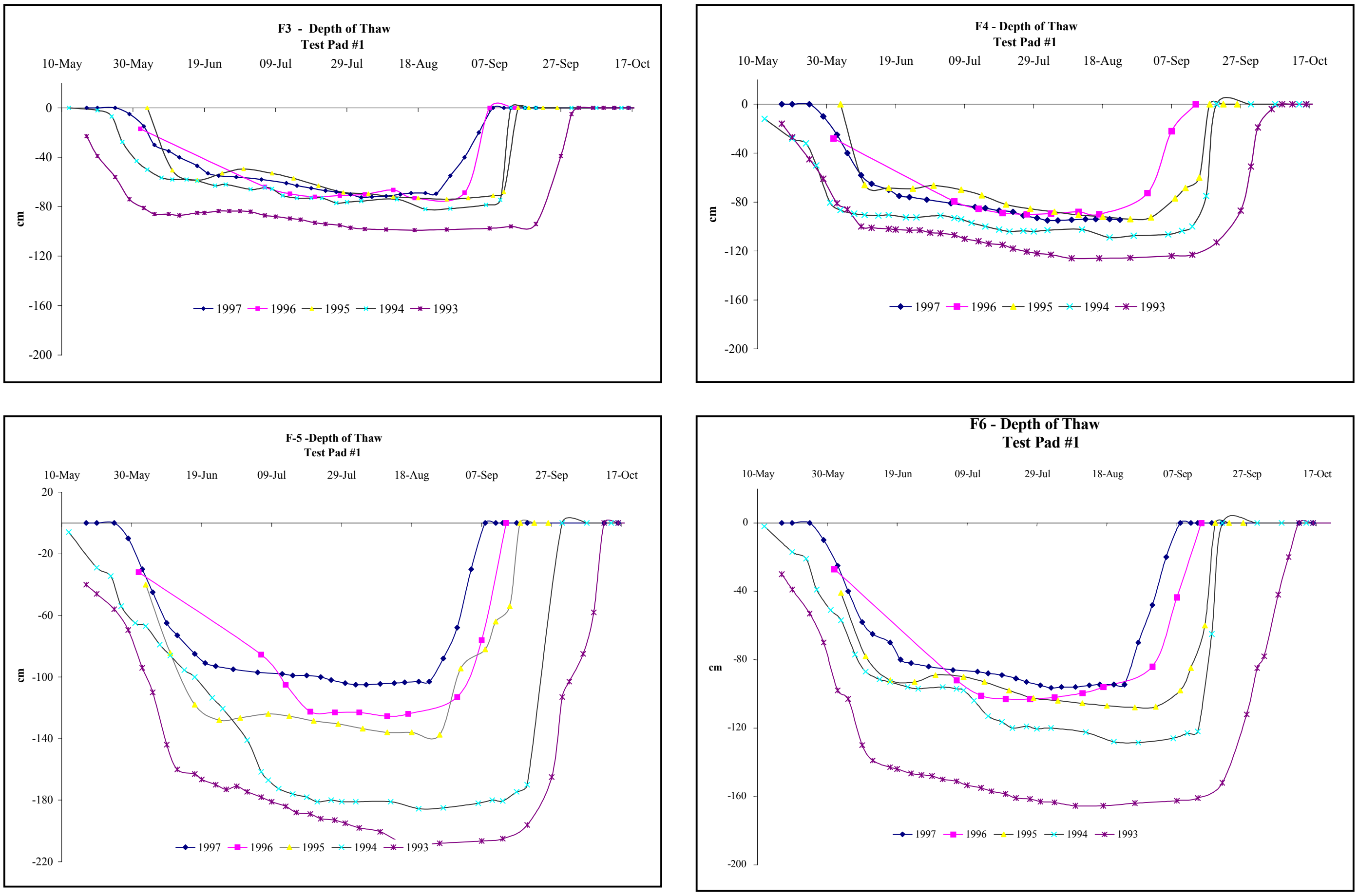



### 6.1.4 Discussion

Active layer thaw results presented above meet with the expected results of the geotechnical test program initiated in 1990. General observations in the Nanisivik area at that time noted that, in areas of fine-grained materials, the active layer was often less than 1 metre. Terratech (1993) reported that natural processes (i.e. runoff, precipitation) provide a high degree of saturation at the approximate base of the active layer, and that finer grained materials have a higher degree of saturation than coarse materials. Further, the ice content at the base of the active layer is usually greater than the minimum amount of moisture which would completely saturate the overburden forming a diffusive barrier to air and water infiltration. With this in mind the test covers were constructed with local fine grained materials (i.e. shale) and were monitored as natural processes (snow melt and run-off) annually increased the ice zone.

The annual trends reported above support the expected results. The steep downward trend of thaw in the early part of the melt season can be seen to reach a depth after which the rate is abruptly slowed. If this observation were explained by the heat diffusive properties of the shale alone, one would expect the point (depth) at which the thaw rate changes (slows), to remain approximately the same each year. However, as can be seen in the graphs, the thaw depth for the initial steep thaw period, generally diminishes each year (i.e. thaw depth becomes shallower). This becomes more apparent on examination of the graphs in Appendix 1 and perhaps most dramatically illustrated in the F3, F4, F5 and F6 graphs below (Figure 3).

## Figure 4: Frost Gauges, Depth of Thaw




This recurring trend can be further supported by the thermodynamic principles of *specific heat* and *latent heat* as defined below:

*The heat capacity or the measure of the amount of heat required to raise the temperature of a unit mass of a substance one degree Celsius is known as specific heat. The specific heat of water is 1 calorie, because 1 calorie of heat causes a rise of 1°C in 1 gram of water.*

*The amount of heat required to produce a change of phase (i.e. solid to liquid) is called latent heat. The latent heat required to melt 1 gram of ice is 79.7 calories.*

These principles would enforce the rapid thaw behaviour in the early melt period and the sudden retarding of the rate when thaw reaches the ice saturated zone at the base of the active layer.

Another significant observation noted during the monitoring period was the influence of the test cell water reservoir as a heat sink. It has already been pointed out, as one of the **life of project** trends discussed above, that the water reservoir had a measurable effect on the frost indicators in Test Pad 1. In addition, the relatively deeper thaw results noted in Test Pads 3, 4 and 5 are believed to be attributed to this same influence. As can be seen in Figure 1, pads 3, 4 and 5 were built on a causeway projecting into the reservoir, while pads 1 and 2 were built on the original shoreline of the lake and are “shore fast”. This orientation can also be observed in the photograph shown as Figure 5. In terms of relative thaw, the averaged results from pads 3, 4 and 5 at the end of the program (1997) reached 0.41 metres deeper than the averaged results from pads 1 and 2. It is postulated that there may have been some amount of influence from the Test Cell water reservoir on all the test pads due to their proximity. Should this be the case we would expect the performance of a cover on the Surface Cell will be somewhat better.

**Figure 5: Test Cell Area**

There were no noticeable correlations between construction methodology and cover performance. In fact Test Pad 1, which had no construction controls (i.e. compaction, saturation or controlled lifts) showed the best results with a depth of thaw of 0.73 metres recorded in F3.

Finally, it should be noted that at the end of the observation period (1997) the depth of thaw had not yet reached stability and had continued to lessen (improve) annually, albeit by a diminishing annual improvement as noted in the **life of project** trends. This imparts an additional level of conservatism to the cover depth proposal that is based on the 1997 results.

### 6.1.5 Summary of Field Observations

The proposal for the Surface Cell cover is based largely on the performance observed from Test Pad 1, which is summarized as follows:

1. Test Pad 1 was constructed of a nominal thickness of shale fill without controlled saturation or compaction.
2. Thaw depth in the 4 frost gauges in this pad (F3- F6) showed that the maximum depths of thaw improved continuously between 1991 and 1997 and were continuing to improve, albeit slowly, at the termination of the monitoring period. This is attributed to the gradual build-up of the ice layer at the bottom of the active zone.
3. Results in 1997 (end of program) showed thaw depths at each of the instruments measuring 0.73, 0.95, 1.05 and 0.97 metres respectively (or an average value of 0.92 metres).
4. Direct comparison of the two pairs of frost gauges in Test Pad 1 (F3 vs. F4; and F5 vs. F6) indicates that areas with light surface coloured material (F3 and F6) experienced an average of 0.26 m less thaw depth than their darker coloured counter parts (F4 and F5).

This information is included with the geothermal modeling and the climate change considerations and is used as a basis to develop the details of the final cover design. This provides for a level of conservatism because thaw conditions were continuing to improve at the end of the test program and the influence of water as a heat sink will not be a factor in the Surface Cell as it was for the test cells.

## 6.2 Geothermal Model (BGC Engineering Inc.)

A geothermal modeling assessment was conducted by BGC Engineering Inc. to evaluate the potential variations in the depth of active layer thaw, as opposed to an assessment of potential variations in subsurface temperature regimes. The results of this model, calibrated to site test pad data, were then extended for potential global warming scenarios over the next century. Comments on the expected warming amounts for the Nanisivik site are provided in BGC (2002). The modeling reviewed herein serves as the preliminary basis for the required cover thickness for the closure phase of this facility.

The results of geothermal analyses are based on assumed parameters correlated between some site specific measurements and published values from various references. A calibration of the geothermal model, based on extensive site-specific measurements, has been made. In addition to the input assumptions, global warming estimates have been made for the next 100 years, not accounting for any potential variations in precipitation and/or associated climatic conditions.

### 6.2.1 1D Geothermal Software

Geothermal analyses were undertaken using the commercially available, explicit finite difference program, THERM1 written by Dr. Derick Nixon. This program solves one-dimensional heat transfer problems involving freezing and thawing, including the latent heat of fusion. A power law function represents the relationship between unfrozen water content and temperature in each soil / rock unit. The program requires a variety of standard physical properties as input, but it is versatile in accommodating several alternative combinations of meteoric input. In the analyses reported herein, mean monthly air temperatures, solar radiation, wind velocities, and snow cover thicknesses are specified and a surface energy balance routine was used to calculate the ground and snow surface temperatures.

Input for THERM1 can be categorized as either meteoric or physical. The values used for the analyses are described in detail below.

### 6.2.2 Meteoric Input

Climate data was obtained from the Nanisivik Airport AES site, along with climatic data modified from the Canadian Climate Normals for Resolute, located on Cornwallis Island, approximately 350 km to the northwest. Where available, site-specific data (temperature, precipitation) were used. Where applicable, the climate data were modified based on the calibration geothermal modeling undertaken. The climate data are summarized below in Table 1.

**Table 5 - Summary of Climate Data Used for Model**

| Month | Temperature[1] (°C) | Wind Speed[2] (km/hr) | Snow Cover[3] (cm) | Solar Radiation[4] (W/m°C) |
|---|---|---|---|---|
| January | -29.4 | 23.1 | 18.4 | 0.0 |
| February | -30.2 | 23.1 | 19.1 | 7.7 |
| March | -27.7 | 22.0 | 20.6 | 63.6 |
| April | -19.9 | 22.0 | 22.1 | 178.9 |
| May | -10.5 | 23.1 | 22.5 | 280.1 |
| June | -0.3 | 23.1 | 12.8 | 302.7 |
| July | 4.9 | 22.0 | 1.5 | 227.1 |
| August | 1.4 | 23.1 | 0.4 | 134.1 |
| September | -5.7 | 26.4 | 4.1 | 63.4 |
| October | -14.8 | 25.3 | 11.3 | 15.5 |
| November | -22.8 | 24.2 | 15.4 | 0.8 |
| December | -26.6 | 23.1 | 16.9 | 0.0 |

Note [1]: from Nanisivik Airport AES over the period 1976 to 2001.
Note [2]: from Resolute Airport AES station.
Note [3]: modified from Resolute Airport AES Station.
Note [4]: modified from Resolute Airport AES Station plus 5% increase.

The first day and last day of snow cover were assumed to be August 25 and June 25, respectively. These dates are based on the mean monthly temperature data.

### 6.2.3 Physical Properties

**Snow**

A snow cover thermal conductivity of 0.30 W/m°C was used. This corresponds with a snow pack density representative of average conditions between fresh snow and wind-toughened snow (Johnston, 1981). A snow cover albedo of 0.75 was used (Savigny *et. al.*, 1995).

**Soil / Rock**

Relationships between the thermal conductivity of a soil and its porosity and degree of saturation are reported by Kersten (1949) and others, mainly on the basis of experimental data. The thermal conductivity of ice is much higher than that of water; hence the thermal conductivity of a frozen soil generally exceeds it unfrozen equivalent. As soil porosity approaches 100%, frozen and unfrozen thermal conductivity values in a saturated system approach those of ice and water, respectively. Conversely, as the porosity of a soil approaches zero, frozen and unfrozen thermal conductivities converge on average values related to mineral constitutes.

In addition, Meldrum *et. al.* (2001) provides thermal conductivity measurements for sulphide-rich tailings that have been deposited in Rankin Inlet. Additional reference sources were also consulted for some of the parameters selected.

Soil thermal conductivities and other soil properties for the soil layers used in the geothermal analyses are listed in Table 2.

Albedo is a parameter in the geothermal model and it is defined as the ratio of solar radiation that is reflected back by a material to the atmosphere. Numerous references provide a range of possible values for soil albedo factors as partially summarized below:

1. Bare black soil – 0.07.
2. Open soil cover with low shrubs – 0.08 to 0.23.
3. "Light" soil albedo – 0.11 to 0.15.

For the model, a ground surface albedo of 0.10 was used in the analyses (Savigny et. al., 1995).

**Unfrozen Water Content**

Soils that are below 0°C still contain some portion of unfrozen water within their pore space. The power law relation below represents the relationship between unfrozen water content and temperature in each soil and rock unit.

$w_u = A(-T)^B / w_{tot}$

where:

$w_u$ = unfrozen water content (fraction of total water content);

A = gravimetric unfrozen water content at -1°C;

B = exponent in power law function;

T = temperature in °C (negative); and,

$w_{tot}$ = total water content.

Values of the A and B parameter used the geothermal analyses are shown in Table 2 that come from Nixon, 1992:

**Table 6 - Summary of Soil / Rock Parameters**

| Unit Description | Thermal Conductivity | | A | B | Moisture Content (%) | Dry Density (Mg/m³) |
|---|---|---|---|---|---|---|
| | Thawed (W/m°C) | Frozen (W/m°C) | | | | |
| Sand and Gravel | 2.19 | 2.38 | 0.05 | -0.5 | 9 | 1.70 |
| Shale Cover | 2.46 | 2.89 | 0.05 | -0.4 | 20 | 1.74 |
| Tailings | 1.80* | 3.00* | 0.10 | -0.5 | 22 | 1.56 |
| Shale Bedrock | 1.72 | 1.98 | 0.05 | -0.3 | 15 | 2.10 |

*Based on Meldrum *et al.*, 2001.

In addition, a nominal freezing point depression of –0.05°C was assumed as the phase change boundary within the soil pore space.

**Geothermal Gradient**

A geothermal gradient of 0.0396°C/m was used based on measurements reported by Brown (1966).

### 6.2.4 Model Calibration - Test Pad #1

The one-dimensional geothermal model was calibrated to site conditions using data collected from Test Pad #1, which was constructed in late 1991. This test pad consists of nominally 2.0 m of truck compacted shale gravel overlying 1.8 m of saturated, frozen tailings over a 30 m by 30 m area. There was no moisture control on the shale gravel when placed. Although a 2.0 m shale gravel was indicated, a 2.5 m thickness was noted in the borehole logs for thermocouple T3. Consequently, a thickness of 2.5 m was used for the shale gravel cover in the calibration model.

The western half of this test pad was covered with 0.05 to 0.10 m of light coloured “Airport Sand” to test the effect of albedo change on the geothermal regime. In comparing the various frost gauge readings, there appears to be a significant difference (approximately 0.25 m) in the thaw depths recorded for F3 (under light coloured cover) versus F4 (under shale cover). Thaw depth differences between F5 and F6 are not so apparent. For the purposes of calibration, no cover layer of sand and gravel was used.

The frost gauge data were analyzed, and any erroneous or unstable data were discarded. Based on the stable data, an active layer of 0.72 to 1.03 m was noted. The data from the thermocouples are considered unsuitable for the purposes of calibration (these instruments are only accurate +/-1°C) and were consequently ignored.

An active layer of 0.90 m was predicted using the geothermal model created for the test pad stratigraphy. This is in the range of the active layer thicknesses measured in the frost gauges in this test pad.

### 6.2.5 Cover Model - Base Case

Based on the calibration model of Test Pad #1, a predicted cover model was generated to evaluate the effectiveness of a shale cover to maintain frozen conditions in the underlying tailings. The model stratigraphy consists of 1.25 m of shale gravel overlying 17 m of tailings, which in turn overlies 11.75 m of shale bedrock. The model was run for a 10-year period under average climate conditions to ensure model stability.

An active layer thickness of approximately 0.89 m was predicted. This geothermal regime is shown in Figure 6.

If the albedo value of the surface was changed to 0.15 from 0.1 to reflect a lighter-coloured surface, then the depth of thaw reduced by 6 cm to 0.83 m. This result is based on the output of the geothermal model and may not be reflected in actuality, given the potential angle of inclination of the sun at this site.

A 0.25 m thick protective cap of Twin Lakes sand and gravel was then added to the model. The surface albedo was not changed from the 0.1 value due to the limited effect on the calibration run noted earlier. With the sand and gravel protective cap, an active layer thickness of 0.89 m was again predicted indicating that the protective cap moved the active layer up by the it's thickness.

### 6.2.6 Cover Model - Global Warming

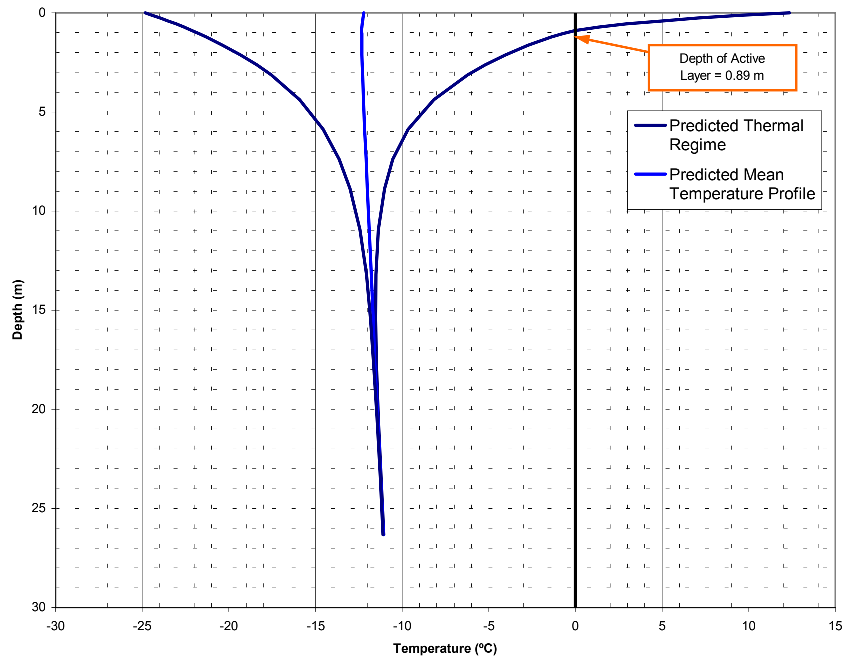
Based on a review of global warming estimates for the Nanisivik area undertaken by BGC (2002b), Best Estimate and High Sensitivity global warming rates of 3.1°C/100yrs and 5.5°C/100yrs, respectively were used. The base case model with no sand and gravel running surface was run for a 100 year period for both the Best Estimate and the High Sensitivity cases. An active layer thickness of 1.07 m and 1.25 m was predicted for the end of the 100-year run for the Best Estimate and High Sensitivity cases, respectively. The geothermal regime predicted at the end of the 100-year run is representative of the geothermal regime for 2100 AD. The predicted geothermal regime is shown in Figure 7 for both cases.

If a sand and gravel protective cap is added, the thaw penetration depth is expected to remain the same (1.25 m below the surface of the protective cap). It is possible the effect of a protective cap layer may be more pronounced over the longer term, but this aspect was not modeled.

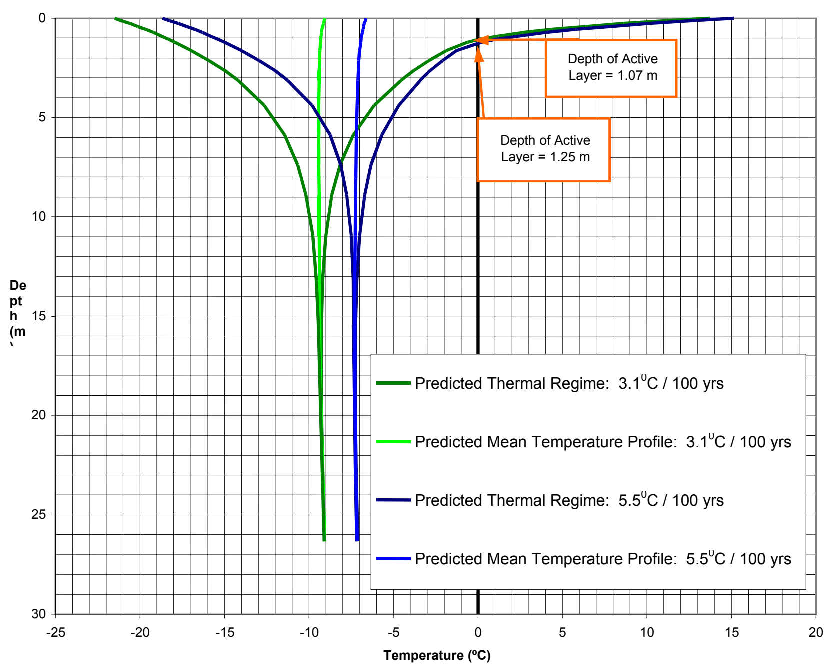
### 6.2.7 Summary

The preliminary design of the cover system should be composed of approximately 0.25 m of Twin Lakes sand and gravel overlying 1.0 m of weathered shale fill. Based on the results of the modeling, these proposed thicknesses appear adequate to resist a high sensitivity estimate of global warming over the next 100 years. This conclusion is based on the assumption that the thermal properties assumed within the geothermal model can be constructed (and maintained) within the actual cover system.

## Figure 6: Predicted Baseline Geothermal Regime




## Figure 7: Predicted Global Warming Geothermal Regime: 2100 AD



# 7. Final Cover Design

## 7.1 Summary of Design Considerations and Selected Cover Configuration

The final cover design draws on the preceding descriptions of material properties and design considerations to select a cover system that will achieve the project objectives, which are:

> *The principle closure objectives for the tailings deposit are mitigating the potential long term impacts and returning the area, as nearly as possible, to its natural state.*

The relevant observations and conclusions of the preceding descriptions relating to a reclamation cover over the Surface Cell are summarized as follows:

1. Water cover is not preferred due to significant risk of causing instability of West Twin Dyke.
2. Geosynthetic materials are not preferred due to cost considerations, material lifespan, requirement for a protective cap of natural material, and risk of exposure of unfrozen tailings to oxidizing conditions.
3. Of the locally available natural materials, shale is preferred as the primary cover material due to availability and due to demonstrated (through onsite test cells and lab testing) beneficial physical properties: thermal insulation, moisture retention, grain size and availability.
4. Shale has a poor physical durability rating relative to other natural materials.
5. Of the locally available natural materials, Twin Lakes sand and gravel is preferred as the protective cap due to its availability, durability and albedo.
6. Tailings is confirmed to be potentially acid generating and shale is confirmed to be acid consuming.
7. Maintaining frozen conditions in the tailings will retard the rate of oxidation as demonstrated in both generic, northern studies and in site-specific studies.
8. Maintaining frozen conditions in the tailings will result in the formation of a frozen, saturated zone at the base of the cover that will serve as an oxygen diffusion barrier and that will prevent transport of contaminants in surface water.
9. Exothermic reactions in the tailings may generate a small amount of heat on a local or microscopic level; however, the range of possible heat generation is small relative to the heat required to thaw permafrost and this heat is not considered to represent a risk to achieving the project objectives.
10. Extensive on-site field testing of shale covers demonstrated that shale thicknesses of 0.7 to 1.0 metres maintained tailings below zero degrees C over a 7-year period and that permafrost aggradation was rapid, as expected.
11. One-dimensional geothermal modeling, calibrated to the demonstrated field experience, indicated that an additional 0.32 metres of cover material would be required to maintain frozen conditions in the tailings for a high-estimate 100-year global warming scenario relative to the calibration data.

The resulting cover configuration based on the preceding discussions is:

1. 1.0 metres of shale directly overlying tailings.
2. 0.25 metres of Twin Lakes sand and gravel directly overlying shale.

## 7.2 Construction Considerations

The following are considerations for construction of the cover. These considerations could be specified to greater detail in the future subsequent to regulatory approval of the cover design, where this was necessary to ensure that construction of the cover will achieve the project objectives.

### 7.2.1 Borrow Areas

Testing of shale from the various existing borrow areas did not identify any physical or geochemical variances between borrow areas that are considered to be significant to the design application. Therefore, shale can be sourced from any of the existing borrow areas for use in the reclamation cover.

There is only one identified source of Twin Lakes sand and gravel that is intended to be utilized for the reclamation cover.

### 7.2.2 Grain Size

The grain size of the shale that is used for the reclamation cover must be similar to that used in the construction of the test cells and to that used in the various laboratory tests.

The established shale borrow methodology involving ripping the ground, loading and hauling, dumping and spreading by bulldozer should ensure that the grain size is as desired. Any boulders that appear in the borrow material should be visually examined and removed if not broken down by the load –haul-dump-spreading activities.

If blasting in the shale borrow areas is desired, then the blasthole spacing and loading should be such that the material produced is broken down by the load-haul-dump-spreading activities. Any boulders that are not broken down should be removed from use.

The Twin Lakes sand and gravel is expected to be produced from the borrow area at a consistent grain size. Boulders should be excluded from placement.

### 7.2.3 Compaction

Compaction (using a smooth or sheep-foot compactor in addition to the compaction provided by trucking and bulldozing) of the shale during placement on the Surface Cell could be done, if desired, but is not considered to be critical to achieving the project objectives. Field data from the on-site cover test cells indicated that controlled compaction may have accelerated permafrost aggradation by a short interval (one to two years) but that non-compacted cover materials achieved the same results as regards depth of the active layer. Additionally, if placement of the cover continues according to the established practice of

30 cm lifts with the use of mining trucks and bulldozer, then this will result in a considerable level of compaction.

### 7.2.4 Surface Contours

The final surface contours should provide a positive gradient to the outflow spillway, which is proposed to be constructed at the south abutment of West Twin Dyke (BGC, 2002). The surface contours should prevent any pooling of water on the surface.

It may be beneficial to perform a small amount of contouring of the tailings surface prior to placement of the cover where this would assist placement of the cover materials. It is likely that the costs of contouring the tailings surface would be less than the costs of borrowing and hauling extra shale that might be required to fill small hollows or dips in the tailings surface.

### 7.2.5 Performance Monitoring

A Performance Monitoring Program should be designed and implemented. The following items should be considered in the design of the program:

1. Thermistors should be used to measure ground temperatures that have a resolution of less than $1^0$ C.
2. Data loggers should be considered for continuous data collection.
3. Test pit investigations of the cover should be considered as part of the annual geotechnical inspection in order to assess moisture content, ice saturation and other parameters of interest.
4. Consider continued climate data collection at the WTDA or at the Nanisivik airport to assess the performance of the cover relative to climatic conditions.

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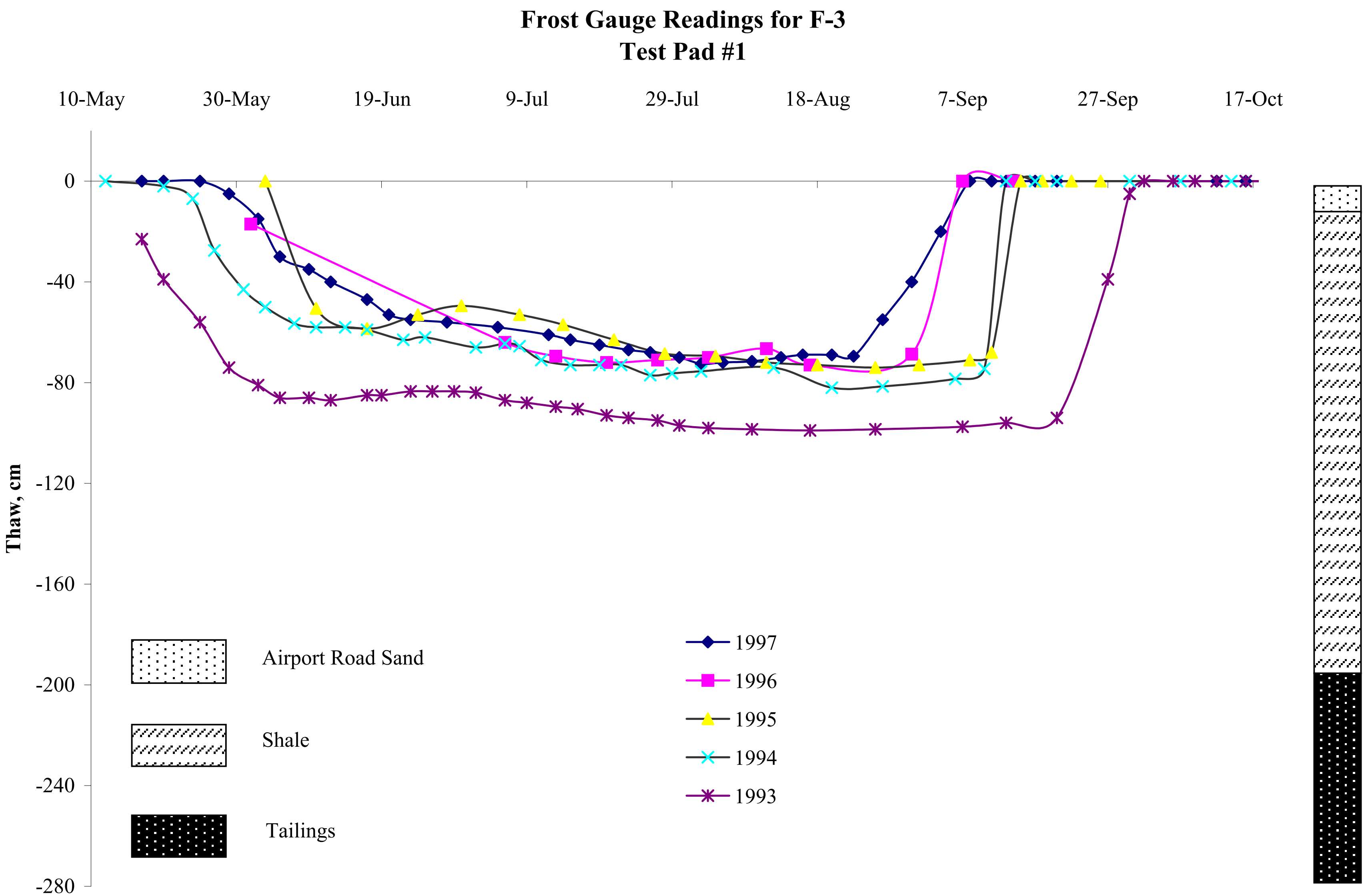
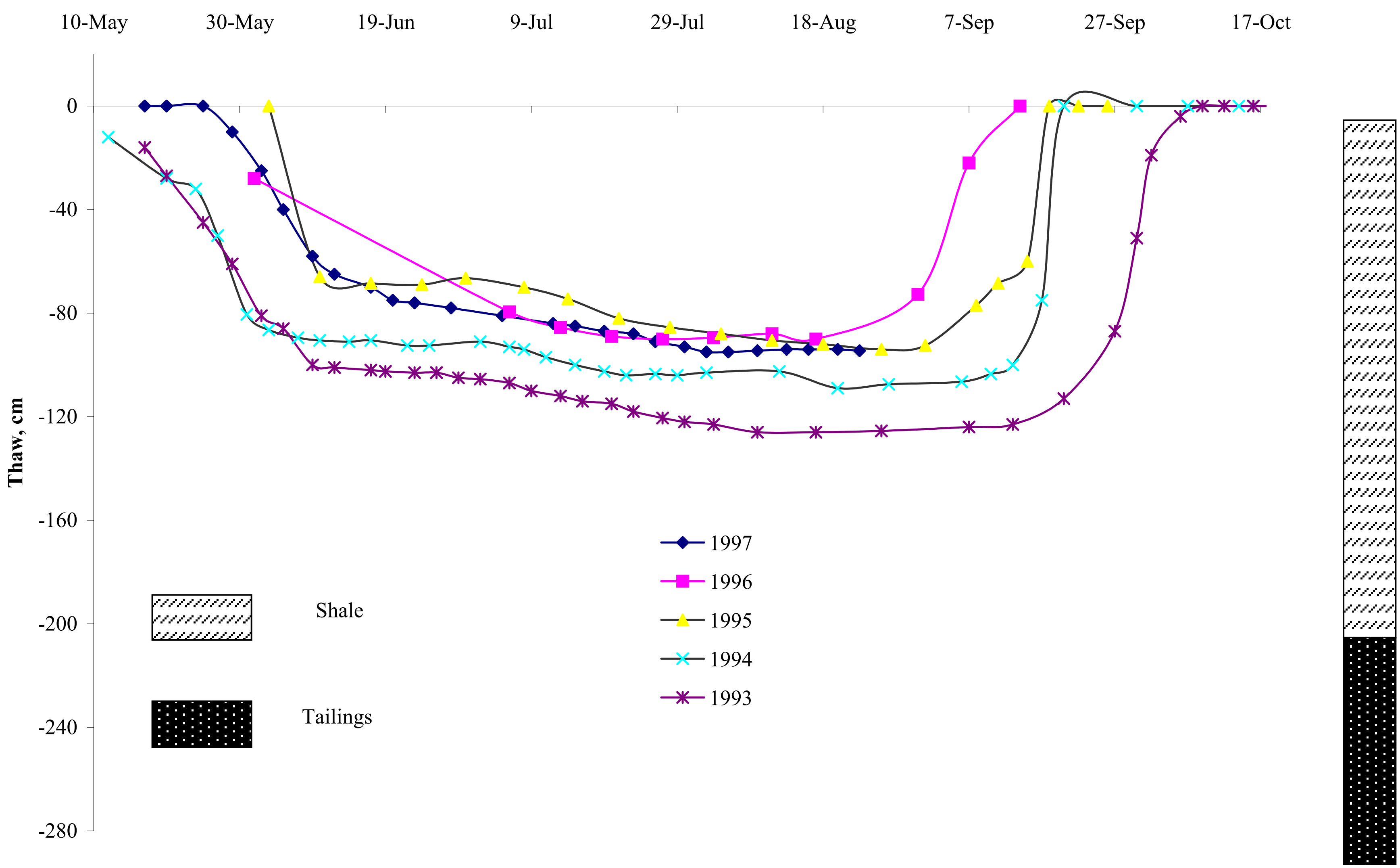
# Appendix A

# Frost Gauge and Temperature Data

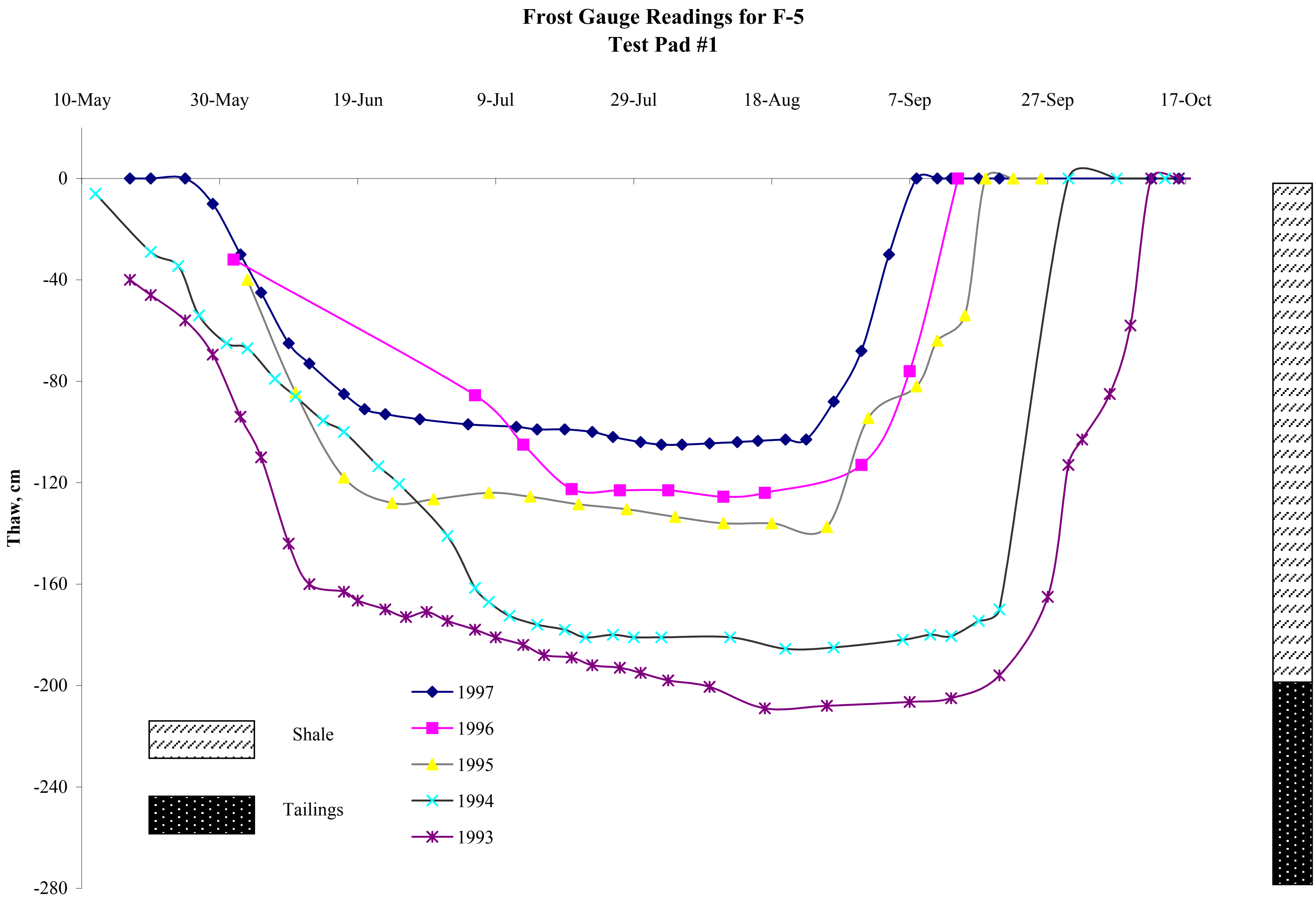



-Nanisivik Mine-
1998 Test Cell Study

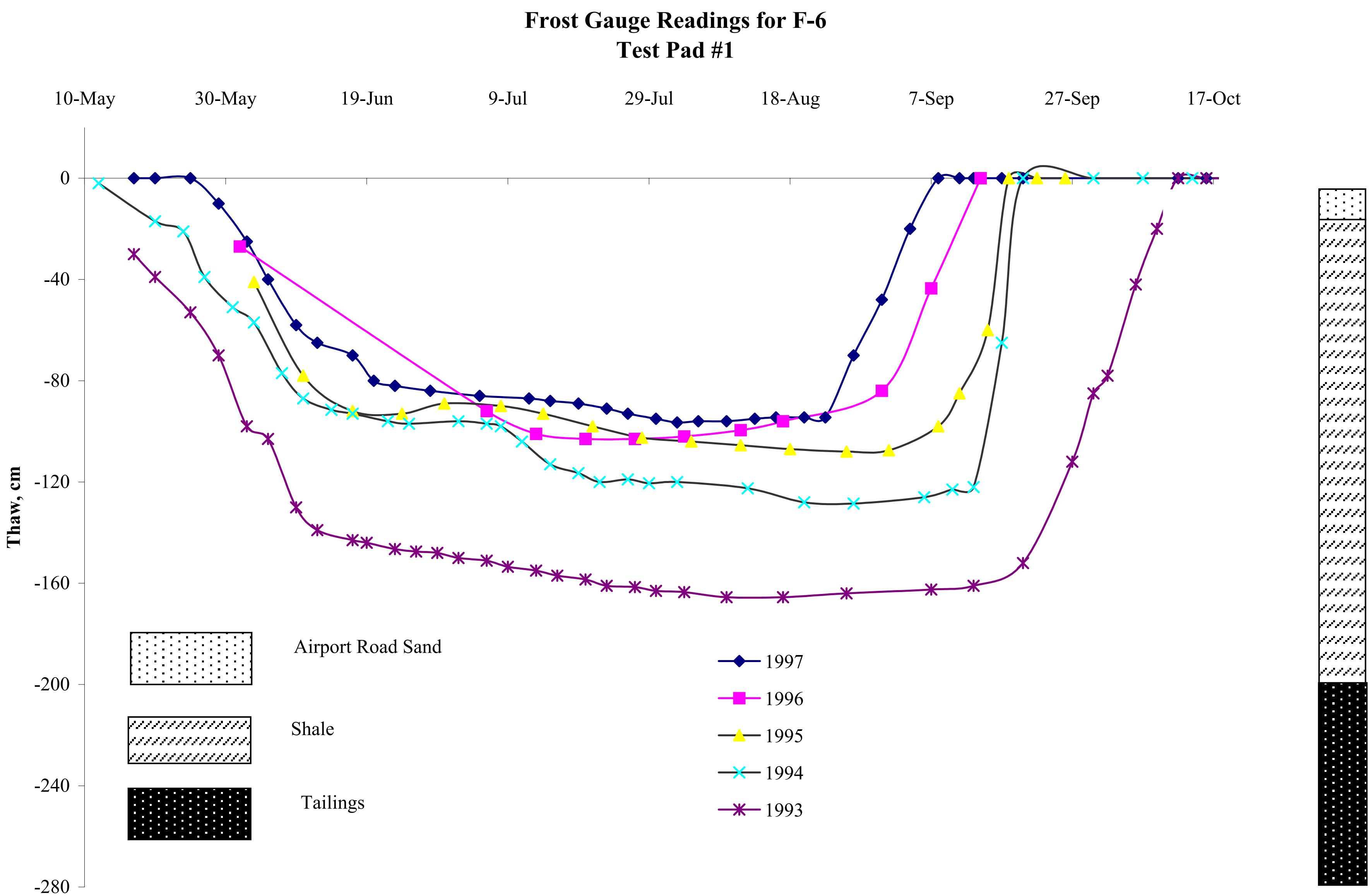
**Frost Gauge Readings for F-4**
**Test Pad #1**




-NANISIVIK MINE-
1998 Test Cell Evaluation

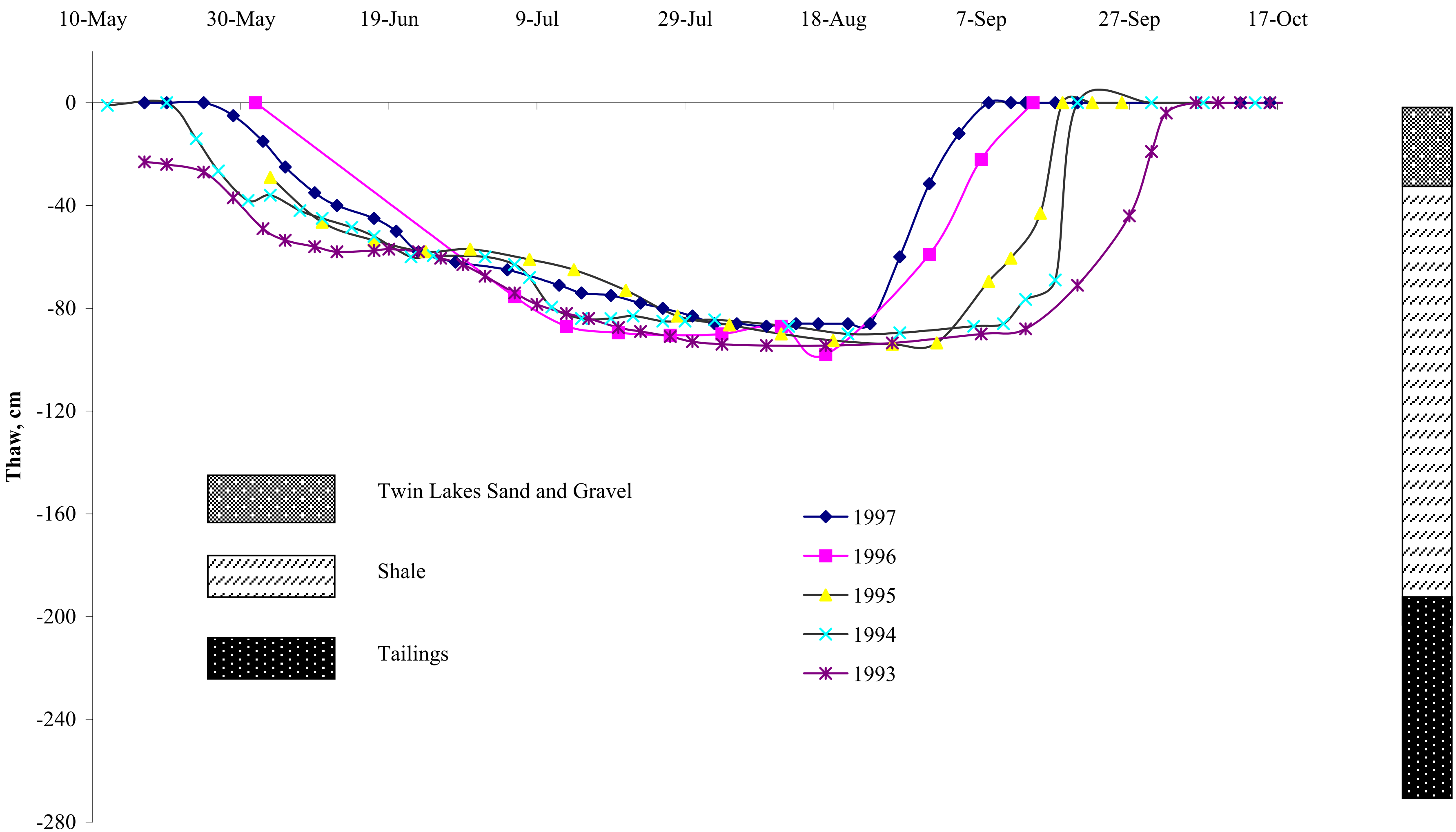



-NANISIVIK MINE-
1998 Test Cell Evaluation

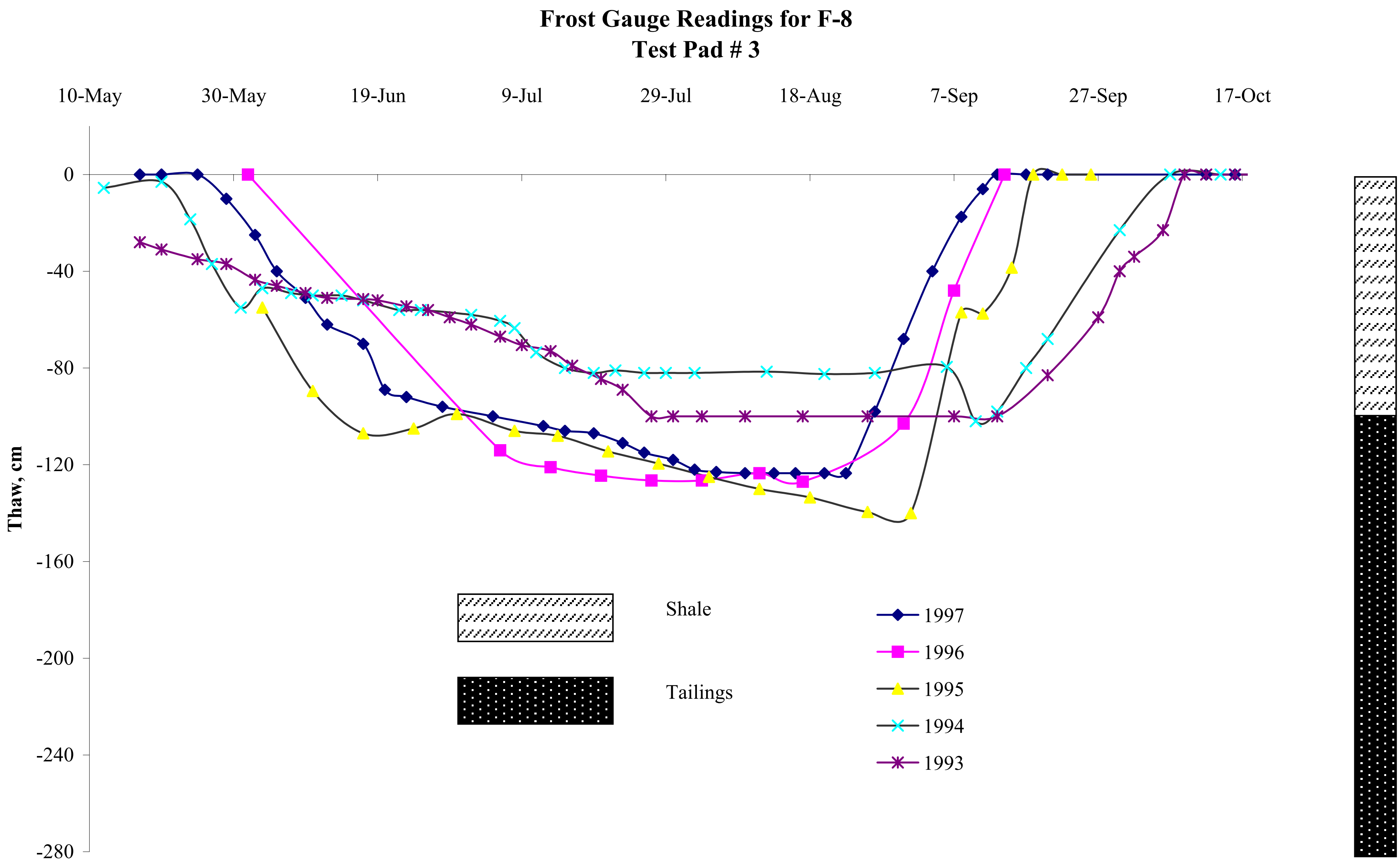



NANISIVIK MINE-
1998 Test Cell Evaluation

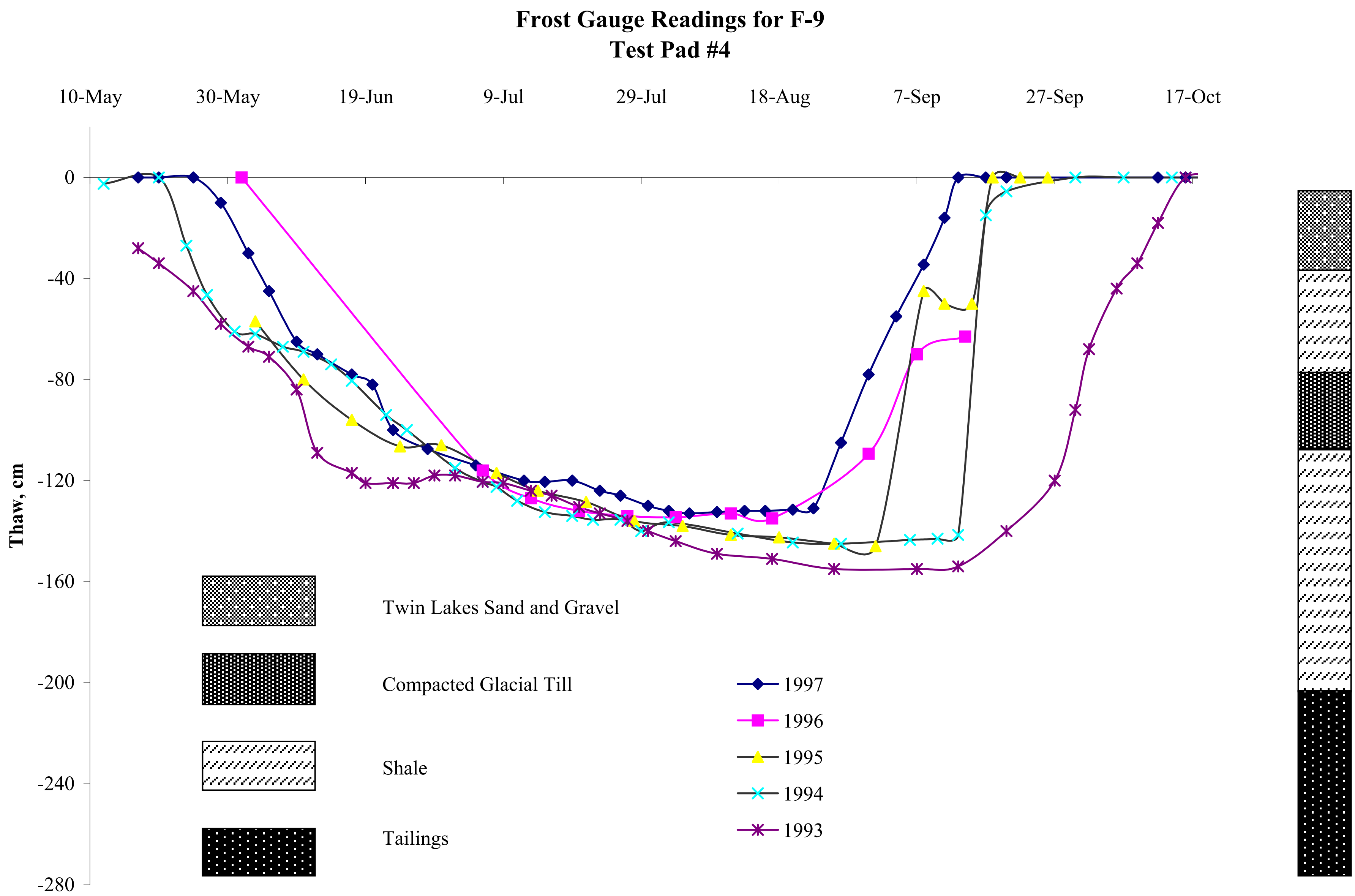
## Frost Gauge Readings for F-7
## Test Pad # 2



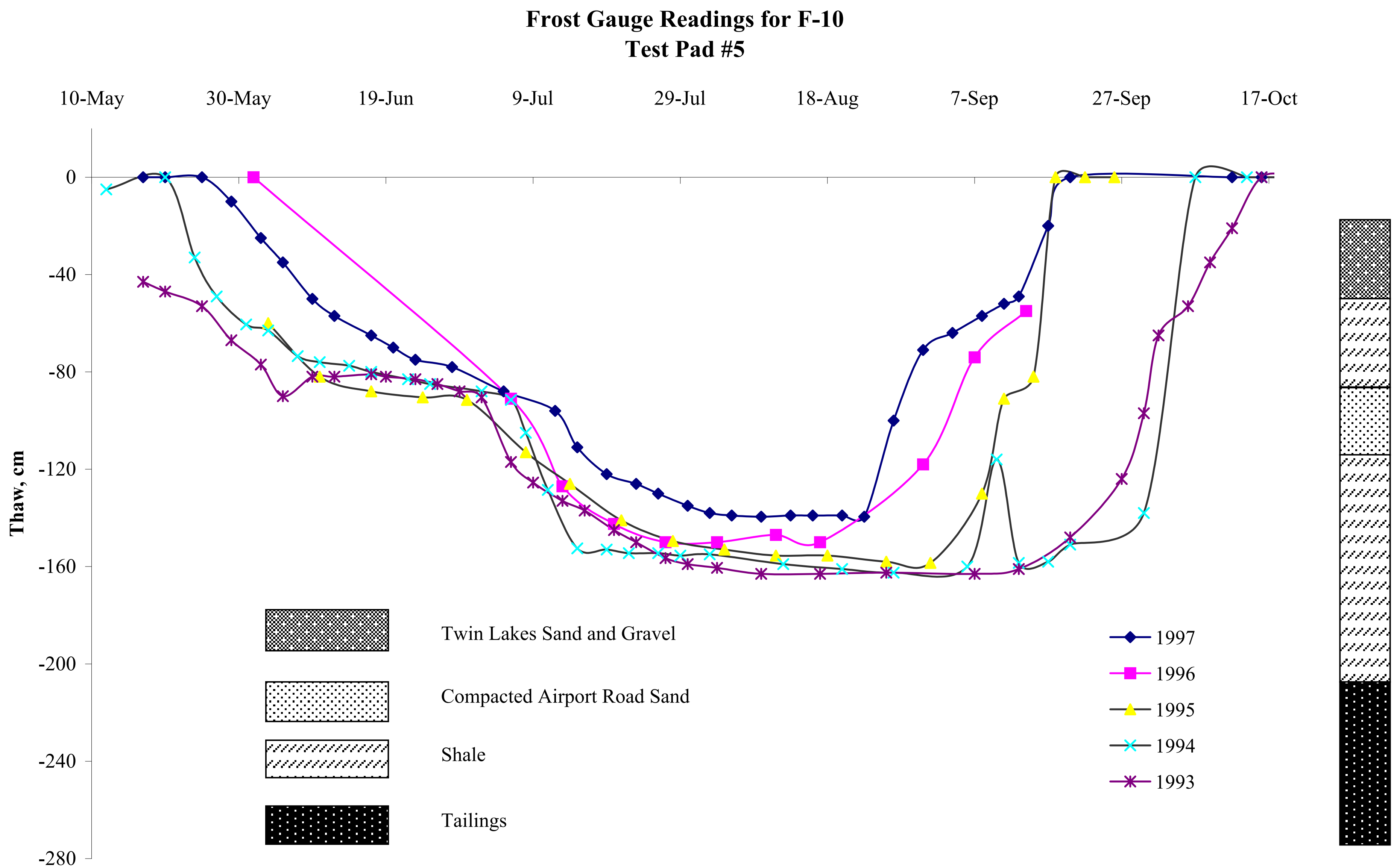

-NANISVIK MINE-
1998 Test Cell Evaluation



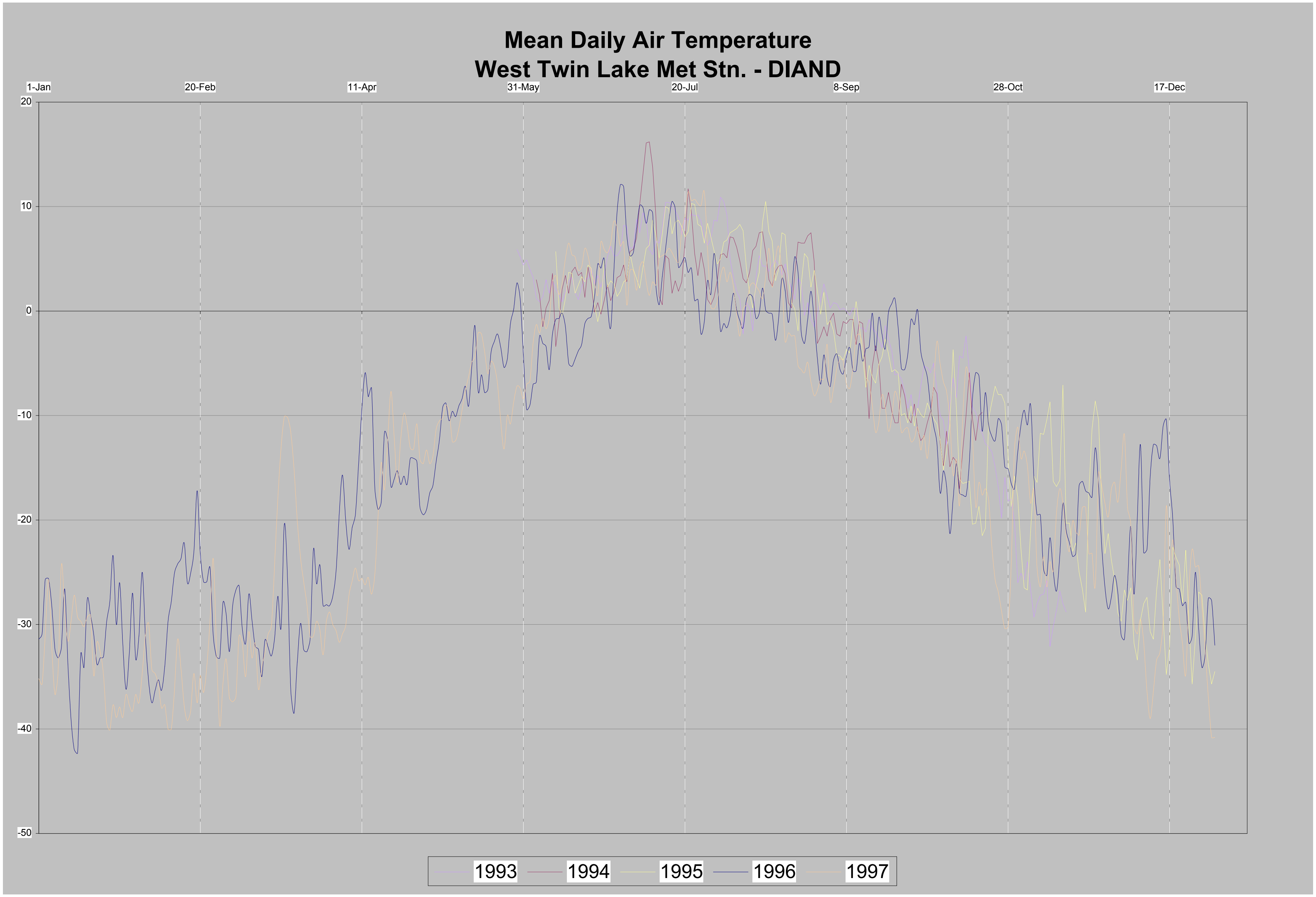

-NANISIVIK MINE-
1998 Test Cell Evaluation




-NANISIVIK MINE-
1998 Test Cell Evaluation




-NANISIVIK MINE-
1998 Test Cell Evaluation


Mean Daily Air Temperature
West Twin Lake Met Stn. - DIAND
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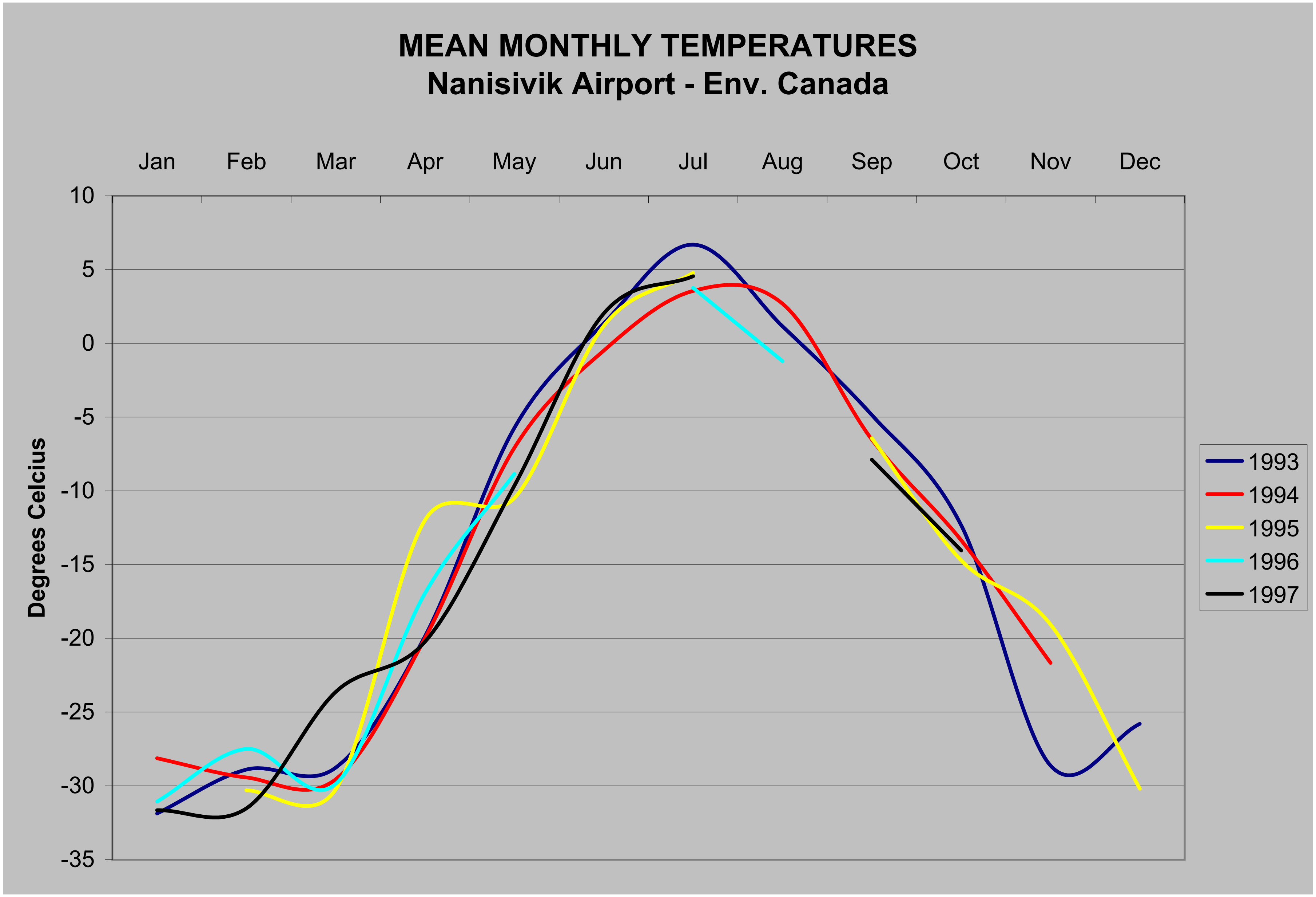
MEAN MONTHLY TEMPERATURES
Nanisivik Airport - Env. Canada
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Degrees Celcius
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