AN INTERPRETIVE MANUAL FOR REPORTS ON GRANULAR DEPOSITS IN THE INUVIALUIT SETTLEMENT REGION

Prepared for:
INDIAN AND NORTHERN AFFAIRS CANADA

Part of the Inuvialuit Final Agreement Implementation Program
Task 7-Sand and Gravel

Prepared by:
FRANK THOMPSON
MARCH, 1994

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EXECUTIVE SUMMARY

In the Western Arctic, granular deposits for road building and other construction needs are scarce and generally small. Much of the granular material is derived from glacial and post-glacial sand and gravel deposits. Buried ice, present in most of these deposits, further limits recoverable reserves and poses logistical and environmental problems unique to cold northern regions.

The volumes of granular material extracted prior to 1970 were small, but during the 1970's and 1980's there was a substantial increase in demand by the oil and gas industry and local communities. In response to this demand several studies of potential granular sources were undertaken, by both government and private agencies, and some deposits were exploited.

Unexpected problems associated with these extraction activities resulted in inefficient use of the granular resources, wasted effort and unnecessary environmental damage. Some deposits selected for development were not fully utilized and others proved uneconomic because of thick overburden cover or unsuitable aggregate. Melting of buried ice, exposed by extraction activities in some of the borrow pits, resulted in surface disturbances and flooding of the pit which limited access to the remaining granular material. Drainage from some of these ice rich pits entered adjacent natural waterbodies. Many of the abandoned borrow pits are visually unattractive because they lack vegetation, have steep slopes not in keeping with the natural landscape and are marked by irregular water filled depressions.

Under the Inuvialuit Final Agreement [IFA], signed between the Government of Canada and the Inuvialuit in 1984, ownership of most of the accessible granular deposits in the Western Arctic Region was transferred to the Inuvialuit. Management of this resource is now the responsibility of the Inuvialuit Land Administration [ILA] in consultation with local groups such as the Community Corporations and Hunters and Trappers Associations.

To implement the requirements of the IFA and provide for more efficient development of the resource, the Government of Canada set up a granular materials project designated as Task 7-Sand and Gravel Inventories. The objectives of this project are to determine the 20 year demands for granular material, provide an inventory of potential sources, determine the quality and quantity at the more promising deposits and form a plan for reservation and development of the granular material. Several studies of granular resources in the Inuvialuit Settlement Region have been conducted as a part of this project.

The reports on granular deposits are detailed and technical in nature because such information is required to determine which deposits are suitable for development and how they can be developed to maximize recoveries, while at the same time minimizing environmental damage. However, most of the community representatives called upon to approve development plans do not have scientific or technical training and are unable to fully utilize these reports. As a result the Inuvialuit are not always able to direct development of the granular deposits, and some control is left in the hands of the borrow pit operators and non-resident scientific experts.

For the Inuvialuit to effectively manage the granular resources of the Inuvialuit Settlement Region it is critical that they be able to use the reports on granular deposits. This manual was prepared to serve as a guide to help people with limited technical background make use these reports.

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1.0 INTRODUCTION

This manual is designed to help people with limited technical training use reports on granular deposits in the Inuvialuit Settlement Region. It describes, in laymans language and with the use of illustrations, how to interpret the technical data in these reports. Environmental protection measures and monitoring procedures recommended for borrow pit operations in northern climate conditions are also discussed. The focus is on sand and gravel sources of granular construction materials because these deposits present unique logistical and environmental problems not encountered in bedrock sources of granular materials. Off-shore sources of granular material are not discussed.

Although extensive, the manual is easy to use. It is divided into sections that can be used independently and, throughout, the reader is referred to other parts of the manual or other reports that provide additional information. Figures, photographs and tables are used extensively for demonstration. These illustrations, together with their captions, can be used independently of the text to understand the basics of borrow pit exploration, development and restoration. Technical terms commonly used in reports on granular deposits are presented, together with their definitions, at the end of the report.

This study is a part of the Inuvialuit Final Agreement Implementation Program: Task 7-Sand and Gravel Inventories and was authorized under contract number A7134-2-0070/01-ST. The scientific authority for the project is R. J. Gowan, Geotechnical Advisor, Natural Resources and Environment Branch, Indian and Northern Affairs Canada. The manual was prepared by F. J. Thompson of Ottawa, Ontario.

Inuvialuit Land Administration [ILA] staff and community representatives provided ideas and suggestions that formed the bases for this manual. Particular thanks go to Charles Klingenberg and William Gruben of the ILA in Tuktoyaktuk, Denis Thrasher and Vince Teddy of the Community Corporation in Tuktoyaktuk, Jane Bicknell of the ILA in Inuvik and Joey Amos of the Hunters and Trappers Association in Inuvik. Their cooperation and assistance was critical to the success of the project. The manual was improved by the suggestions of A. Judge and G. Brooks of the Geological Survey of Canada, who acted as critical reviewers.

2.0 GENERAL GEOLOGY

2.1 Introduction

In this section, the geological setting of granular deposits in the Inuvialuit Settlement Region [ISR] and the sediment types commonly encountered are discussed. This discussion is general in nature and the reports on granular deposits should be used to determine the geological setting of any specific deposit.

2.2 Geology of Granular Deposits

Granular construction material in the ISR is derived from bedrock or from glacial and post-glacial sand and gravel deposits. Bedrock sources of granular materials are not discused in this manual. Glacial deposits were formed about 10,000 to 13,000 years ago when glaciers that covered the ISR melted. These glaciers carried huge volumes of rock debris. Some of this debris was deposited in lakes and streams that formed to accommodate water released by the melting glacier and some was deposited directly from the glacier with no sorting action from water. Many of these lakes and streams are now dry or much smaller. Post-glacial deposits formed in lakes and streams that continued to exist after the glaciers melted.

The suitability of glacial and post-glacial deposits as sources of granular construction material is dependent primarily on the type of rock fragments they contain, and by the sorting during deposition [see Sections 5 and 7.2]. These deposits include:

Till

This is material that was carried by the glacier and deposited directly without further sorting. It is commonly an unsorted mix of material from large boulders to fine silt and clay. The larger stones [over 3 inches/76 millimetres] and a high percentage of fine material [less than 0.003 inches/0.076 millimetres] are undesirable for most construction applications, and till is often unsuitable as a source of granular material in the ISR.

Glaciofluvial Deposits

Glaciofluvial deposits are formed in meltwater streams flowing at or near the edge of the glacier. Due to the sorting action of the stream these deposits are commonly composed primarily of sand and gravel sized particles [0.003 to 3 inches] and can provide granular material suitable for road building and other construction applications. The geological terms applied to these deposits [kame, esker, terrace, delta, glaciofluvial outwash--see Section 12] reflect geological setting during deposition.

These deposits commonly occur in small hills and broad plateaus a few metres above the surrounding land [Illustration 1]. The hilly nature of the land is, in part, caused by melt of erratically distributed ice that was buried under the sand

and gravel. Granular deposits suitable for development are more commony in hills than in low areas because the granular material is generally thicker in high areas and because high well drained areas provide fewer complications for borrow pit operations than low poorly drained areas [see Section 8 and Illustration 17].

Glaciolacustrine and Glaciomarine Deposits

Glaciolacustrine and glaciomarine deposits are formed in glacial lakes and oceans respectively. Deposits formed along the shoreline of these waterbodies are commonly composed of sand and gravel sized particles due to sorting by wave action. These glacial beach deposits often occur as well drained ridges, which can provide granular material suitable for road building and other construction applications. Deposits formed off-shore in these waterbodies are commonly fine sand, silt and clay and do not generally provide granular material suitable for road building and other construction applications. Off-shore sources of granular material are not discussed in this manual.

Post-Glacial Deposits

Some granular deposits in the ISR formed in streams and beaches that post-date, and are unrelated to, glacial activity. These deposits are similar in character to those formed in glacial streams and beaches.

2.3 Materials Encountered in Granular Deposits

The materials commonly encountered in or associated with granular deposits in the ISR are shown in Illustration 1 and discussed below. Uneconomic fine grained sediments and organics that overlie granular deposits are called **overburden.**

Organics

Some deposits are nearly bare of vegetation but in most parts of the ISR organic material forms a thin but nearly continuous cover at surface. The organic material includes living vegetation such as moss and shrubs and decaying vegetation such as peat.

When glacial deposits formed there was no vegetation cover and all organics at surface have developed within the last 13,000 years. The amount and type of organic material and vegetation is dependent on factors such as topographic situation, climate conditions, drainage, type of sediment at surface and length of time since the surface was last disturbed by natural or human activity.

Sand and gravel

Coarse grained sediments such as sand and gravel were deposited primarily in glacial and post-glacial streams and beaches. Granular deposits commonly consist of several different layers of sand and gravel.

Silt and clay

Fine grained sediments such as silt and clay were deposited in glacial and post glacial lakes and oceans or in slow flowing parts of streams. Layers of silt and clay often occur within granular deposits.

Ice

Ice, ranging from scattered crystals to massive concentrations of pure clean ice, is commonly present in granular deposits in the ISR . Where it occurs as scattered crystals or small pockets of ice within organic material or sediments it is called the ice content or moisture content. Pure ice or ice containing minor amounts of sand and silt commonly occurs in granular deposits as wedges, lenses or layers called massive ice or ground ice. These vary from a few millimetres to tens of metres in thickness and can be several hundred metres across. Large ice bodies may be either remains of the glacier that were buried and have not melted or ice that formed in-place after the sand and gravel was deposited. Ice in granular deposits is discussed in Sections 5.2, 8 and 10.3.

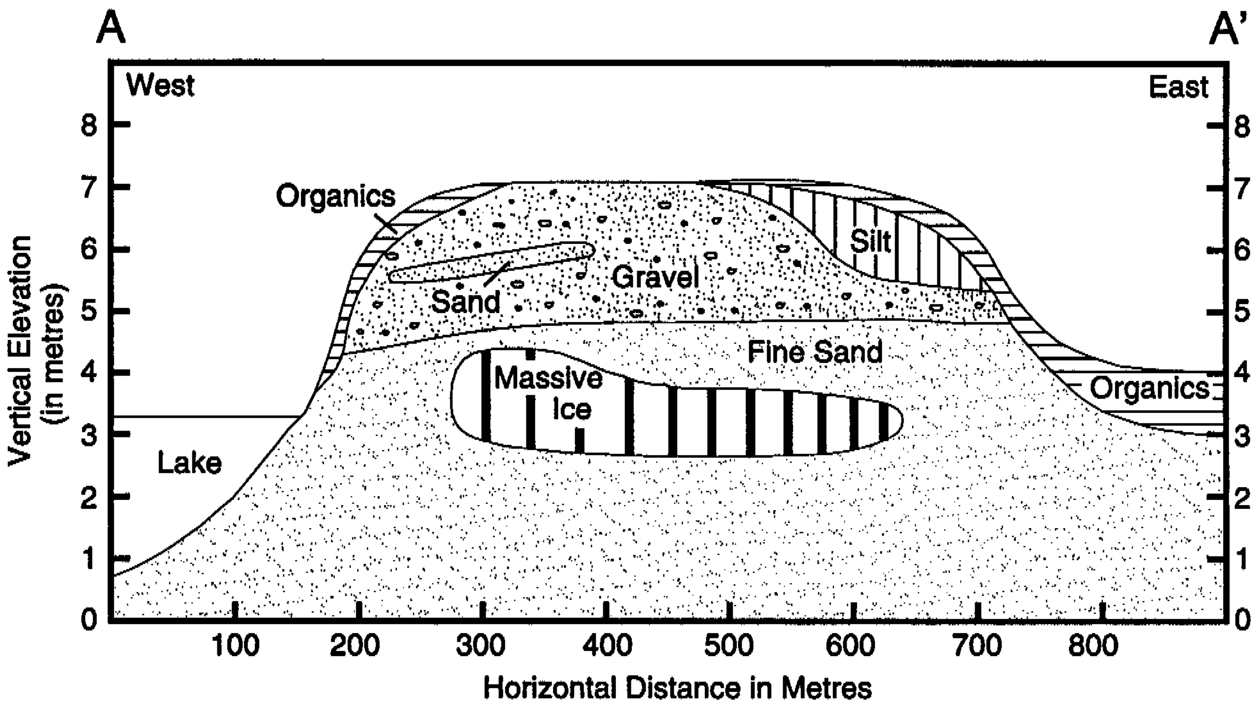


Illustration 1--Materials Encountered in Granular Deposits

This is a side view of a vertical slice through a hill showing some of the materials commonly encountered in granular deposits in the Inuvialuit Settlement Region [ISR]. The hill is about 500 metres across, 3.5 metres above the surrounding lowland and is composed primarily of gravel with some sand layers. Organics are thin and discontinuous on the hill, but thicker in low areas. Silt overlies gravel on the right [east] side of the hill. Fine sand and massive ice underlie the gravel.

This fictitious granular deposit is used for demonstration throughout the manual and is followed through stages of exploration, development and restoration [see Illustrations 2, 11, 12, 13, 17, 18, 20, 21, 22]. These illustrations are stylized for demonstration purposes and not necessarily true to scale.

3.0 EXPLORATION FOR GRANULAR MATERIAL

3.1 Introduction

Information on surface and subsurface conditions is essential to develop strategies for the exploitation of granular deposits that are cost effective, maximize recoveries and minimize environmental damage. The use of aerial photographs, surface and subsurface exploration surveys, and laboratory tests to evaluate granular deposits is discussed in Sections 3 through 7.

The amount and type of exploration conducted is not the same in all parts of the ISR. Evaluation of granular deposits is more extensive and more detailed in the Tuktoyaktuk and Inuvik areas, where there has been demand for high quality granular material by the oil and gas industry, than it is in other parts of the ISR. Exploration drilling is expensive and it is not always practical to conduct large drilling programs.

It is recommended in "Environmental Guidelines Pits and Quarries" [MacLaren Plansearch, 1989] that, to evaluate subsurface conditions, drill holes should be no more than 50 metres apart. Drill holes should also be extended a minimum of 2 metres below the planned base of the borrow pit and through any massive ice encountered to determine the extent of ice that could be exposed to thaw when the granular material is removed. In the ISR, test pits or drill holes 100 metres apart are commonly considered adequate to evaluate subsurface conditions and guide borrow pit development. However, in some areas where preliminary exploration suggests that subsurface conditions do not vary substantially or that logistical and environmental problems are not expected, ground surveys and test pits or more widely spaced drill holes are sometimes considered adequate.

Granular deposits that have not been fully evaluated prior to exploitation may present problems because the amount and grade of the material may not be up to expectations, extraction may be more difficult than expected or thick overburden cover may prevent access to some of the granular material. Furthermore, undetected buried ice in the deposit may present unexpected logistical and environmental problems.

3.2 Factors Affecting Economic Viability of Granular Deposits

- Distance from the community and ease of access.
- Topographic setting and drainage.
- Amount of granular material.
- Quality of the granular material.
- Thickness of the overburden cover.
- Moisture content of the sediments.
- Location and amount of buried massive ice.
- Environmental concerns.

3.3 Preliminary Studies

Before ground surveys are attempted, aerial photographs and geological reports are studied to identify areas that may contain suitable granular material. Areas are selected by their topographic features [some features such as ridges and plateaus can contain granular material] and other geological considerations. On-site investigations are conducted during the summer in the more promising areas. At this stage any natural exposures are studied and test pits may be excavated. If this work indicates that the area is likely to contain suitable volumes and quality of granular material, further test pitting or exploration drilling may be conducted.

3.4 Evaluating Subsurface Conditions

Natural exposures, test pits and exploration drill logs all provide an opportunity to evaluate subsurface conditions. These exploration methods are demonstrated in Illustration 2 and discussed below.

Natural exposures

Natural exposures occur on slopes, commonly where water [along a river bank or at a beach] has cut back into the sediments. These exposures can provide an excellent 2 dimensional view of the deposit. Illustration 3, Photograph 1 shows a typical natural exposure.

Advantages

- Commonly provides a view of a larger area than a single test pit or drill hole.
- Sediments are intact and it is possible to observe detailed features such as thin layers of sediment.
- Relatively inexpensive means to examine buried sediments.

Disadvantages

- Does not provide a true picture of ice content [any buried ice will have melted].
- Only available in a few locations.

Test pits

Multiple test pits can provide a good view of the near surface sediments. Pits are generally excavated during the summer when the surface material has thawed. Illustration 3, Photograph 2 shows a test pit being excavated by shovel. In some cases a bulldozer is used to open a larger pit and provide a 3 dimensional view of the deposit.

Advantages

- Sediments are intact and it is possible to observe detailed features such as thin layers of sediment.
- Relatively inexpensive means to examine buried sediments.

Disadvantages

- It is difficult to penetrate frozen ground and depth of test pits is often limited to the depth of summer thaw [less than 2 metres].
- Test pits do not always provide a reliable test of ice content or extent of overburden. They are commonly excavated where sand and gravel is exposed at surface, because depth of summer thaw is deepest where there is no organic cover. Overburden cover and ice content may be greater in other parts of the study area.

Drill holes

Exploration drilling in the ISR is generally conducted with an auger drill. Sediments are brought to surface along the outside "screw" of the auger. An exploration drill is shown in Illustration 3, Photograph 3.

Advantages

- Depth of penetration is not limited by depth of thaw and holes can be drilled deep enough to determine the full thickness of overburden, granular material and buried ice.
- Location of test sites is not controlled by surface materials and suitably spaced drill holes can provides a more accurate evaluation of the extent of overburden, granular material and buried ice than tests pits or natural exposures.
- Provides a more reliable evaluation of ice content in the sediments than tests pits or natural exposures.

Disadvantages

- Sediments are disturbed by the drilling process and it is not possible to observe detailed features such as thin layers of sediment or ice.
- Provides a view of a much smaller area [the diameter of the drill rod] than test pits or natural exposures.
- Relatively expensive means to examine buried sediments.

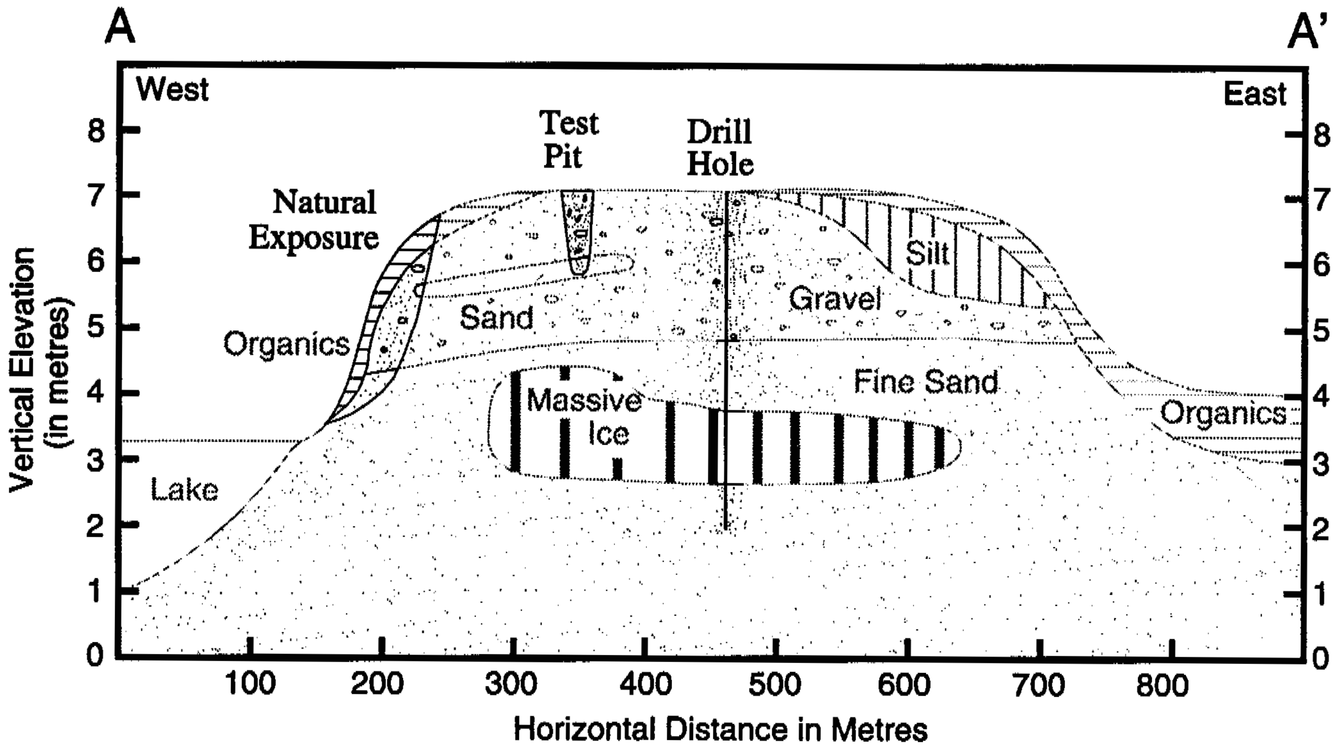


Illustration 2--Evaluating Subsurface Conditions

In our example from Illustration 1, subsurface conditions are still unknown. Previous review of geological reports and aerial photographs has indicated that this hill may contain granular material.

For the first stage of on-site exploration, the hill is examined using a natural exposure, a test pit and a drill hole. The test pit, 2 metres across by 1.5 metres deep, is excavated where there is no organic material at surface. This provides a good view of the near surface materials but is not deep enough to determine the full thickness of gravel. The natural exposure near the lake shore is about 40 metres long and 3 metres deep. It is deep enough to determine the full thickness of sand and gravel and provides a good view of the near surface materials. The drill hole is deep enough to intersect the underlying fine sand and buried ice.

In this example, the preliminary exploration indicates that there is good quality granular material in the hill, but more detailed exploration is required to determine if it is an economically viable deposit. Drilling is the most suitable exploration method to further define subsurface conditions at this site. There are no other natural exposures, and any test pits will be limited to the depth of summer thaw [less than 0.6 metres where there is organic cover at surface and 1 to 2 metres where there is no organic cover].

Results of this exploration drilling are shown in Illustrations 11, 12 and 13.

Photograph 1
A natural exposure.

Loose material was scraped off the slope to expose fresh sediments.

Photograph 2
A test pit excavated by shovel.

The surface in the foreground, where the pit is being dug, is bare of organics and vegetation.

Photograph 3
An exploration drill.

There is a thin, discontinuous cover of vegetation at surface

Illustration 3--Photographs of Exploration Methods

4.0 USING DRILL HOLE LOGS

4.1 Introduction

The information obtained from each drill hole, natural exposure and test pit is commonly presented on a drill log form in the appendix of a report. In this section, use of these logs is explained through a series of examples from these reports.

4.2 Types of Observations in Drill Logs

The buried sediments are visually evaluated to determine if the material is suitable for road building material or other construction applications and if it can be economically extracted. These visual observations are summarized below and discussed in more detail in Section 4.3.

Type of sediment
The sediments encountered are described in detail. This information helps to determine any potential uses of the material.

Type and amount of ice
This information helps to determine limitations on use of the granular material and any potential logistical and environmental problems associated with borrow pit development [see Sections 8 through 10].

Ice bonding
This is based on difficulty in penetrating the sediments during exploration and indicates potential for difficulties in extracting and using the granular material [see section 5.2]. Sediments may be called poorly bonded or friable [easy to penetrate] or hard bonded [difficult to penetrate].

4.3 Interpreting Drill Log Forms

A standard format is generally used to provide a consistent way to describe ground conditions. Standardized terms used to describe the size of particles are show in Illustration 4. The Modified Unified Classification System for Soils [Illustration 5] and Ground Ice Classification Table [Illustration 6] are generally used to describe the materials encountered in granular deposits.

The presentation of data and the types of drill log forms used are not the same in every report. Examples of drill logs from two different reports are presented in Illustrations 7A to 7E. Most reports contain an explanation of the format, terms and symbols used which should be consulted for more specific information.

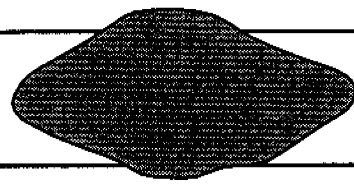
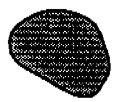
Type of Material	Size Range	Grain Size Drawn to Actual Scale
Boulder	More than 8 inches 203 millimetres	Too Large for Demonstration Purposes
Pebble	3 to 8 in. 76 to 203 mm	Too Large for Demonstration Purposes
Coarse Gravel	.75 to 3 in. 19 to 76 mm	
Fine Gravel	.19 to .75 in. 4.75 to 19 mm	
Coarse Sand	.08 to .19 in. 2.0 to 4.75 mm	
Medium Sand	.017 to .08 in. .425 to 2.0 mm	
Fine Sand	.003 to .017 in. .076 to .425 mm	
Fines (silt & clay)	Less than 0.003 inches 0.076 millimetres	Too small to be seen with the unaided eye. When wet, silt and clay are generally muddy. When dry, silt is generally dusty and clay forms a hard crust.

Illustration 4--A Graphic Illustration of Sand and Gravel Sized Grains

The terms used to describe particle size are standardized as demonstrated in this figure.

Illustration 5--The Modified Unified Classification System for Soils

In most reports, the Modified Unified Classification System for Soils is used to describe buried sediments encountered in granular deposits. It provides a standard set of abbreviations to replace a more lengthy description. A letter designation is given to the different materials [see group symbol column]. The first letter of this designation refers to type [G for gravel, S for sand, M for silt, C for clay, Pt for organics]. For clean sand and gravel the second letter of this designation refers to the grading [W for well graded, P for poorly graded]. For dirty sands and gravels the second letter refers to the type of fines [M for silty, C for clayey, F for undifferentiated fines].

Sands and gravels are defined as less than 50% fines by weight. If the course part of the sample [part courser than fines] is more than half gravel sized particles the material is called gravel, if the coarse fraction is more than half sand sized particles it is called sand. Sands and gravels are called clean if they are less than 12% fines and dirty if more than 12% fines. Silts and clays are defined as more than 50% fines by weight. The distinction between silts and clays is based on plasticity [how easily the material will flow when wet], which is determined by laboratory testing. Grading is explained in Section 5.3 and Illustration 10.

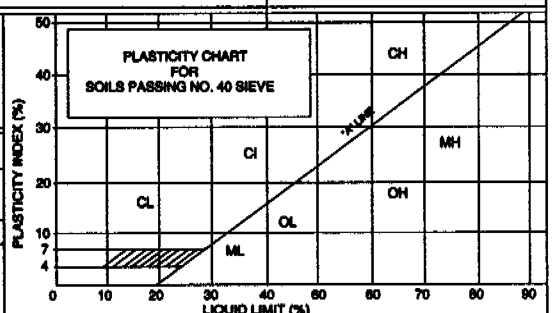
MODIFIED UNIFIED CLASSIFICATION SYSTEM FOR SOILS

MAJOR DIVISION			GROUP SYMBOL	GRAPH SYMBOL	COLOR CODE	TYPICAL DESCRIPTION	LABORATORY CLASSIFICATION CRITERIA	
COARSE-GRAINED SOILS (MORE THAN HALF BY WEIGHT LARGER THAN 200 SIEVE)	GRAVELS MORE THAN HALF COARSE GRAINS LARGER THAN NO. 4 SIEVE	CLEAN GRAVELS (LITTLE OR NO FINES)	GW		RED	WELL GRADED GRAVELS, LITTLE OR NO FINES	$C_U = \frac{D_{60}}{D_{10}} > 4 \quad C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}} = 1$ to 3	
			GP		RED	POORLY GRADED GRAVELS, AND GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	NOT MEETING ABOVE REQUIREMENTS	
		DIRTY GRAVELS (WITH SOME FINES)	GM		YELLOW	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES	CONTENT OF FINES EXCESS 12%	ATTERBERG LIMITS BELOW "A" LINE OR P.I. LESS THAN 4
			GC		YELLOW	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES		ATTERBERG LIMITS ABOVE "A" LINE P.I. MORE THAN 7
	SANDS MORE THAN HALF FINE GRAINS SMALLER THAN NO. 4 SIEVE	CLEAN SANDS (LITTLE OR NO FINES)	SW		RED	WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	$C_U = \frac{D_{60}}{D_{10}} > 6 \quad C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}} = 1$ to 3	
			SP		RED	POORLY GRADED SANDS, LITTLE OR NO FINES	NOT MEETING ABOVE REQUIREMENTS	
		DIRTY SANDS (WITH SOME FINES)	SM		YELLOW	SILTY SANDS, SAND-SILT MIXTURES	CONTENT OF FINES EXCESS 12%	ATTERBERG LIMITS BELOW "A" LINE OR P.I. LESS THAN 4
			SC		YELLOW	CLAYEY SANDS, SAND-CLAY MIXTURES		ATTERBERG LIMITS ABOVE "A" LINE P.I. MORE THAN 7
FINE-GRAINED SOILS (MORE THAN HALF BY WEIGHT PASSES 200 SIEVE)	SILTS BELOW "A" LINE NEGLIGIBLE ORGANIC CONTENT	$W_L < 50\%$	ML		GREEN	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY SANDS OF SLIGHT PLASTICITY	CLASSIFICATION IS BASED UPON PLASTICITY CHART (see below)	
		$W_L > 50\%$	MH		BLUE	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS, FINE SANDY OR SILTY SOILS		
	CLAYS ABOVE "A" LINE ON PLASTICITY CHART NEGLIGIBLE ORGANIC CONTENT	$W_L < 30\%$	CL		GREEN	INORGANIC CLAYS OF LOW PLASTICITY, GRAVELLY, SANDY, OR SILTY CLAYS, LEAN CLAYS		
		$30\% < W_L < 50\%$	CI		GREEN-BLUE	INORGANIC CLAYS OF MEDIUM PLASTICITY, SILTY CLAYS		
		$W_L > 50\%$	CH		BLUE	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS		
	ORGANIC SILT & CLAYS BELOW "A" LINE ON CHART	$W_L < 50\%$	OL		GREEN	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY	WHENEVER THE NATURE OF THE FINE CONTENT HAS NOT BEEN DETERMINED, IT IS DESIGNATED BY THE LETTER "F", E.G. SF IS A MIXTURE OF SAND WITH SILT OR CLAY	
		$W_L > 50\%$	OH		BLUE	ORGANIC CLAYS OF HIGH PLASTICITY		
HIGHLY ORGANIC SOILS			Pt		ORANGE	PEAT AND OTHER HIGHLY ORGANIC SOILS	STRONG COLOR OR ODOR, AND OFTEN FIBROUS TEXTURE	

SPECIAL SYMBOLS

BEDROCK (undifferentiated)

VOLCANIC ASH



1. ALL SIEVE SIZES MENTIONED ON THE THIS CHART ARE U.S. STANDARD, A.S.T.M. E.11.
2. BOUNDARY CLASSIFICATIONS POSSESSING CHARACTERISTICS OF TWO GROUPS ARE GIVEN COMBINED GROUP SYMBOLS, E.G. GW-GC IS WELL GRADED GRAVEL SAND MIXTURE WITH CLAY BINDER BETWEEN 5% AND 12% 12%.

SOIL COMPONENTS

FRACTION	U.S. STANDARD SIEVE SIZE		DEFINING RANGES OF PERCENTAGE BY WEIGHT OF MINOR COMPONENTS	
	PASSING	RETAINED	PERCENT	DESCRIPTOR
GRAVEL coarse	76 mm	19 mm	50 - 35	and
fine	19 mm	No. 4		
SAND coarse	4.75 mm	2.00 mm	35 - 20	...y (eg. silty)
medium	2.00 mm	425.4 µm	20 - 10	some
fine	425 µm	75.4 µm		
SILT (non plastic) or CLAY (plastic)	75 µm		10 - 1	trace

SOIL COMPONENTS

Rounded or subrounded cobbles 76 mm to 203 mm BOULDERS > 203 mm	Not rounded ROCK FRAGMENTS > 76 mm ROCK > 0.76 cubic metre in volume

GROUND ICE CLASSIFICATIONS				
CATEGORY	GROUP SYMBOL	SUBGROUP SYMBOL	GRAPHIC SYMBOL	DESCRIPTION
		F		UNDIFFERENTIATED
NON-VISIBLE ICE	N	Nf		POORLY BONDED OR FRIABLE FROZEN SOIL
		Nbn		WELL BONDED FROZEN SOIL WITH NO EXCESS ICE
		Nbe		WELL BONDED FROZEN SOIL WITH EXCESS ICE. FREE WATER PRESENT WHEN SAMPLE THAWED.
VISIBLE ICE LESS THAN ONE INCH THICK	V	Vx		INDIVIDUAL ICE CRYSTALS OR INCLUSIONS
		Vc		ICE COATINGS ON PARTICLES
		Vr		RANDOM OR IRREGULARLY ORIENTED ICE FORMATIONS
		Vs		STRATIFIED OR DISTINCTLY ORIENTED ICE FORMATIONS
VISIBLE ICE GREATER THAN ONE INCH THICK	ICE	ICE+ Soil Type		ICE GREATER THAN ONE INCH THICK WITH SOIL INCLUSIONS
		ICE		ICE GREATER THAN ONE INCH THICK WITHOUT SOIL INCLUSIONS

NOTE: 1. UF signifies unfrozen ground.
2. F/UF signifies that it was not possible to determine whether the ground was frozen, or unfrozen during drilling.

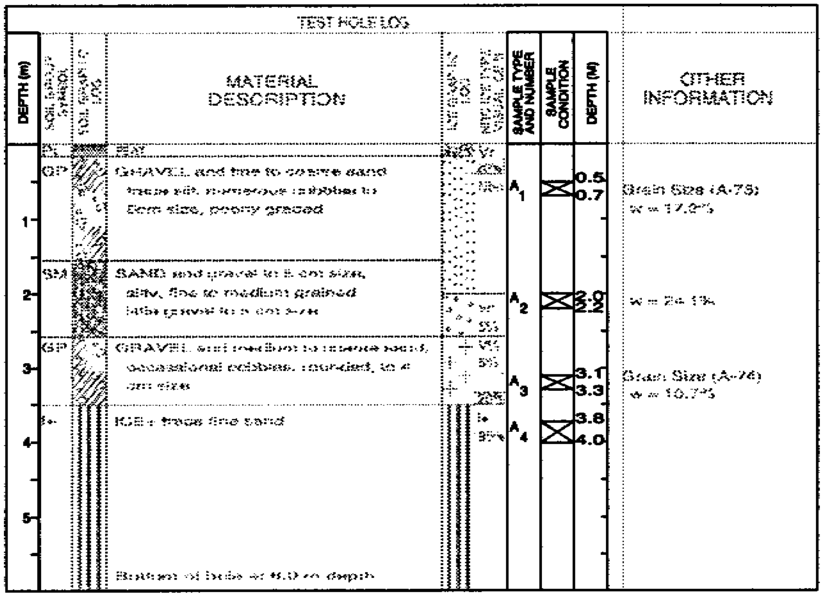
Illustration 6--The Ground Ice Classification Table

In most reports, the Ground Ice Classification Table is used to describe the ice encountered in granular deposits. A graphic symbol and letter designation is given to the different types of ice [see group and subgroup symbol columns]. The first letter of this designation indicates if the ice can be seen with the unaided eye [N for frozen soil with no visible ice and V for visible ice less than one inch thick]. Where ice is not visible the second letter of this designation refers to how hard the material is [f for poorly bonded, bn for well bonded, be for well bonded soil with excess ice]. Where ice is visible the second letter of this designation refers to distribution of the ice.

Illustration 7--Interpreting Drill Log Forms

Drill log forms are used to present the data collected in natural exposures, test pits and drill holes. Illustrations 7A to 7E demonstrate how to interpret these logs (see over). The format used is not the consistent between reports and therefore, examples from two different reports are used in each illustration.

7A-1



7A-2

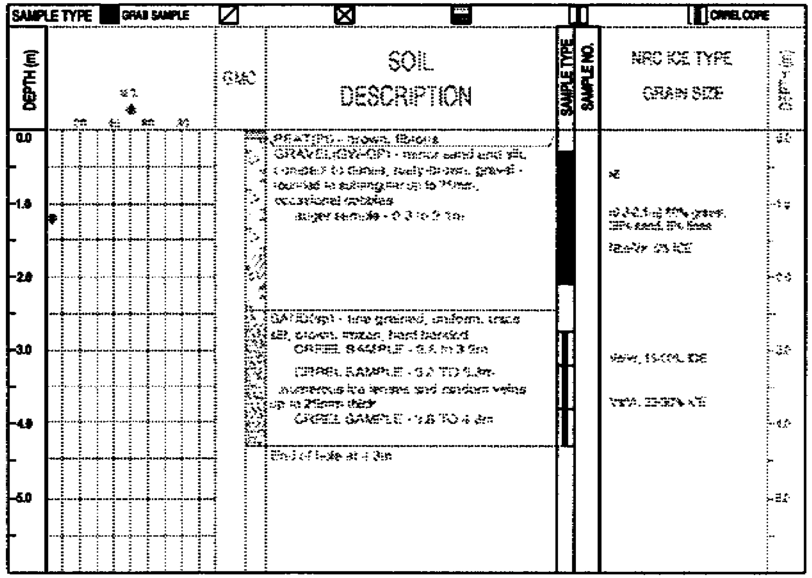
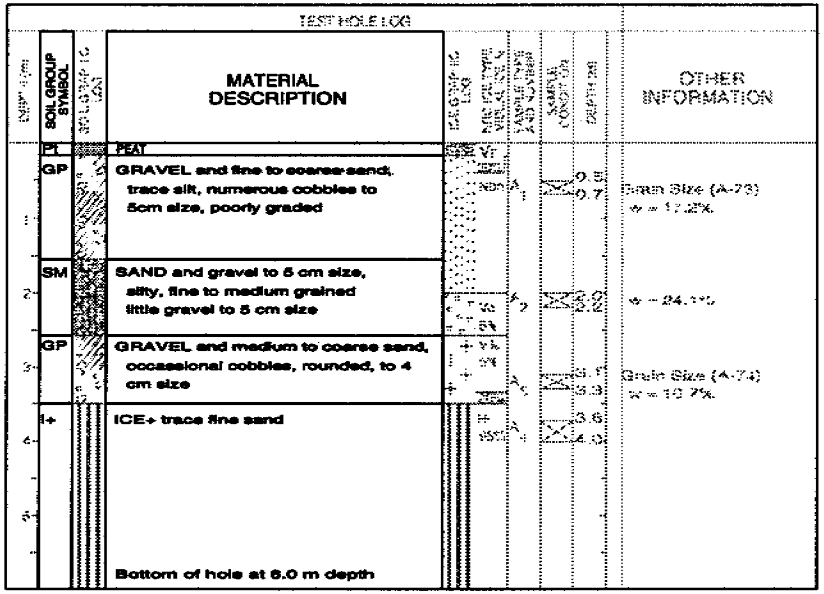


Illustration 7A--Interpreting Drill Log Forms---Depth and Sample Location

Depth from ground surface is generally presented on the left side of the log. The type and location of samples collected is shown on the right side if the log. In example 7A-2, the legend for sample type is at the top of the log.

7B-1



7B-2

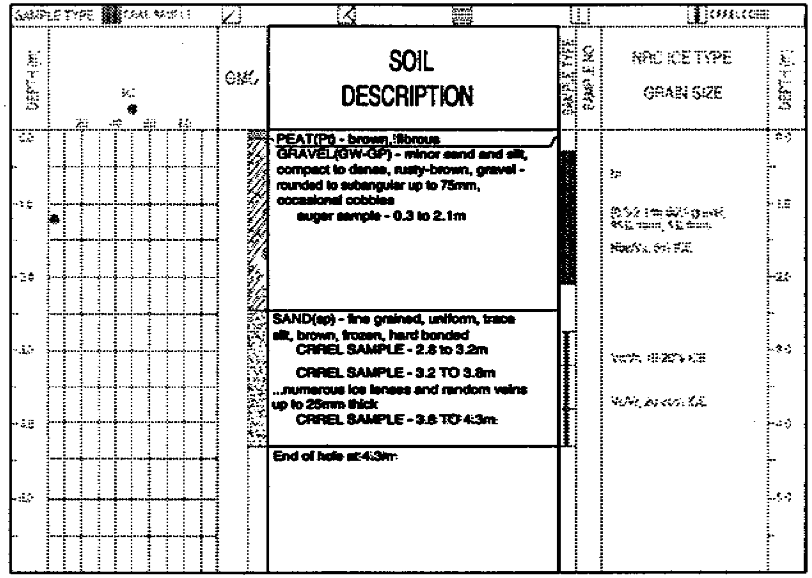
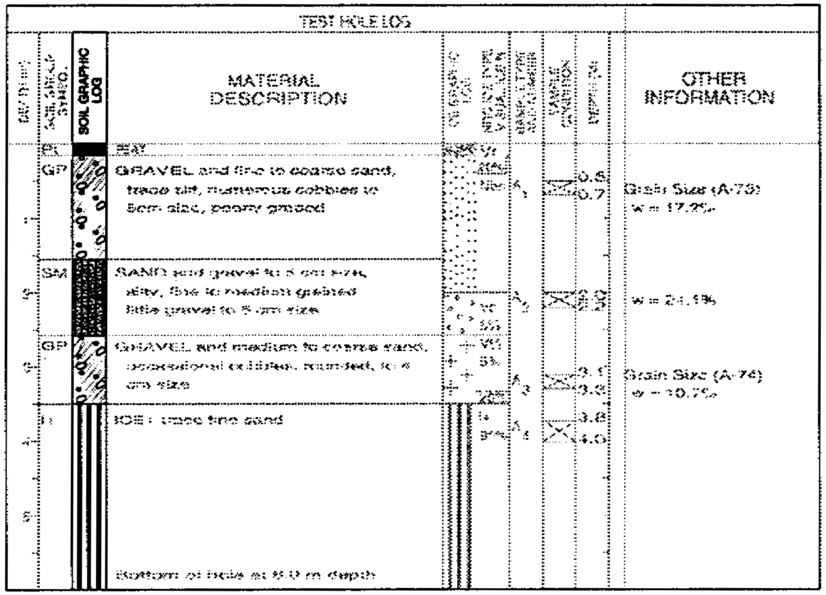


Illustration 7B--Interpreting Drill Log Forms---Written Description

The written description of buried sediments is based on the Modified Unified Classification System for Soils. In example 7B-1, the letter designation derived from the Unified Classification System is shown in the "soil group symbol" column. In example 7B-2 the Unified Classification is included with the written description, and this letter designation capitalized only where it has been confirmed by laboratory tests.

7C-1



7C-2

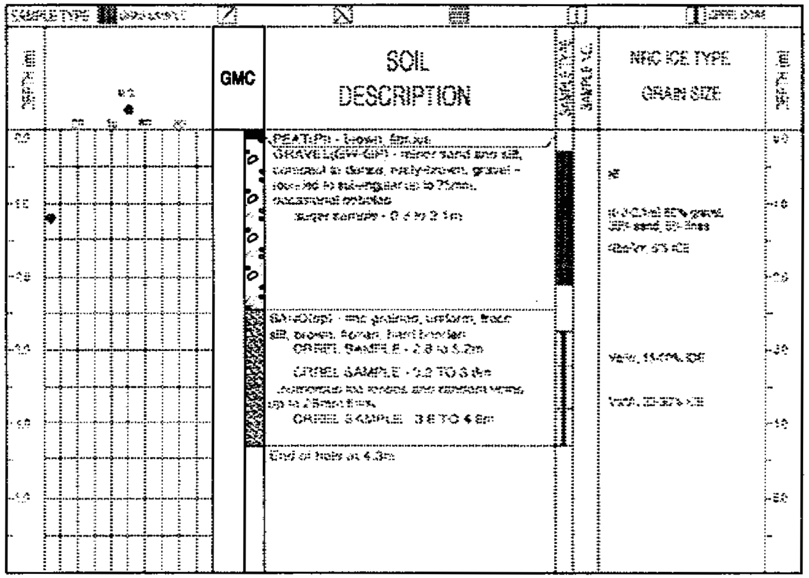
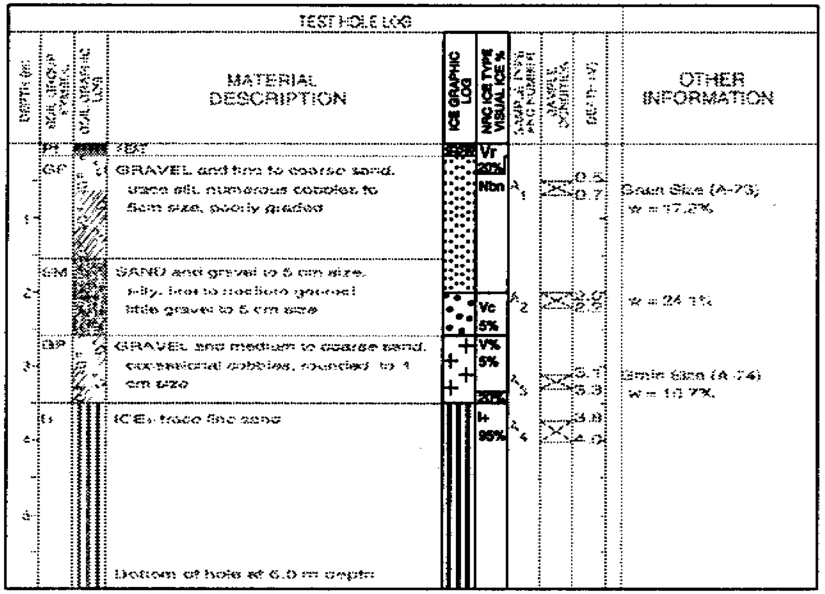


Illustration 7C--Interpreting Drill Log Forms---Graphic Log

A graphic log is generally presented to the left of the written description. The symbols used to indicate sediment type are commonly based on the Modified Unified Classification System for Soils but they are not always consistent between different reports.

7D-1



7D-2

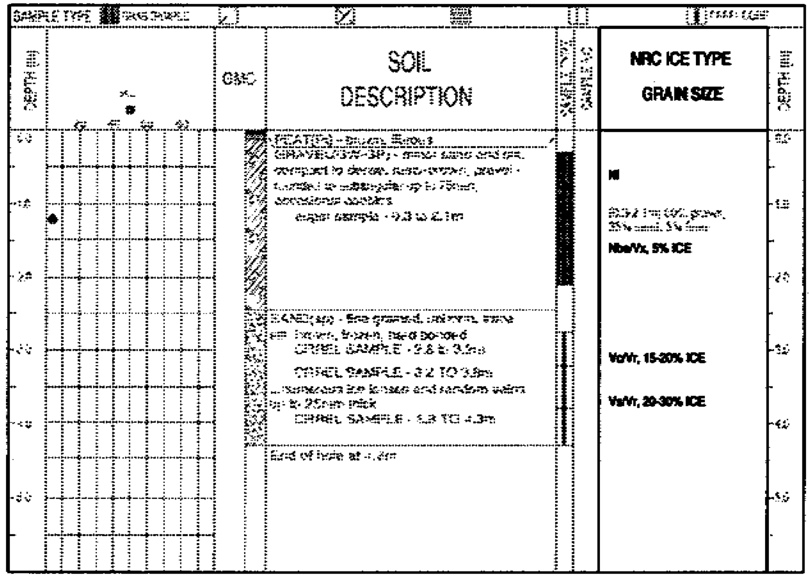
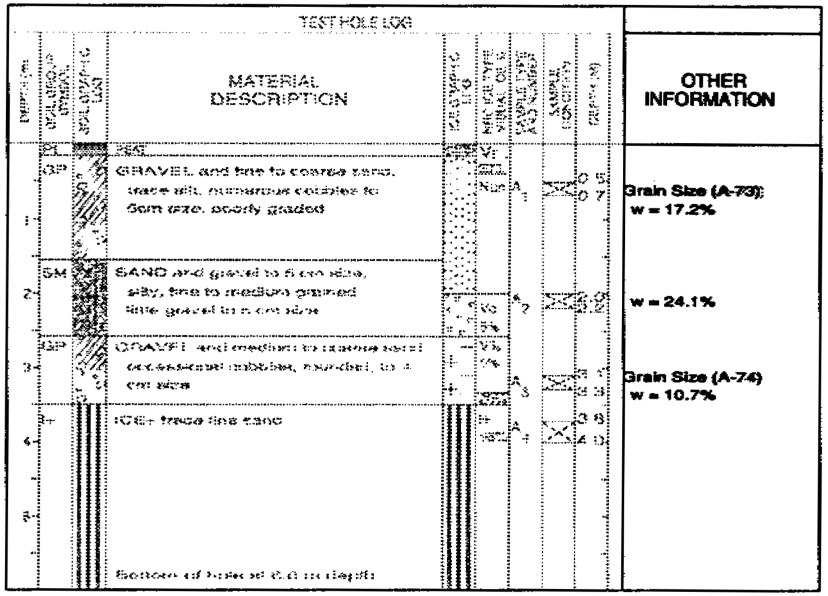


Illustration 7D--Interpreting Drill Log Forms---Ice and Ice Bonding

In both examples, the type of ice and ice bonding are recorded in the column for "NRC Ice Type". A visual estimate of ice content is also recorded in this column. The letter symbols used are based on the Ground Ice Classification Table. Example 7D-1 shows a graphic log of ice type based on the Ground Ice Classification Table.

7E-1



7E-2

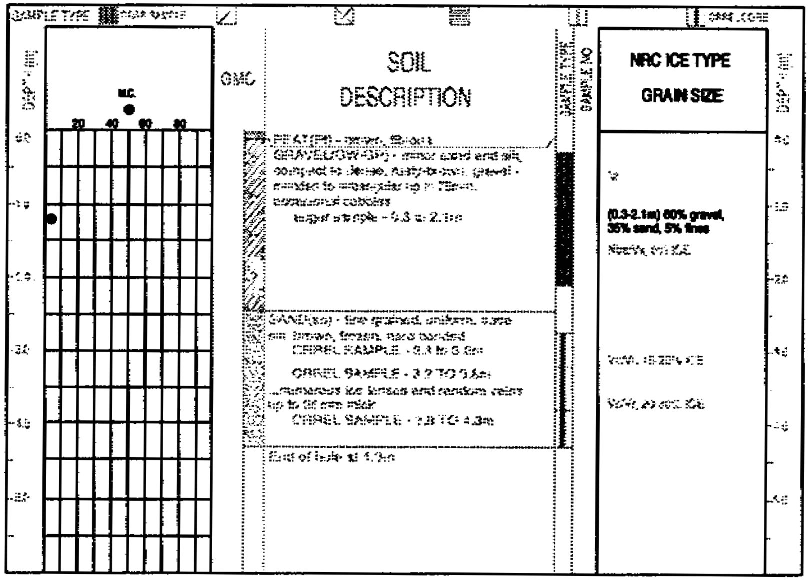


Illustration 7E--Interpreting Drill Log Forms---Laboratory Tests

Results of some of the laboratory tests are recorded on the logs [laboratory tests are discussed in Section 5]. In example 7E-1, moisture content for each sample analyzed is recorded in the column "other information" [w=moisture content]. Grain size analysis is not recorded but page reference where this can be found in the report is noted in the column "other information". In example 7E-2, grain size analysis is presented in the column "NRC Ice Type and Grain Size" on the right side of the log. Moisture content is presented in a graphic format on the left side of the log [M.C. refers to moisture content].

Moisture content is reported as % water by weight of dry sample and is not the same as the visual estimate of ice content which is % ice by volume of soil and ice combined.

5.0 LABORATORY TESTS

5.1 Introduction

Visual evaluation of sediments does not provide enough information to fully evaluate granular deposits. Samples are sent for laboratory tests to help determine potential uses of the granular material. The tests commonly used are summarized in Illustration 8 and discussed in more detail below. These tests are used to determine potential uses of the granular material as discussed in Section 7.2.

5.2 Moisture Content

This test is used to determine how much water is contained with the granular material by measuring weight loss when the sample is dried.. With the exception of samples collected near surface during the summer, ground temperatures are below freezing and the moisture is present as ice. Visual estimates of ice content are generally included on the drill logs as shown in Illustration 7D. Visual estimates of ice content are reported as volume percent ice by combined volume of soil and ice, and are generally less than moisture content which is reported as weight percent moisture by weight of dry sample.

Moisture contents in excess of 10% presents problems for both extraction and use of granular material [see Section 8]. Frozen sediments, particularly fine sand, with a high moisture content are hard bonded and difficult to extract. Thaw of previously permanently frozen ice rich sediments or massive ice may cause surface disturbances and flooding of the borrow pit which can affect the quality of, and limit access to, unextracted granular material. Granular material with a high moisture content is sometimes unsuitable for fill or for road building because the material could become wet and unstable as the ice melts. Granular material with a high moisture content is commonly stockpiled and permitted to thaw and drain before it is used.

Moisture content in granular deposits is dependent on the type of material, topographic considerations and depth from surface. Ice content is generally low in well drained areas which thaw during the summer. In low poorly drained areas and in permanently frozen ground, ice content is generally higher making the material more difficult to extract.

5.3 Grain Size Analysis

Grain size analysis is one of the most important tests used to evaluate granular material. The sample is passed through a series of screens to separate it into different size fractions. The amount of material in each of the different size ranges is reported as weight % of the whole sample. The results are presented on a graph as shown in Illustration 9.

Sediments composed primarily of sand and gravel sized grains make the best quality granular material [see Illustration 4]. A large proportion of fines are undesirable because they hold water which can lead to frost heaving and thaw slumping. Cobbles and boulders [stones over 3 inches] are also undesirable for most applications.

Grading, determined by grain size analysis tests, is the range of grain sizes within a sample. Deposits are referred to as well graded or poorly graded material as demonstrated in Illustration 10. Well graded granular material can be used to build a stable platform. Poorly graded material is more likely to shift or compact and cannot be used to build a strong pad to support heavy structures.

5.4 Petrographic Analysis

The type of rock fragments that make up sand and gravel deposits can affect the quality of the granular material. Some rock fragments such as quartzite, granite and hard sandstone are resistant to physical abrasion and chemical attack and make good quality granular construction material. Rocks such as dolomite, shale, ironstone and soft sandstone are more easily broken down into smaller fragments and therefore can have a negative impact on the quality of granular material.

For petrographic analysis, the pebbles are visually evaluated and the rock types classified according to their resistance to physical abrasion and chemical attack. The results are reported as the petrographic number [PN] for the sample. This is determined by mathematical calculation based on type and amount of the different rock fragments. Granular material with a PN of less than 160 is suitable for most construction purposes.

5.5 Tests to Determine Suitability of Granular Material for Concrete Aggregate

Concrete is about 60-80% granular material and therefore its properties are affected by the characteristics of the granular material. To be suitable for making concrete aggregate, granular material must be well graded, have a low fines content, low moisture content and low PN. When grain size analysis, moisture content tests and petrographic analysis indicate that the material may be of suitable quality the following additional tests may be conducted. It is generally necessary to test only a few samples [see Illustration 8] or to test bulk samples [several samples combined to determine an average for the deposit rather than provide site specific information] because suitability of granular material for concrete aggregate is in part dependent on factors, such as the types of rock fragments in the deposit, that do not vary substantially from site to site throughout the granular deposit.

The following tests are designed to determine how well the granular material will perform as concrete aggregate. They are done to specific laboratory standards. It is not critical to know how they are done or to be able to read the laboratory reports. It is important to know why the tests are done and how they are used to determine potential uses of the granular material [see also Section 7.2]. The tests are discussed below.

Los Angeles Abrasion Test

This test is used to determine how resistant the granular material is to physical abrasion. The gravel fraction of the sample is run through a small grinding mill designed to simulate conditions it would be subjected to in the making of concrete. The results are reported as a % of the gravel fraction that breaks down into smaller particles. Granular material with a Los Angeles Abrasion loss of less than 35% is suitable for making concrete aggregate.

Sulphate Soundness

This test is designed to determine how resistant the granular material is to weathering. To simulate natural weathering conditions the gravel fraction of the sample is placed in a sulphate solution. The results are reported as the % of the sample broken down by the sulphate solution during a set period of time. Granular material with a soundness loss of less than 12% is suitable for making concrete aggregate.

Alkali-Aggregate Reactivity

Chemical reaction between cement and granular material can cause deterioration of concrete. For this test a piece of concrete made using the granular material is placed in an alkali solution for a time period of 3 months to one year. Excessive expansion of the concrete indicates that the granular material may not be suitable making concrete aggregate. The results are sometimes reported as innocuous [no unfavorable reaction] or deleterious [unfavorable reaction].

Bulk specific gravity

Specific gravity is a ratio of the density [mass per unit volume] of the granular material relative to water. Granular material with a relatively low bulk specific gravity may not be suitable for uses such as concrete or riprap.

Absorption

Some particles in granular material can absorb water into pore spaces. For this test the granular material is immersed in water. The amount of water absorbed is reported as weight % increase. A high % of moisture absorbed indicates potential for freeze-thaw degradation of concrete.

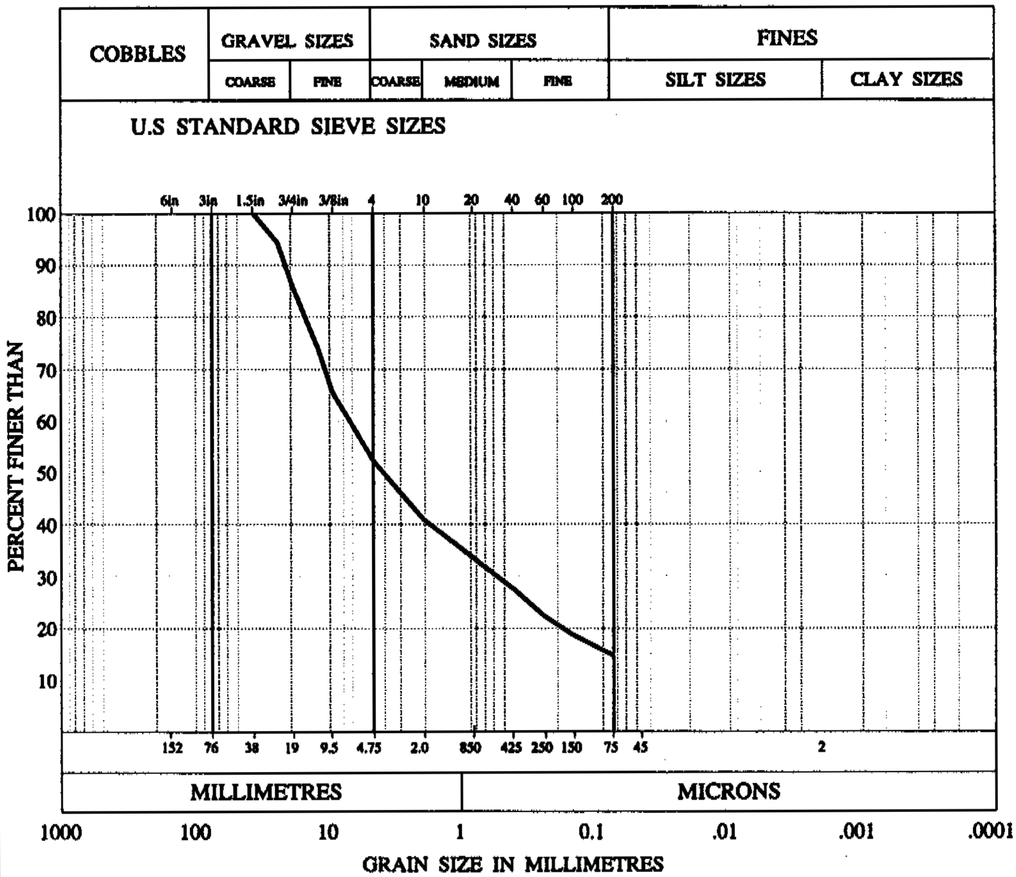
Organic impurities

Granular material that contains organics, such as peat or other fine woody material, may not be suitable for making concrete. The organic impurities test provides an approximate measure of the amount of organics in the granular material. If the deposit is found to contain organic material, further tests may be required to determine if the granular material is suitable for making concrete.

Test		Approximate Number of Tests Required	Rationale For Test
	Moisture Content	2 tests per 3 metres of drilling/test pitting	helps to determine difficulties extracting granular material, limitations on use of granular material and potential for drainage and flood control problems.
	Grain Size Analysis	3 tests per 10 metres of drilling/test pitting	helps to determine potential uses of the granular material.
	Petrographic Analysis	1 test per 5 drillholes/test pits	helps to determine rock types in the deposit and their impact on the quality of the granular material.
Test to Determine Concrete Aggregate Suitability	Los Angeles Abrasion	1 test per 10 drillholes/test pits	indicates resistance of particles in the deposit to physical abrasion.
	Sulphate Soundness	1 test per 10 drillholes/test pits	indicates resistance of particles in the deposit to weathering.
	Alkali-Aggregate Reactivity	1 test per 10 drillholes/test pits	indicates potential for adverse reaction between the granular material and cement.
	Bulk Specific Gravity	1 test per 10 drillholes/test pits	minimum specific gravity is required for some uses such as concrete and riprap.
	Absorption	1 test per 10 drillholes/test pits	indicates potential for freeze thaw degradation
	Organic Impurities	1 test per 10 drillholes/test pits	detects the presence of any organic material.

Illustration 8--Laboratory Tests Employed to Evaluate Granular Material.

This is a summary of some of the tests commonly used to evaluate granular material in the ISR. The number of tests required is only a general guideline and is dependent on factors such as the type of deposit and amount of exploration conducted.



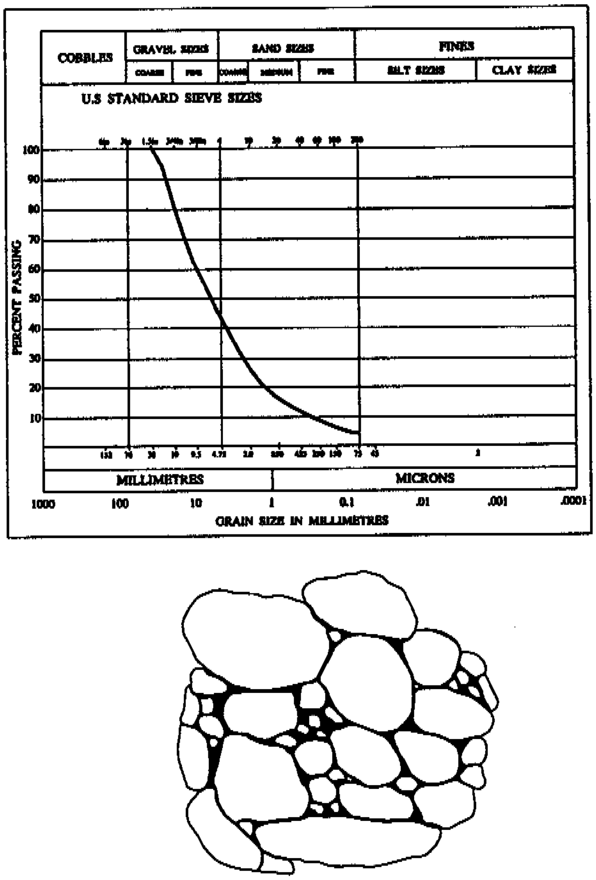
SUMMARY				
D_{10} -		mm	GRAVEL	48. %
D_{30} -	0.60	mm	SAND	36 %
D_{60} -	7.5	mm	FINES	16 %

Illustration 9--Grain Size Analysis

For this laboratory test, the sample is passed through a series of screens to separate it into different sized particles [particle size is shown in Illustration 4]. The amount of material in each size range is reported as a weight % of the whole sample. This information is generally presented on a graph as shown in this illustration. The horizontal scale on the top and bottom is grain size. The vertical scale to the left side is the proportion of the sample finer than the size indicated. The steeper the slope of the graph, the more uniform the grain size of the sample. The further the graph is to right, the finer the grain size of the sample.

On the graph in this illustration, 100% of the sample is finer than 1.5 inches indicating that there are no large stones [cobbles] in the sample. Reading down the graph along the boundary between fine sand and silt indicates that 16% of the sample is finer than sand and classified as fines. In the summary box, below the graph, is a written list of what percentage of the sample is in each of the main grain size groups. Using the Modified Unified Classification System for Soils this sample would be called GF and could be described as sand and gravel with some fines.

A - Well Graded



B - Poorly Graded

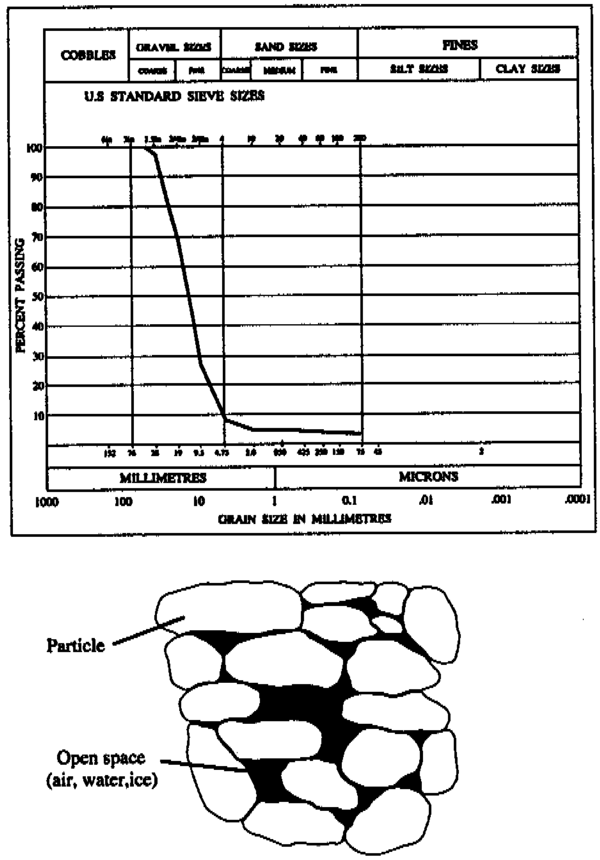


Illustration 10--Well Graded and Poorly Graded Granular Material

Well graded granular material [A] is a complete mix of grain sizes. This forms a stable base for construction purposes because smaller particles fill the spaces between larger particles minimizing any potential for compaction. Poorly graded material [B] is mostly one grain size, or has an unequal mix of grain sizes [in this example dominantly gravel sized particles]. Poorly graded material is more likely to shift or compact because spaces between grains are not filled. Therefore, poorly graded material does not form a strong pad that can be used to support heavy structures.

The grain size distribution graph for the well graded gravel shows a smooth curve from coarse gravel to fine sand. It is 56% gravel, 39% sand and 5% fines. The grain size distribution for the poorly graded gravel in this example shows a steep slope from coarse gravel to coarse sand. It is 92% gravel, 5% sand and 3% fines

6.0 DATA PRESENTATION

6.1 Introduction

The type of information collected and the way it is presented is not the same in all reports. There are generally maps showing location and extent of the deposit. Some of the information provided by the exploration program and laboratory testing is presented in maps and cross sections and/or summarized in tables.

6.2 Location Maps

Location maps are generally presented on a regional topographic map and include the deposit together with topographic features such as lakes and streams. The objective of this map is to show the location of the deposit relative to the community and major topographic features.

6.3 Detailed Maps

Detailed maps of granular deposits are commonly presented on a topographic base or aerial photograph. They are more detailed than the location map and show the deposit with location of test pits, sections and drill holes [Illustration 11]. Where aerial photographs are used, tonal differences on the photo may reflect vegetation cover and this can give some indication of subsurface conditions.

6.4 Cross Sections

A cross section is a side view of a vertical slice of the deposit [Illustration 12]. This is prepared from the data collected at the test pits, natural exposures and drill holes. Cross sections are an interpretation of subsurface conditions between tests sites and are therefore not perfectly accurate, but they do provide a good way to present this information and to visualize the deposit.

6.5 Isopach Maps

Isopach maps are used to show the thickness of a geological formation [Illustration 13]. They are prepared using data from the test pits, natural exposures and drill holes and generally presented on the same base as the detailed map of the deposit. Isopach maps are an interpretation of this subsurface data and are therefore not perfectly accurate but they do provide a good way to present this information and to visualize the deposit. These maps can be used to show areas, such as those with thick overburden cover or thin extractable material, that may be unsuitable for development.

6.6 Tables

Tables are not presented in all reports, but where available they can provide an easy to use summary of the important data from the drill logs and laboratory tests.

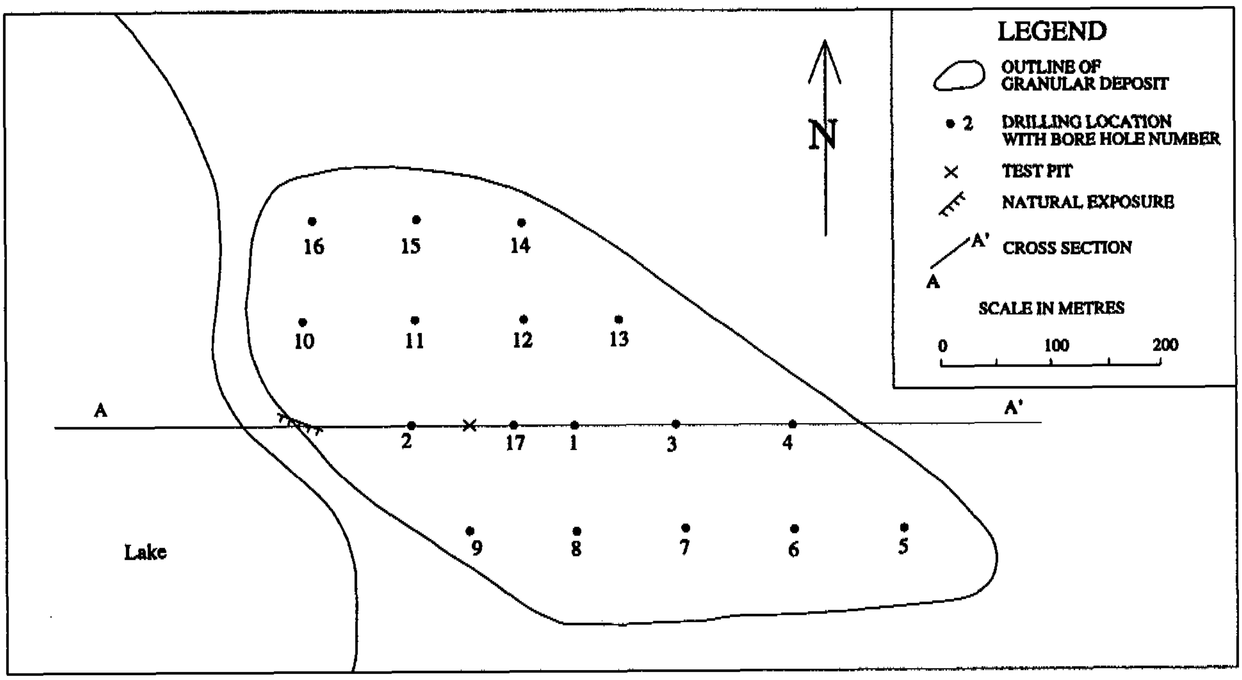


Illustration 11--Detailed Plan Map of the Granular Deposit

In our example, from Illustration 2, additional exploration drilling is conducted to further evaluate subsurface conditions. Illustration 11 is a detailed map showing the size and location of the deposit, and the locations of the natural exposure, test pit and drill holes. The north arrow shows the orientation of the map. The line of cross section A--A' shows the surface location of the vertical slice of the deposit shown in Illustration 12.

The symbols used and scale of the map are explained in the legend.

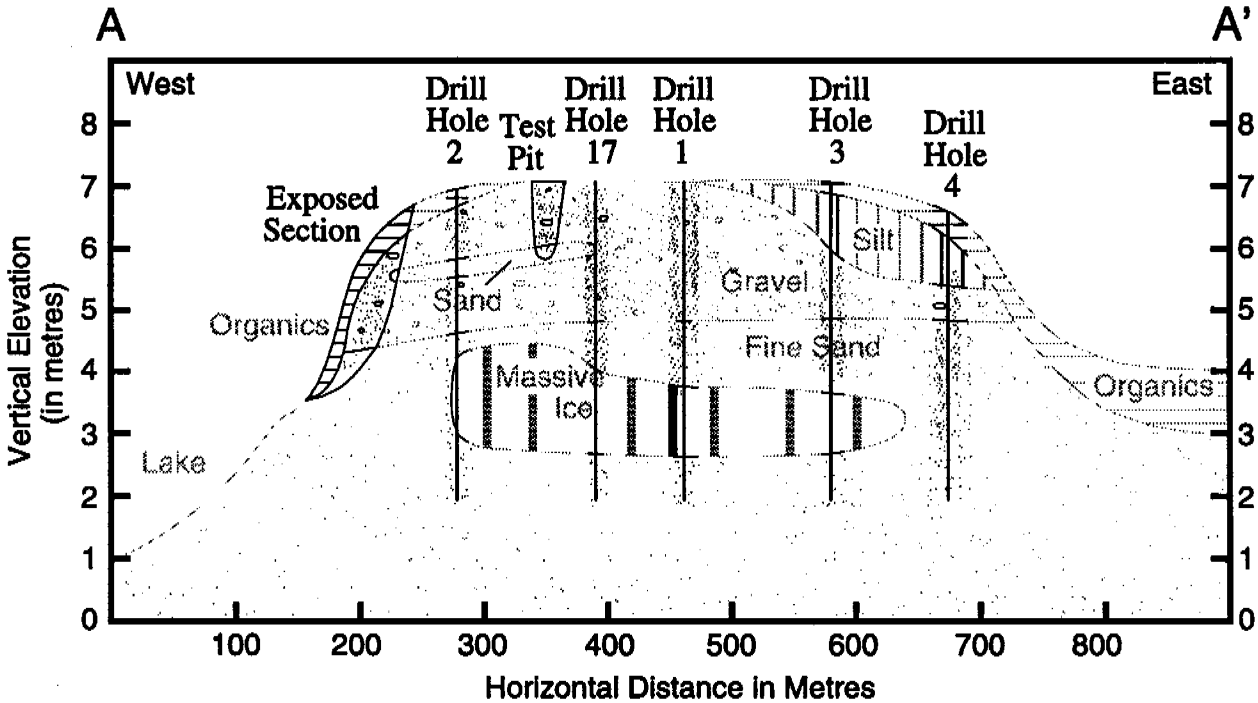


Illustration 12--Cross Section of the Granular Deposit

Results of the exploration drilling are presented in this cross section [side view of a vertical slice through the deposit]. Subsurface conditions between test sites are approximated based on the information provided at the test sites. Drill holes on 100 metre spacings generally provide sufficient information to guide borrow pit development and restoration.

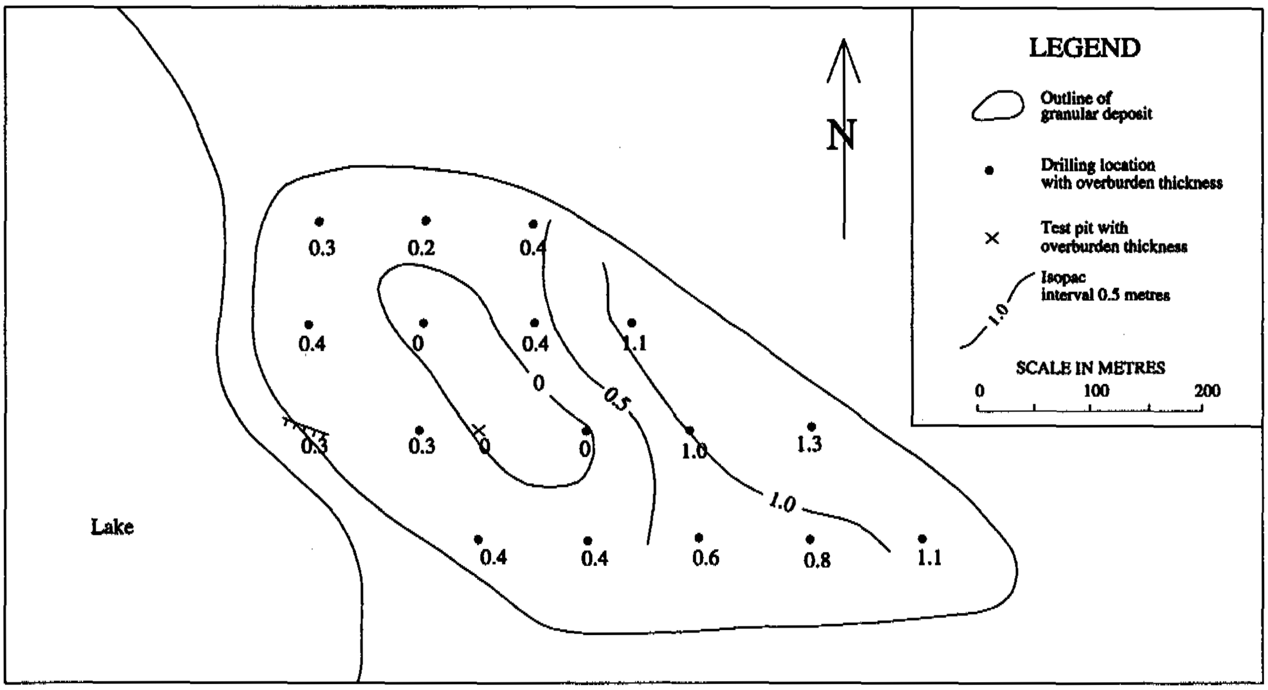


Illustration 13--Isopach Map of the Granular Deposit

This is an Isopach map showing the thickness of overburden cover [organics and silt overlying the sand and gravel] at our example granular deposit. The reported thickness of overburden is shown beside the test sites. Assumed thickness between test sites is shown by lines joining points of equal thickness. Overburden cover is thin in the central, north and west parts of the deposit but exceeds one metre on the east side of the deposit. This map provides a good visual presentation of areas of thick overburden cover where it may be economically impractical to extract the buried granular material.

7.0 RESERVES OF GRANULAR MATERIAL

7.1 Introduction

Granular reserves are the amount of granular material in a deposit. This is determined by multiplying surface area of the deposit by average thickness of granular material [Illustration 14]. Reserves are commonly subdivided by quality of the material [Section 7.2] and level of confidence in the estimate of reserves [Section 7.3].

7.2 Classification of Granular Materials

Data provided in the drill hole logs [Section 4] and by laboratory tests [Section 5] is used to determine the quality [class] and potential uses of granular material. These classes are summarized below.

Class 1--Excellent quality material

- *Gradation*
  Well graded sand and gravel with less than 5% fines.
- *Moisture content*
  Ideally less than 10% but higher moisture content can be reduced by drying.
- *Technical parameters*
  PN less than 160. Los Angeles Abrasion loss less than 35%. Sulphate soundness loss [Magnesium Sulphate] less than 12%. Meets other requirements of CSA A23.1-1973.
- *Uses*
  Portland cement concrete, asphaltic concrete, masonry sand, concrete block, surface treatment and roofing aggregate. This can be used as high quality surfacing material, but sources of Class 1 material are scarce in the ISR and, therefore, commonly reserved for making concrete.

Class 2--Good quality material

- *Gradation*
  Well graded sand and gravel with less than 10% fines
- *Moisture content*
  Ideally less than 10% but higher moisture content can be reduced by drying.
- *Technical parameters*
  PN less than 200. Los Angeles Abrasion loss less than 60%. Any fines in excess of 10% can be removed with minimal processing

- *Uses*

  Pads for structures, granular base and sub-base, winter fill for trenches and slabs. Class 2 material can be used in highway construction but is commonly reserved as a source of lower quality concrete aggregate or structural fill.

Class 3--Fair quality material

- *Gradation*

  Poorly graded sand and gravel with less than 20% fines
- *Moisture content*

  Ideally less than 10% but higher moisture content can be reduced by drying.
- *Technical parameters*

  PN less than 250. Can be processed to meet local frost susceptibility criteria.
- *Uses*

  Pads for equipment, granular sub-base, general backfill. Class 3 material with a high fines content is ideal as a road surfacing material which requires the presence of a binding agent. This provides fair quality general fill for roads, foundation pads or lay-down yards.

Class 4--Poor quality material

- *Gradation*

  Poorly graded granular material with more than 20% fines
- *Moisture content*

  Ideally less than 10% but higher moisture content can be reduced by drying.
- *Technical parameters*

  None. May contain weak particles and deleterious materials.
- *Uses*

  General non-structure supporting fill.

Class 5--Bedrock, felsenmeer [broken bedrock in open area] and talus [broken bedrock at base of a slope]

Bedrock generally requires crushing before it can be used as granular material. Crushed bedrock may provide excellent sources of construction material ranging from general fill to concrete aggregate and erosion control material such as rip-rap or armour stone. Quality of the granular material is dependent primarily on the quality of the rock [see Section 5.4].

7.3 Confidence Level for Estimates of Granular Reserves

The differences between proven, probable and prospective granular reserves are shown in Illustration 15 and discussed below.

Proven

Reserves of granular material are considered to be proven [Illustration 15, Area A] if the distribution, thickness and quality has been tested by ground truth information such as drilling, test pitting and/or exposed sections. For purposes of calculating reserves, an area of 50 metres on all sides of a drill hole or test pit is generally considered proven [with some adjustments based on how consistent the type and thickness of granular material is from site to site and other geological considerations].

Probable

Reserves of granular material are considered to be probable [Illustration 15, Area B] if the distribution, thickness and quality is inferred on the bases of both direct [drill holes, test pits and/or exposed sections] and indirect evidence [topographic setting and landform characteristics]. Probable reserves reported for a deposit will include the proven reserves.

Prospective

Reserves of granular material are considered to be prospective [Illustration 15, Area C] if the distribution, thickness and quality is inferred from indirect evidence such as aerial photographic interpretation [topographic setting and landform characteristics] and general geological considerations. Prospective reserves reported for a deposit will include the proven and probable reserves.

7.4 Summary of Reserves of Granular Material in the ISR

Summaries of granular reserves in the ISR are provided in the series of reports titled "Inuvialuit Settlement Sand and Gravel Inventories and Recommendations for Development" [EBA, 1987] and in "Report on Evaluation of Granular Resource Potential MacKenzie Delta Region" [Hardy BBT Limited, 1991]. An example of the EBA presentation is shown in Illustration 16.

In reporting prospective reserves there are significant differences between bedrock and granular sources. It is relatively simple tp speculate on the amount and quality of material at a bedrock source and prospective reserves generally become proven when exploration work is conducted. However, topographic features such as glacial landforms that are considered to contain prospective reserves of granular material often turn out to be unsuitable for development.

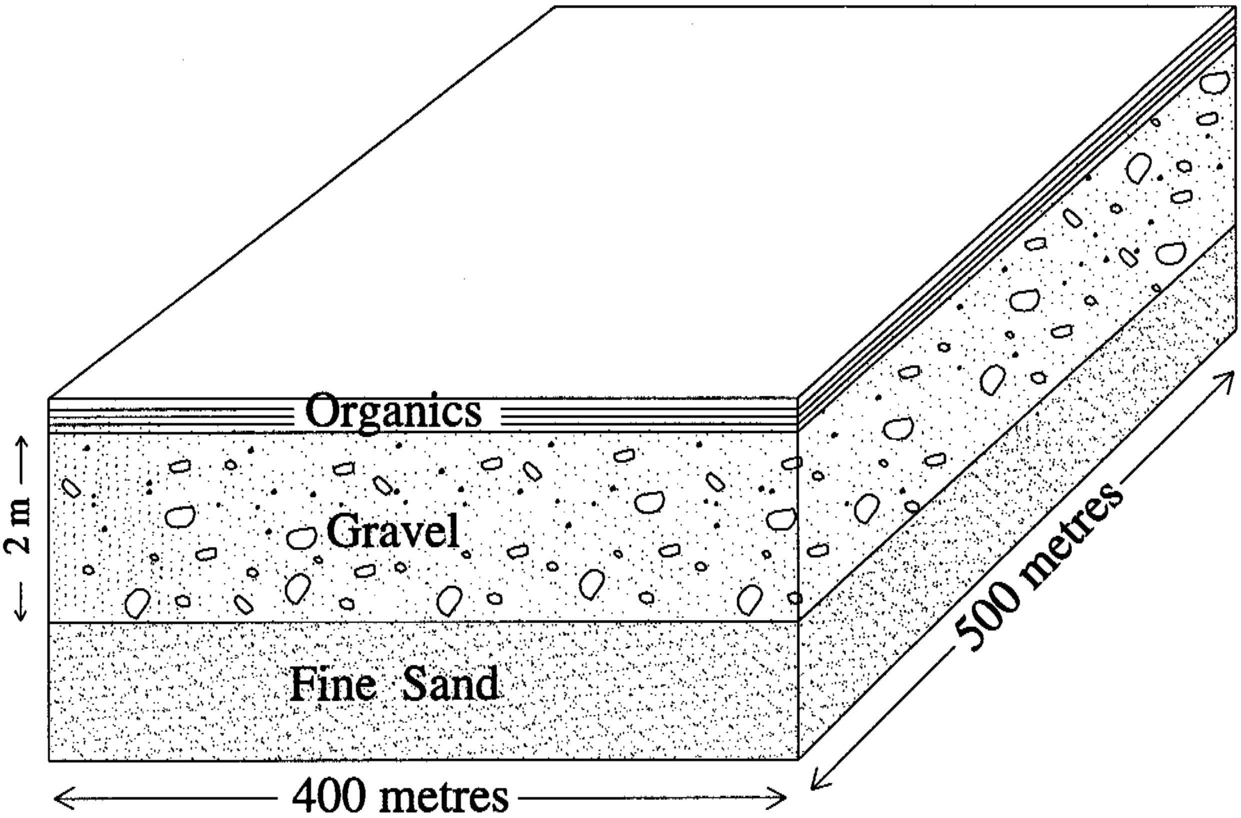


Illustration 14--Calculating Reserves of Granular Material

This is an idealized example of a deposit with surface dimensions of 400 by 500 metres. Surface area is 200,000 square metres [500 multiplied 400]. The granular material is 2 metres thick and therefore reserves are 400,000 cubic meters [200,000 multiplied 2].

In real deposits, it is neither as simple nor exact as show in this example. Deposits are irregular in outline and, thickness of granular material is variable.

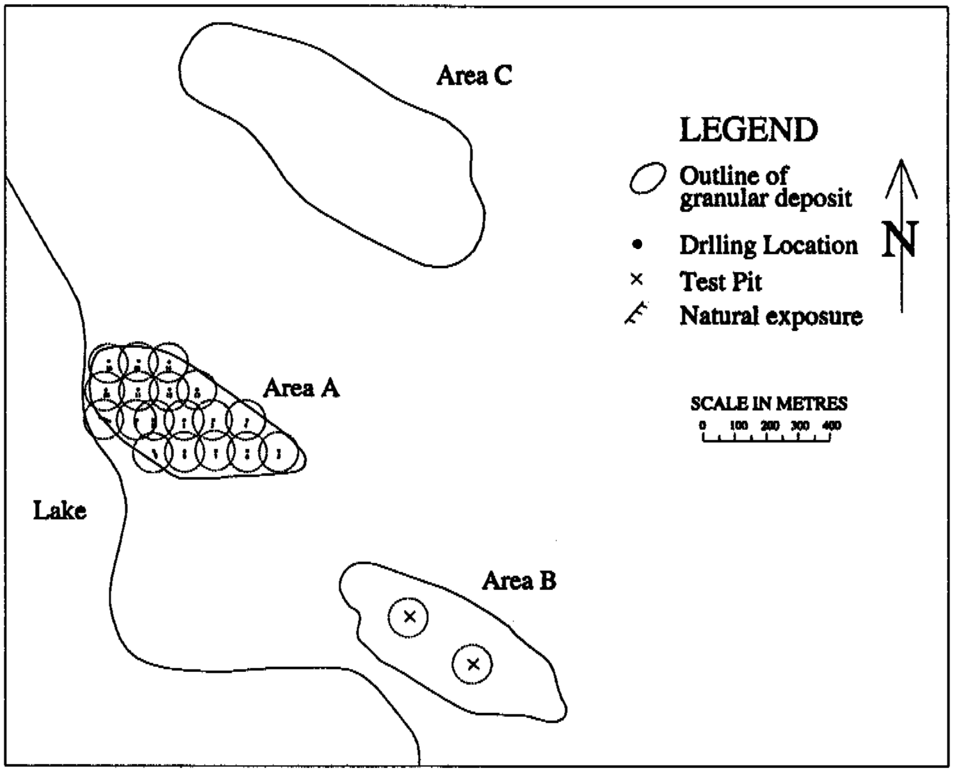


Illustration 15--Confidence Level for Estimates of Granular Reserves

This is a map of our example deposit with two nearby hills and demonstrates the difference between proven, probable and prospective reserves. For calculating reserves an area of 50 metres on all sides of a exposed section, test pit or drill hole is considered proven.

In Area A [our example deposit from Illustration 11], drill holes are about 100 metres apart. The 50 metre radius circles drawn around all test sites in this example, demonstrate that the deposit is fully tested by the drill holes. Reserves of granular material are considered **proven.**

In Area B, there are 2 test pits, both of which intersected granular material. It is expected that the rest of the hill contains similar granular material. To determine reserves, the surface area of the deposit is estimated based on studies of aerial photographs and from topographic and geological considerations. The thickness and quality of granular material is estimated based on topographic and geological considerations and from information provided by the test sites in areas A and B. The granular reserves in this hill are considered **probable.** Only the reserves within 50 metres of the test pits are considered proven.

In Area C, there has been no on-site exploration. Interpretation of aerial photographs indicates that this hill is similar in character to Areas A and B and may contain granular material. To determine reserves, the surface area of the deposit is estimated based on studies of aerial photographs and from topographic and geological considerations. The thickness and quality of the granular material in the deposit is estimated based topographic and geological considerations and from information provided by exploration in Areas A and B. Reserves of granular material in Area C are considered **prospective.**

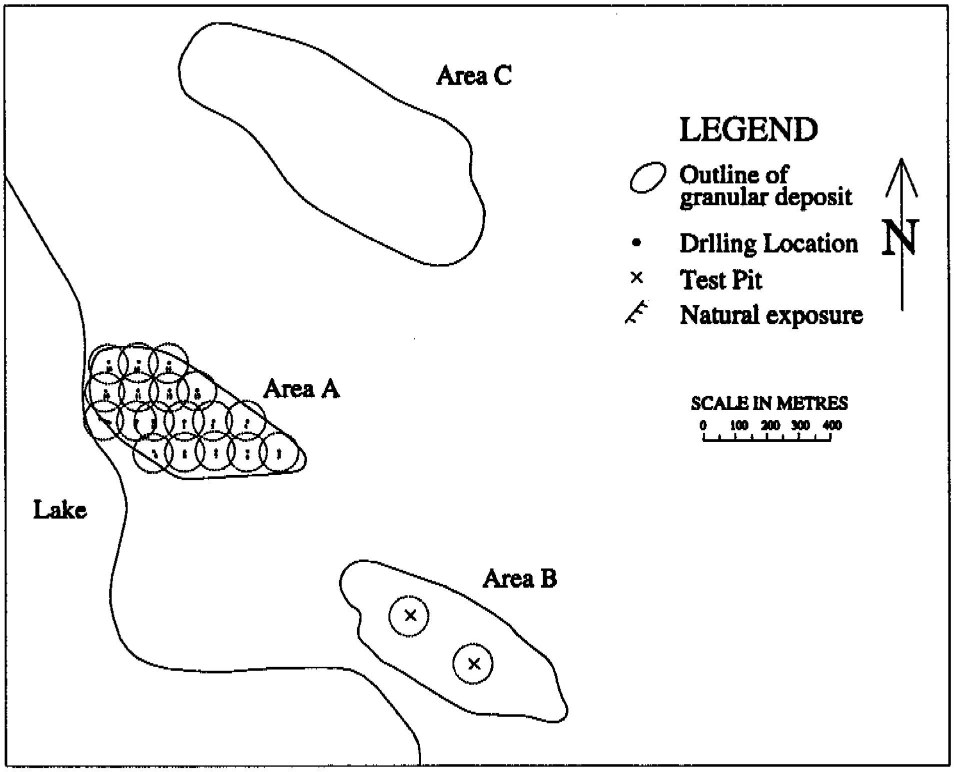


Illustration 15--Confidence Level for Estimates of Granular Reserves

This is a map of our example deposit with two nearby hills and demonstrates the difference between proven, probable and prospective reserves. For calculating reserves an area of 50 metres on all sides of a exposed section, test pit or drill hole is considered proven.

In Area A [our example deposit from Illustration 11], drill holes are about 100 metres apart. The 50 metre radius circles drawn around all test sites in this example, demonstrate that the deposit is fully tested by the drill holes. Reserves of granular material are considered **proven.**

In Area B, there are 2 test pits, both of which intersected granular material. It is expected that the rest of the hill contains similar granular material. To determine reserves, the surface area of the deposit is estimated based on studies of aerial photographs and from topographic and geological considerations. The thickness and quality of granular material is estimated based on topographic and geological considerations and from information provided by the test sites in areas A and B. The granular reserves in this hill are considered **probable.** Only the reserves within 50 metres of the test pits are considered proven.

In Area C, there has been no on-site exploration. Interpretation of aerial photographs indicates that this hill is similar in character to Areas A and B and may contain granular material. To determine reserves, the surface area of the deposit is estimated based on studies of aerial photographs and from topographic and geological considerations. The thickness and quality of the granular material in the deposit is estimated based topographic and geological considerations and from information provided by exploration in Areas A and B. Reserves of granular material in Area C are considered **prospective.**

INDIAN AND NORTHERN AFFAIRS CANADA
INUVIALUIT SETTLEMENT SAND AND GRAVEL INVENTORY AND RECOMMENDATIONS FOR DEVELOPMENT

GRANULAR RESOURCES SUPPLY SUMMARY
Inuvik

SOURCE: I401A

LOCATION: 10km N of Inuvik

REFERENCE(S): RKL 1973,Inuvik; H-BBT 1986

SETTING Hillocks bisected by streams	RELIEF 3 to 5 metres	WINTER ACCESS Tundra/ice road
LANDFORM Kame field	CONTINUITY 2 sources	SUMMER ACCESS None
AREA 1.1 sq km	DEVELOPMENT CONSTRAINTS Wildlife, poor quality	

BOREHOLES (#) 6	TEST PITS (#) 5
MOIST. CON. (#) 7	GRAINSIZE (#) 5

	OVERBURDEN	GROUND ICE
TYPE:	Silt, organics	Massive, excess
EXTENT:	All holes	Intermittent
THICK.:	Up to 0.76 m	Lenses up to 0.6 m

POTENTIAL VOLUME, cu. m. : 1,020,000 RECOVERABLE, cu. m.: 1,020,000

MATERIAL	PROVEN, cu. m. Annual	PROVEN, cu. m. Total	PROBABLE, cu. m. Annual	PROBABLE, cu. m. Total	PROSPECTIVE, cu. m. Annual	PROSPECTIVE, cu. m. Total
CLASS 1						
CLASS 2						
CLASS 3			250,000	750,000	250,000	1,020,000
CLASS 4						
CLASS 5						

Illustration 16--Summary of Reserves of Granular Material in the ISR

Information on individual granular deposits in the ISR is available in summary format. This example is from a series of reports titled "Inuvialuit Settlement Sand and Gravel Inventory and Recommendations for Development" [EBA, 1987] and includes: location and access, topographic and geological setting, amount of exploration, development constraints, type and amount of granular material, type and amount of overburden, type and amount of ice.

8.0 BORROW PIT OPERATIONS

8.1 Introduction

Extracting granular material in cold northern areas is difficult and expensive. This is primarily because the ground is frozen and granular deposits commonly contain large volumes of ice. Logistical and environmental problems associated with borrow pit operations are largely dependent on the moisture content of the sediments, the amount of buried ice, the depth of thaw [Illustration 17] and the season when the work is conducted.

Some of the problems associated with operating borrow pits in permanently frozen ground are discussed in "Environmental Guidelines Pits and Quarries" [MacLaren Plansearch, 1989]. In reports on individual deposits there are suggestions as to how they can be developed with minimal environmental disruption. Borrow pit development is discussed briefly in this section and demonstrated in Illustration 18.

8.2 Winter Development

If there is not an all weather road to the deposit, extraction of the granular material is commonly conducted in winter when the site can be accessed by winter road. Building new roads or docking facilities for transporting aggregate in the summer is expensive and uses some of the aggregate. Where possible, winter roads are built on frozen waterbodies to minimize costs and environmental impact. The working season is often limited to a few weeks in late winter and must be completed while the winter road is strong enough to support hauling equipment.

Granular deposits are developed in stages. Any organics and overburden overlying the granular material are bulldozed off and carefully stockpiled so that they can be replaced at surface when the deposit is abandoned. The granular material is broken up by a bulldozer equipped with a ripper, pushed into stockpiles, loaded into trucks and hauled to the community.

For winter operations, extracting frozen overburden and granular material with a moisture content over 10% is slow, difficult and expensive. Moisture content of overburden and granular material in the ISR is commonly less than 10% in areas near surface that thaw each summer [the active layer], but exceeds 10% in permanently frozen ground [permafrost]. Consequently, the thickness of material that can be economically extracted in one winter working season is often limited to the depth of summer thaw [less than 0.6 metres where there is a continuous cover of organics, and 1 to 2 metres where granular material is exposed at surface]. For this reason, deposits are commonly stripped of their organic cover and left exposed during the summer to permit the granular material to thaw and drain. In this manner, moisture content and ice bonding is reduced sufficiently that 1 to 2 metres of granular material can be extracted the following winter.

Where massive ice or sediments with a high moisture content are exposed by borrow pit operations, large volumes of water will be released during the summer thaw. Drainage control measures may be required to avoid environmental damage or flooding of the pit surface, which could complicate access to the remaining granular material the following winter.

8.3 Summer Development

If there is an all-weather road to the deposit, borrow pit operations can be conducted in the summer. As in winter operations, organics and overburden are bulldozed off the surface and stockpiled such that they can be replaced when the deposit is abandoned. The granular material is bulldozed into stockpiles and hauled to the community. Extracting granular material in the summer is sometimes easier because the working surface is not frozen. Unfrozen material is stripped back, permitting thaw of previously buried and frozen granular material. In this manner it is possible to extract several meters thickness of material in one season.

Where the granular material has a high moisture content or buried massive ice is exposed to thaw, extensive drainage control systems may be required to keep the working surface free of water. Drainage ditches are commonly used to direct water from the pit surface to a lower level but these ditches can be difficult to maintain as buried ice melts. Where water cannot be directed away from the working surface, it may prove difficult to use heavy earth moving equipment in the borrow pit and the moisture content in the granular material may be higher than desirable.

At some deposits, where there is no all-weather road, the granular materials are extracted and stockpiled during the summer and then hauled to the community on ice road during the winter. If moisture content of the stockpiled granular material is over 5%, freezing of this stockpile may make it difficult to reclaim in the winter.

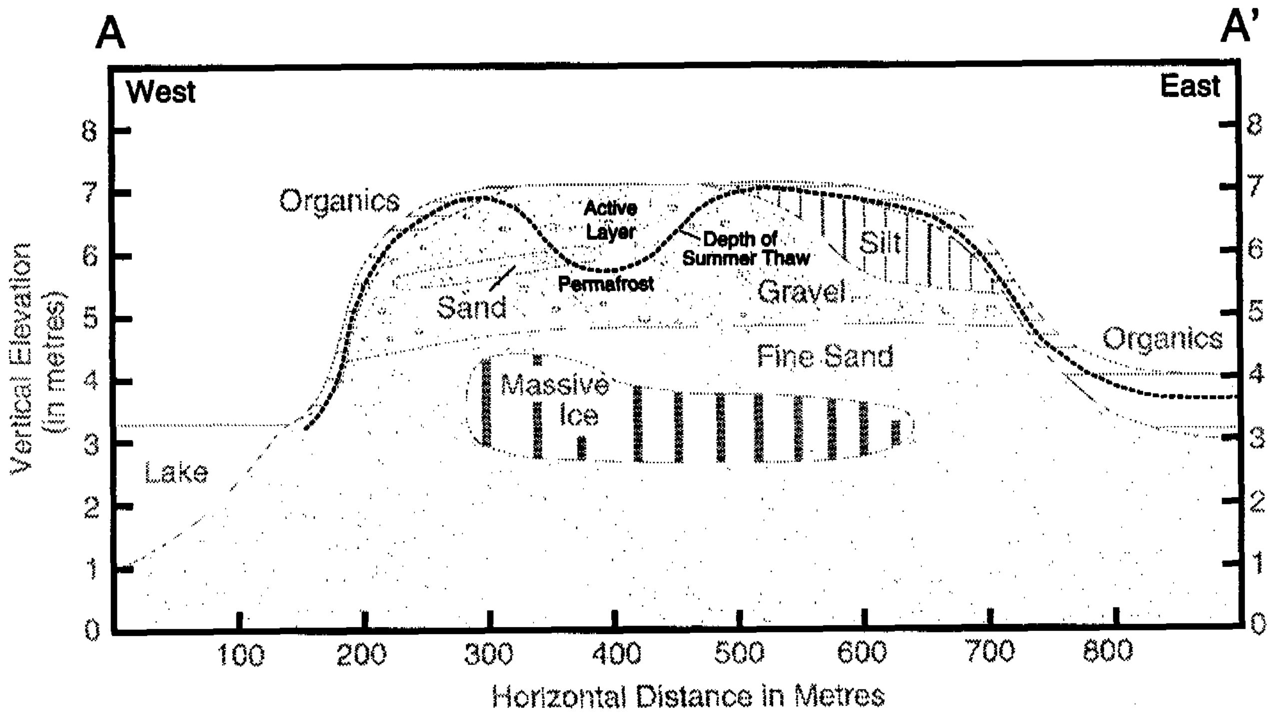


Illustration 17--Depth of Summer Thaw

With the exception of a thin layer at surface that thaws each summer, ground in the ISR is permanently frozen. Depth of summer thaw is generally 1 to 2 metres where granular material is exposed at surface and less than 0.6 metres where there is a cover of organics to provide insulation. The zone between land surface and permafrost [permanently frozen ground] that thaws each summer is called the active layer.

Extracting frozen overburden and granular material with a moisture content over 10% is difficult. Moisture content is generally lower and granular material easier to extract in the active layer of well drained granular deposits than in permanently frozen ground or poorly drained areas because some of the water is released during the summer thaw.

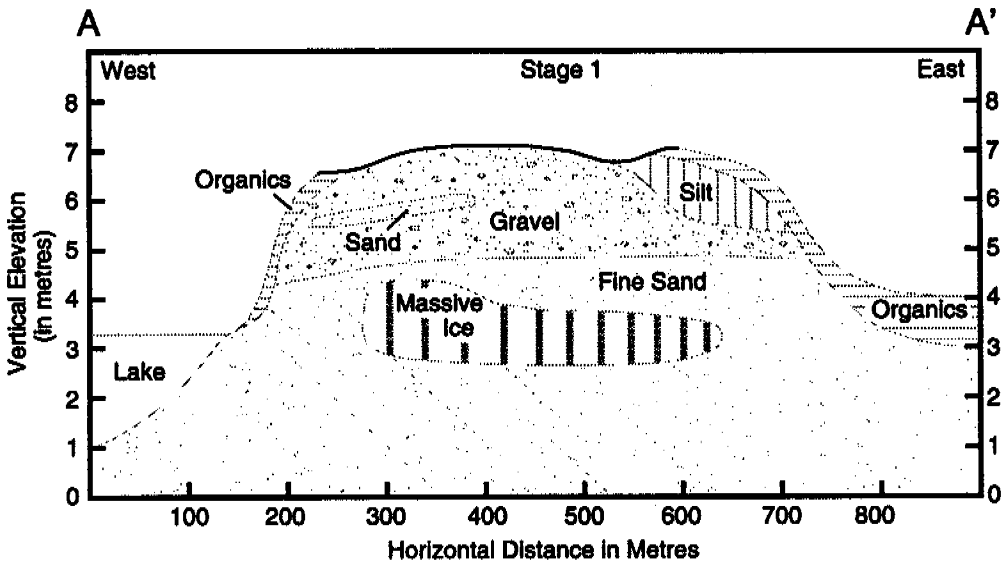
Illustration 18--Borrow Pit Development

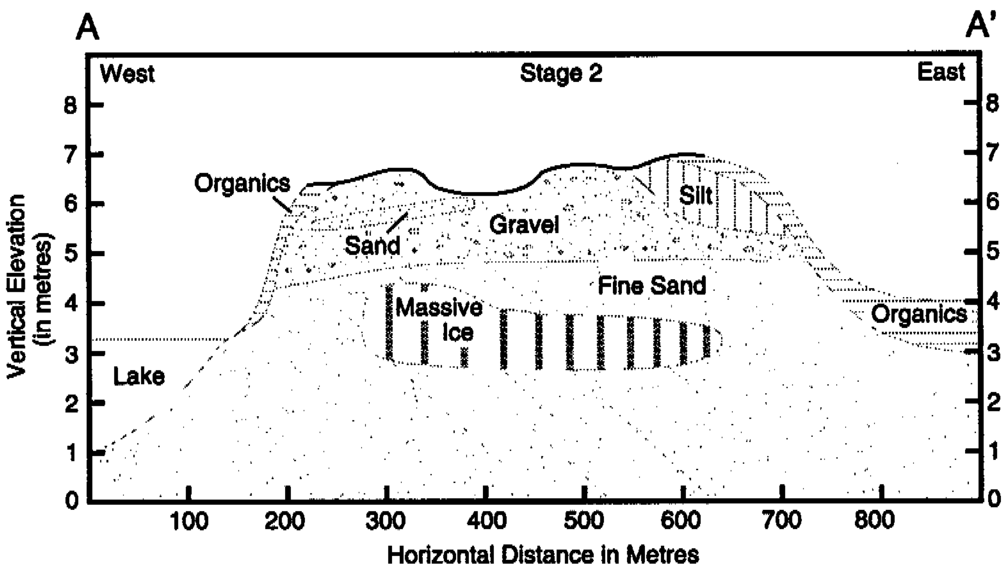
This series of diagrams shows development at our example borrow pit. This is simplified showing only three stages. In most deposits, only a part of the borrow pit would be worked at one time and development would extend over several years.

Stage 1 Organics and overburden are removed from the areas to be developed. This provides access to, and permits thaw of, the underlying granular material. Fine grained sediments, such as silt, are commonly frozen solid [hard bonded] and difficult to remove. For this reason, removing the thick overburden cover on the east side of the deposit to access the underlying granular material is economically impractical. A narrow ridge of undisturbed organics and granular material is left on the west side of the deposit to provide a protective barrier between the lake and the borrow pit.

Stage 2 Areas where the granular material is loosely bonded and easily extracted [where there was no organic cover prior to development] are exploited first. In other parts of the deposit, the frozen granular material has a higher moisture content and is more difficult to extract [hard bonded].

Stage 3 Extraction of the granular material progresses in stages. If material is to be extracted during the winter, areas stripped of organics are commonly left exposed during the summer to permit the granular material to thaw and drain to reduce moisture content and ice bonding. The following winter, 1 to 2 metres thickness of material at surface is more loosely bonded and can be extracted. If the borrow pit is worked during the summer, extraction of granular material can progress several metres in one season as unfrozen material is stripped back exposing frozen ground to thaw. The borrow pit is permanently abandoned when all of the extractable granular material has been removed [see Illustration 20 Stage 1].


A
A'
West
Stage 1
East
Organics
Sand
Gravel
Silt
Fine Sand
Massive Ice
Organics
Lake
Vertical Elevation (in metres)
Horizontal Distance in Metres


A
A'
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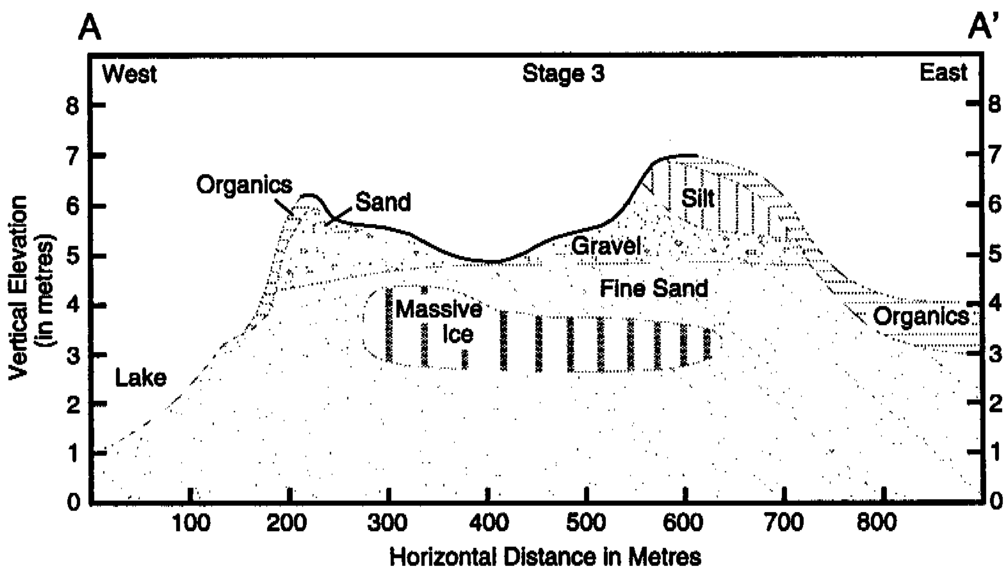
Stage 2
East
Organics
Sand
Gravel
Silt
Fine Sand
Massive Ice
Organics
Lake
Vertical Elevation (in metres)
Horizontal Distance in Metres


A
A'
West
Stage 3
East
Organics
Sand
Gravel
Silt
Fine Sand
Massive Ice
Organics
Lake
Vertical Elevation (in metres)
Horizontal Distance in Metres

9.0 REHABILITATING ABANDONED BORROW PITS

9.1 Introduction

Many of the abandoned borrow pits in the ISR are visually unattractive because they lack vegetation, have steep slopes not in keeping with the natural landscape and are marked by irregular water filled depressions. Steep slopes were left on the margins of some pits when they were abandoned and depressions formed as buried ice melted. Vegetation is generally very slow to redevelop because there is insufficient organic material at surface to support growth. Examples of abandoned borrow pits are shown in Illustration 19.

The visual appearance of borrow pits can be improved with human assistance. Rehabilitation measures are discussed in "Reclamation Guidelines for Northern Canada" [Hardy BBT Limited, 1987] and "Environmental Guidelines Pits and Quarries" [MacLaren Plansearch, 1989]. In reports on specific granular deposits in the ISR, there are generally suggestions as to how the deposit can be worked to minimize environmental damage and how it can be restored when it is abandoned. It is not the objective of this manual to reproduce these works but some rehabilitation measures are discussed in this section and depicted in Illustration 20.

9.2 Recontouring Abandoned Borrow Pits

It is recommended in "Environmental Guidelines Pits and Quarries" that borrow pits be recontoured so that no slopes are greater than 2 to 1 [two horizontal to one vertical]. The objective is to leave the borrow pit with slopes that are in keeping with the natural landscape, control drainage and minimize erosion. This can be accomplished where buried ice is not exposed to thaw. Where buried ice is exposed to thaw, any recontouring efforts could potentially expose more buried ice, initiate more thaw induced collapse, and lengthen the time required for slopes to stabilize. For this reason, where there is buried ice near surface, it may be advisable to permit some steep slopes to stabilize naturally rather than attempt extensive recontouring.

9.3 Revegetation of Abandoned Borrow Pits

Healthy vegetation cover improves the visual appearance of abandoned borrow pits and helps to stabilize slopes and insulate buried ice from thaw. However, re-establishing vegetation growth in abandoned borrow pits in cold northern regions is a very slow process. Where organic material has been replaced it may take several years for vegetation to re-establish. Where there is no organic material at surface it may take decades for vegetation to re-establish.. It may be possible to assist vegetation growth by fertilizing and reseeding. Revegetation measures are discussed in "Reclamation Guidelines for Northern Canada" [Hardy BBT Limited, 1987].

9.4 Storage and Replacement of Organic Material

The natural organic cover at surface in the ISR has taken up to 13,000 years to develop [see section 2.3]. This is a rare and valuable resource, critical for the rehabilitation of abandoned borrow pits. Replacing the organic material after borrow pit abandonment can significantly reduce depth of thaw and provide nutrients and native seed for vegetation regrowth.

It is recommended ["Reclamation Guidelines for Northern Canada" and "Environmental Guidelines Pits and Quarries"] that organics cleared from surface during borrow pit operations be stockpiled and later replaced when work is completed. This is not always done at borrow pits in the ISR. Stockpiling organics for future replacement is difficult. The natural organic cover at most granular deposits in the region is thin and organics stockpiled for several years may lose part of their volume due to wind erosion. Furthermore, borrow pit operations are often conducted in the winter when the materials are frozen and it is difficult to separate organics from the underlying material. In practice, the material available after abandonment may be a frozen mix of overburden, gravel, and organics that can provide only a thin and discontinuous coverage to the borrow pit surface. In many cases in the ISR, organic material has been pushed off the edge of the deposit and not replaced to assist vegetation growth in the pit.

It would be possible to provide a more successful rehabilitation of abandoned borrow pits if the organics are carefully stockpiled and replaced. A few suggestions for handling organic material are listed below:

- Organics and fine grained overburden should be stockpiled separately. If the organics and overburden are both thin and it is impractical to separate them, they could be stockpiled together and used as organics.

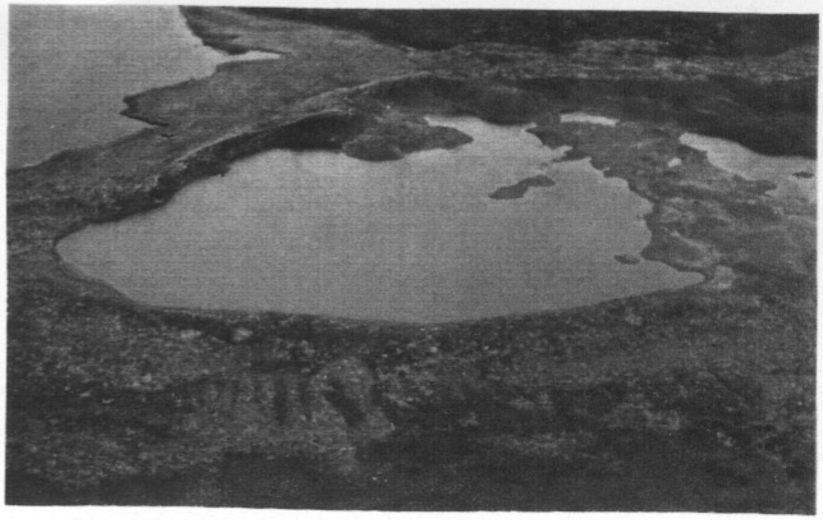
- Where practical, the borrow pit should be worked in sections and the organic cover replaced as soon as any section is abandoned. Minimizing the length of time organics are stockpiled will reduce coagulation of organics due to repeated thawing and freezing. Minimizing the length of time the pit is uncovered will help to minimize melt of buried ice and accelerate recovery of vegetation.

- Securing fabric covers or straw over stockpiles and on organics recently replaced on the abandoned pit surface may help reduce loss of organics from wind erosion and may also help to stabilize new vegitation growth.

Photograph 1

Aerial view.

The thaw pond in the foreground is about 100 metres across and 2.5 metres deep. The light coloured area encircling the pit represents new vegetation growth where the organic cover and vegetation was damaged during borrow pit operations.



Photograph 2

Vegetation regrowth.

Vegetation has started to reestablish in areas where there is some organic material at surface [foreground]. There is no vegetation growth where there is no organic material [background].

Photograph 3

Thaw pond.

The vegetation underwater and the steep margins suggest that buried ice is still melting causing further deepening of the pond.

Illustration 19--Photographs of Abandoned Borrow Pits

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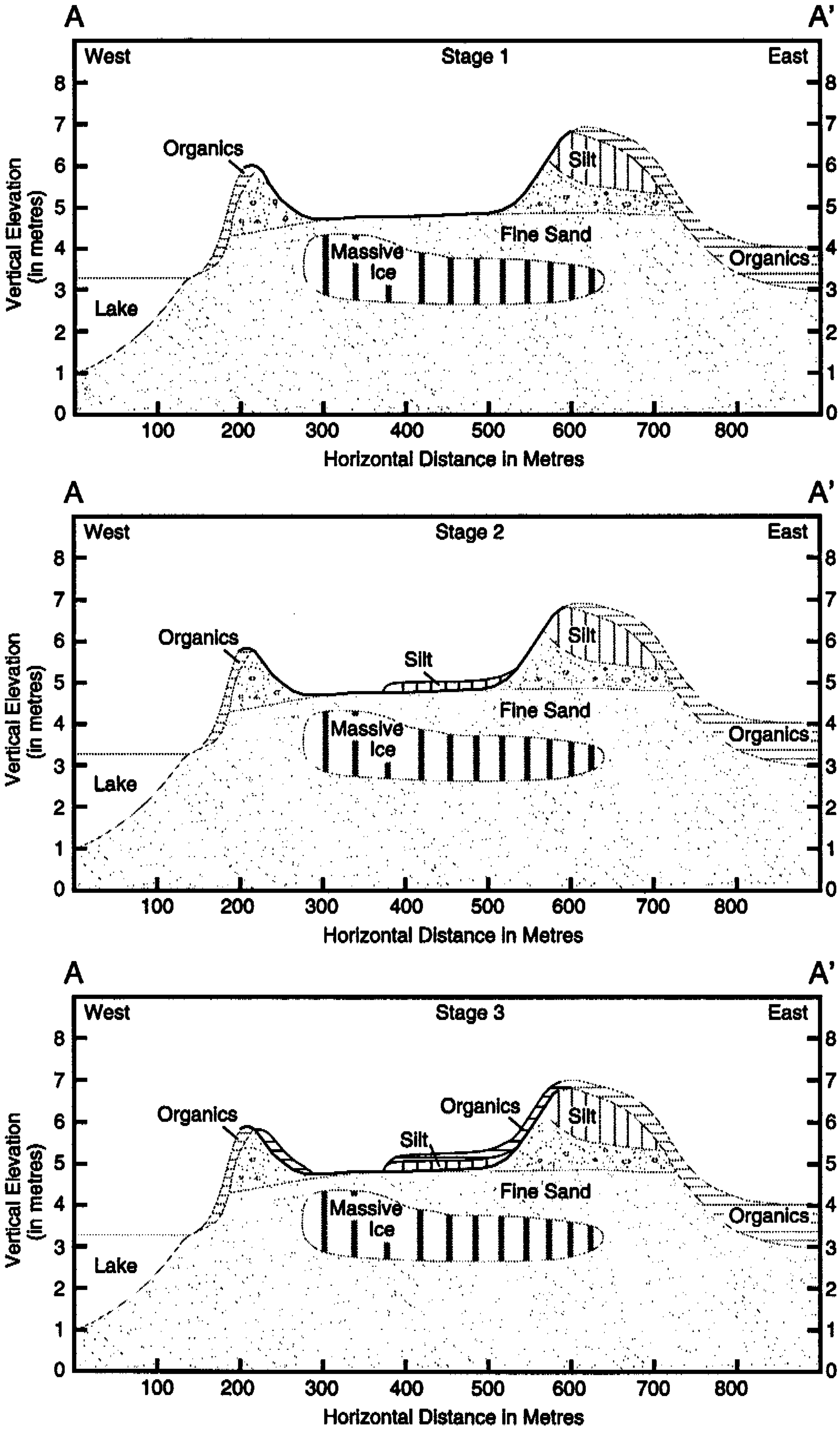
Illustration 20--Borrow Pit Rehabilitation

This series of diagrams shows some of the stages in rehabilitating our example borrow pit. This is an idealized example and these measures may not be required or practical in all cases.

Stage 1 The abandoned borrow pit is recontoured to leave slopes that are stable and in keeping with the natural landscape. Drainage is directed to the base of the pit. Where required, dams are constructed to prevent pit drainage from entering natural waterbodies.

Stage 2 Fine grained overburden previously removed from the pit surface [Illustration 18, Stage 1] is spread in the base of the pit. In this example, most of the overburden is placed over the east side of the pit to prevent buried ice in this area from melting.

Stage 3 Organics previously removed from the pit surface are spread on the base and slopes of the borrow pit. Organics and fine grained sediments are not placed on the west side of the abandoned pit where buried ice is too close to surface to be protected from thaw. It is expected that this ice will melt, causing the pit floor to collapse and flood.


A
A'
West
Stage 1
East
Organics
Silt
Fine Sand
Massive
Ice
Organics
Lake
Vertical Elevation (in metres)
Horizontal Distance in Metres
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Stage 2
East
Organics
Silt
Silt
Fine Sand
Massive
Ice
Organics
Lake
Vertical Elevation (in metres)
Horizontal Distance in Metres
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West
Stage 3
East
Organics
Organics
Silt
Silt
Fine Sand
Massive
Ice
Organics
Lake
Vertical Elevation (in metres)
Horizontal Distance in Metres

10.0 ENVIRONMENTAL CONSIDERATIONS

10.1 Introduction

The land in the ISR is very fragile and slow to heal. Where the organic cover has been damaged or removed, it may take years for vegetation to re-establish. Where buried ice is exposed to melting temperatures, depressions in the land surface will form. Water released by melting of buried ice can enter natural waterbodies and damage fish stocks or other aquatic life. Some of the environmental problems associated with borrow pit operations are discussed below.

10.2 Damage to the Organic Cover

Throughout most of the ISR the organic cover is thin and very easily damaged. This cover is particularly fragile in the summer when the surface is wet. Even in winter organics can be damaged by heavy equipment.

Destruction of the organic cover in the borrow pit is unavoidable, but it is important that measures be taken to avoid unnecessary damage outside of the borrow pit. Overland winter access roads should be built up with snow and ice to protect the organics. To minimize damage around the margins of the borrow pit, snow clearing operations should not be extended beyond the limits of the borrow pit, and, where practical, overburden should be stored within the borrow pit. Storage and replacement of organic material is discussed in Section 9.4

10.3 Melt of Buried Ice

Buried ice occurs throughout the permanently frozen ground [permafrost] in the ISR. This ice is commonly several metres thick and deep depressions form where it is exposed to thaw [Illustration21]. Once thaw of buried ice is started, it can be very difficult to stop. Growth of thaw induced depressions stops only when all the ice has melted or when there is sufficient cover over the ice to insulate it from warm surface temperatures.

Throughout the ISR, there are natural ponds formed by melting of buried ice. In some cases, the formation of new ponds due to the melting of ice exposed during borrow pit operations may be considered acceptable. However, it is important that pre-development exploration be extensive enough to determine the extent and location of buried ice so that thaw induced disturbances to the land surface can be minimized.

10.4 Drainage from Borrow Pits

Large volumes of water can be released when ice rich sediments or massive ice is exposed to thaw. The introduction of meltwater into a natural waterbody can cause damage to fish stocks and other aquatic life if this water has a different temperature, chemistry or sediment content from that in the natural waterbody.

To minimize potential for any damage to aquatic life, it is generally recommended [Environmental Guidelines Pits and Quarries] that a borrow pit be at least 30 meters from any natural waterbody [Illustration 22]. It is also recommended that pits be contoured and dikes constructed to control meltwater runoff. The introduction of small volumes of water from a borrow pit into a waterbody that is not a valuable local resource may in some cases be acceptable. The sudden introduction of large volumes of pit drainage into a stream or lake that is considered to be an important local resource, should not be permitted.

The type and extent of measures required to control meltwater runoff is dependent on the amount of water released and on any thaw induced changes to the land surface. Therefore, it is critical that pre-development exploration be extensive enough to determine the location and extent of buried ice so that suitable drainage control measures can be implemented.

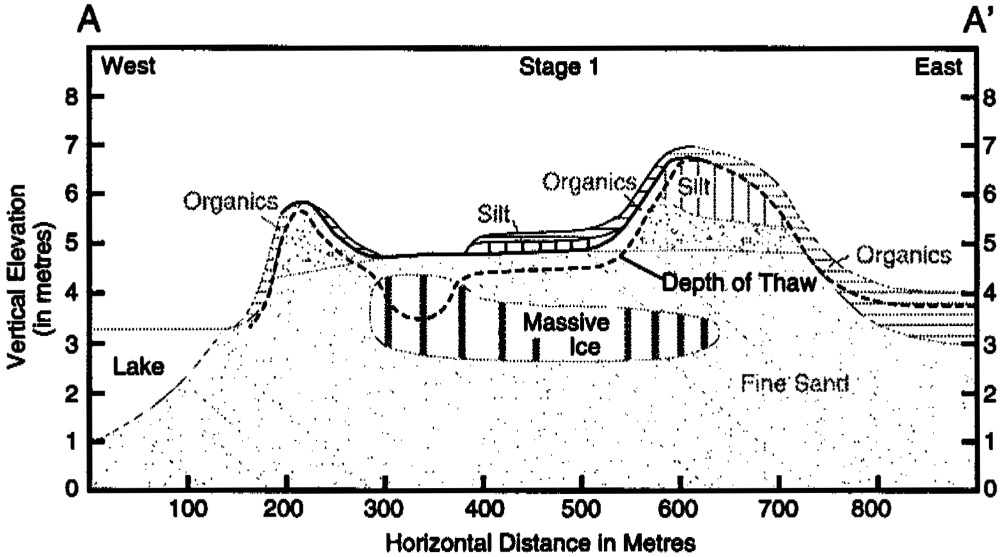
Illustration 21--Melt of Buried Ice and Formation of Thaw Ponds

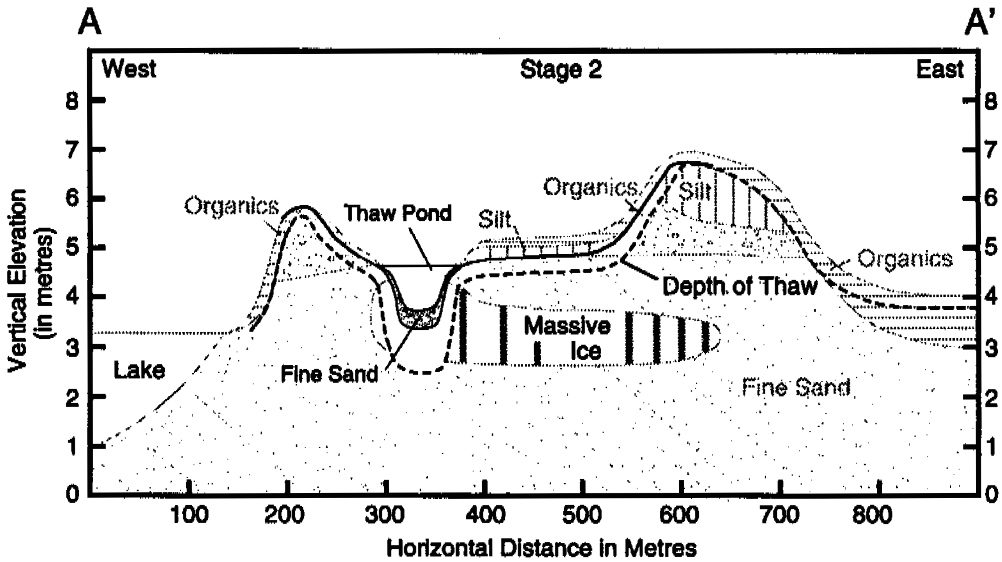
This series of diagrams shows the development of a thaw pond in our example borrow pit as buried ice melts. It may take several years for the ice to melt and the pit floor to stabilize.

Stage 1 After restoration, the depth of summer thaw is less than 0.6 metres in undisturbed terrain, approximately 1 metre where fine grained overburden and organics have been replaced, and 1 to 2 metres where the organics have not been replaced. Buried ice under the west side of the borrow pit is exposed to melting temperatures during the summer.

Stage 2 The buried ice melts and land surface collapses forming a water filled depression [thaw pond]. Fine grained sand that was overlying the ice now lines the bottom of the pond. Depth of thaw is now 1 to 2 metres below the base of the pond and the remaining ice is exposed to thaw.

Stage 3 The remaining ice under the pond melts forming a deeper thaw pond. All of the ice under the pond has melted and the base of the pond is stable. In this example, ice on the margins of the pond is exposed to thaw and the surface area of the pond may expand as this ice melts. Growth of the pond will stop when there is sufficient cover, due to slumping of fine sand on the margins of the pond, to insulate this ice from thaw.


A
A'
West
Stage 1
East
Organics
Silt
Organics
Silt
Organics
Depth of Thaw
Massive Ice
Lake
Fine Sand
Vertical Elevation (in metres)
Horizontal Distance in Metres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Thaw Pond
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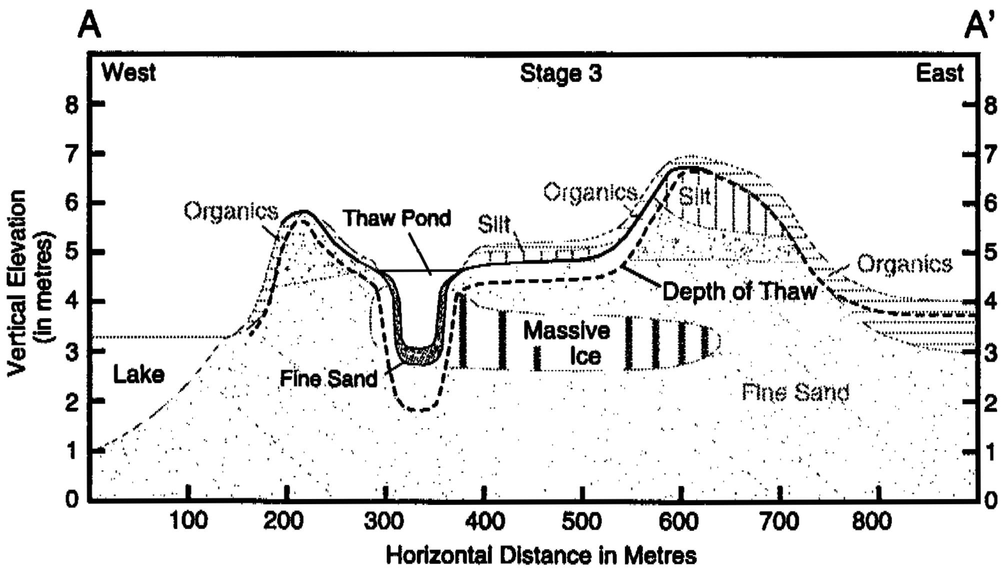
Organics
Depth of Thaw
Massive Ice
Lake
Fine Sand
Fine Sand
Vertical Elevation (in metres)
Horizontal Distance in Metres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Stage 3
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Organics
Thaw Pond
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Organics
Silt
Organics
Depth of Thaw
Massive Ice
Lake
Fine Sand
Fine Sand
Vertical Elevation (in metres)
Horizontal Distance in Metres

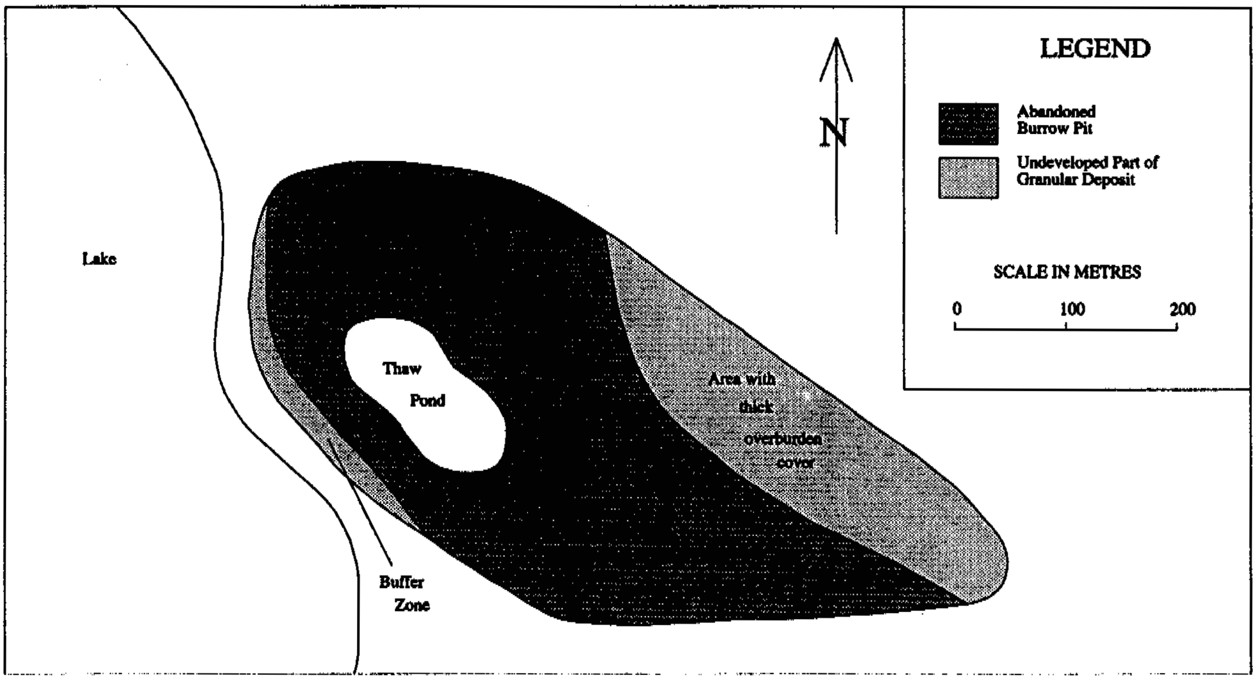

Illustration 22--Plan Map of the Abandoned Borrow Pit

This map shows conditions at our example borrow pit after it has been abandoned for several years. There a thaw pond on the west side of the pit where buried ice melted. The undisturbed buffer between the lake and the borrow pit provides a barrier to protect the lake from pit drainage that could damage fish stocks or other aquatic life. In this example, it was considered prudent to leave more than the minimum acceptable 30 meter buffer because large volumes of water were expected to be released by melt of buried ice. This ridge also provides a visual barrier between the lake and the pit. Less than 5% of the granular material available in the deposit was left in the abandoned borrow pit in order to provide this protective buffer.

11.0 MONITORING BORROW PIT OPERATIONS

11.1 Introduction

To properly manage borrow pit development and restoration, it is critical that these operations be carefully monitored. Monitoring of borrow pit operations is discussed in "Reclamation Guidelines for Northern Canada" [Hardy BBT, 1987] and some general suggestions are presented in this section of the manual.

11.2 Summer Site Visit Prior to Borrow Pit Development

Borrow pit operations are sometimes extended into areas that are not suitable for development. For this reason it is critical that areas selected for development are staked out on the ground before new parts of the pit are opened. Areas where development is unsuitable for economic or environmental reasons should be clearly marked. Areas where organics are to be stored or replaced should also be clearly marked.

11.3 Site Visit During Borrow Pit Operations

The borrow pit should be visually inspected during operations to check that the deposit is being developed in a manner to to maximize recoveries and minimize environmental damage. Some suggestions are summarized below.

- Where a winter access road is being used, check that there is a suitable cover of snow and ice on the road to protect the underlying vegetation
- Insure that borrow pit operations are not extend into areas that are considered unsuitable for development.
- Insure that overburden and organics are being properly stockpiled and/or replaced.
- Insure that the granular material is being fully extracted and that grade and reserves are up to expectations.
- Determine if ice has been exposed by the borrow pit operations. Large areas of exposed massive ice should be clearly marked.
- Insure that, where required, the pit surface is sloped and dikes constructed to control drainage.

11.4 Late Summer Site Visit

Active and recently abandoned borrow pits should be checked late in the thaw season to insure that the environmental safeguards are providing suitable protection. Dikes and undisturbed margins designed to contain pit drainage should be checked to insure they are functioning properly. The rate at which any water is escaping from the pit should be monitored.

Land surface should be checked for any changes that may reflect melting of buried ice. Vegetation growth on abandoned pit surfaces should be monitored. Some possible studies that could be undertaken include:

Water Quality Studies

Drainage from a borrow pit can damage fish stocks and other aquatic life in natural water bodies. This occurs primarily because water in a borrow pit commonly has a different sediment content, chemistry and/or temperature than adjacent natural waterbodies. Water samples from the borrow pit and adjacent natural waterbodies can be obtained and submitted for laboratory testing to determine if there are significant differences.

Water Depth Determinations

Thaw ponds formed in the base of the borrow pit can be probed from a small boat during the summer, or by auguring through the ice in the winter to measure water depth. This can help to determine the amount of buried ice that has melted. Where such measurements are made over a period of years it can determine if the pond has stabilized. This will also help to determine if the pond will remain unfrozen at its base during the winter. Depth of annual thaw may be greater in deep ponds that do not freeze completely during the winter.

Active Layer Determinations

Measuring the depth from surface to frozen ground at the end of the summer will indicate how deep the thaw has penetrated and can help to determine if buried ice is being exposed to melting temperatures. To measure depth of thaw, a graduated steel probe is manually forced into the ground. The rod generally penetrates unfrozen sediments but not frozen sediments. This survey provides a good simple determination of the thickness of the active layer.

Level Surveys

Areas where there is potential for environmental problems due to thaw induced collapse of the land surface should be monitored to determine the extent of any surface disturbances. This can be accomplished by establishing permanent markers on stable ground, and measuring any horizontal or vertical changes in the land surface relative to these stable markers during the summer or from one year to the next.

Storage and Replacement of Organics

Experimental studies could be initiated to develop improved methods for storing and replacing organic material removed from the borrow pit.

Revegetation Studies

Experimental plots could be established in abandoned borrow pits to develop improved methods for reestablishing vegetation growth.

12.0 DEFINITIONS OF TERMS

Absorption

See water absorption test.

Active Layer

The ground at surface [above permanently frozen ground] that freezes each winter and thaws each summer.

Aggregate

A general term for crushed rock or sand and gravel used for construction purposes. For reports on granular deposits in the ISR it commonly refers to crushed rock, or sand and gravel used in the manufacture of concrete, mortar or asphalt.

Alkali-aggregate reactivity test

A laboratory test used to determine how granular material will perform if used as concrete aggregate. It indicates potential for adverse chemical reaction between the granular material and cement that can cause deterioration of the concrete.

Alluvial fan

A low relatively flat to gently sloping mass of sediments shaped like an open fan or segment of a cone deposited by a stream where it flows from a narrow valley onto a plain or broad valley.

Beach

A deposit of sediments formed by wave action at the shore of a lake or ocean. An abandoned beach formed at the edge of a lake that is now dry or at the edge of the ocean when sea level was higher than it is today is called a raised beach. Some granular deposits in the ISR are in beaches.

Bedded

See stratified.

Berm

For reports on granular deposits in the ISR the term berm is commonly used to refer to a man-made ridge built to contain or control the flow of water from a borrow pit.

Borrow pit

A pit excavated to extract natural material, such as sand or gravel, for construction purposes.

Bulk specific gravity test

A laboratory test used to determine how granular material will perform if used as concrete aggregate. Specific gravity is a ratio of density [mass per unit volume] relative to water. Granular material with a relatively low specific gravity [relatively light] may not be suitable for uses such as concrete and riprap.

Concrete Aggregate

Granular material used in the making concrete. To be of suitable quality, granular material must be well graded, have a low fines content, low moisture content, low PN and meet certain standards as determined by concrete aggregate suitability tests.

Concrete Aggregate Suitability Tests

A set of tests, the results of which taken together are used to determine the suitability of granular material for making concrete.

Cross-Section

A drawing of a side view of a vertical slice through a granular deposit. This is commonly prepared from the data provided at test pits, natural exposures and drill holes.

CSA Standards

In reports on granular deposits in the ISR this generally refers to test specifications of the Canadian Standards Association for testing of concrete aggregate and soils.

Delta

A flat deposit of sediments formed at the mouth of a river where it enters a lake or sea.

End moraine

A ridge of sediments, commonly sand and gravel, formed at the edge of a glacier.

Esker

A long, narrow, winding ridge composed of stratified sand and gravel. Eskers are deposited by meltwater streams flowing in or on a melting glacier and left behind when the ice melts. Some granular deposits in the ISR are in eskers

Excess ice

A frozen sample of sediment that releases water when thawed is said to contain excess ice.

Felsenmeer

An accumulation of angular rock fragments with no cliff or ledge above as an apparent source. Felsenmeer is commonly formed by frost action forcing up fragments of the underlying bedrock.

Fill

Man-made deposits of natural materials, such as sand and gravel or crushed bedrock, used to fill an enclosed space or raise land level.

Fines

Silt and clay sized soil particles {particles less than 0.003 inches [0.075 millimetres]}.

Flood plain

Relatively flat land adjacent to a river channel which is covered by water when the river overflows its banks. It is built of material deposited by the river during floods. A river valley may have one or more terraces representing abandoned or inactive flood plains.

Friable

See poorly bonded.

Frost susceptible soils

Soils which hold water are susceptible to frost heave due to ice-segregation. Soils with a high fines content are generally frost susceptible.

Glacial deposit

See glacial drift.

Glacial drift

A general term for rock materials [sand, silt, clay, gravel and boulders] transported by a glacier and deposited directly by the ice or by meltwater streams flowing from the glacier.

Glacier

A large ice mass, formed by compaction and recrystallization of snow, which commonly move slowly downslope or outward in all directions due to the stress of it's own weight. Glaciers commonly carry huge volumes of crushed rock fragments which are left behind when the ice melts. In the ISR, glaciers that covered the area for thousands of years melted about 10 thousand years ago.

Glaciofluvial

Refers to the deposits and landforms produced by meltwater streams flowing in, on, under, or from a melting glacier.

Glaciofluvial terrace

See terrace.

Glaciolacustrine

Refers to the deposits and landforms composed of material carried by meltwater streams and deposited in lakes bordering the glacier.

Glaciomarine

Refers to marine sediments that contain glacial material.

Grading characteristics

See grain size analysis.

Grading curve

A graphic plot showing the results of grain size analysis.

Grain size

The dimensions [average diameter] of the particles in a sediment.

Grain size analysis test

A laboratory test used to determine how granular material will perform if used for building structure supporting pads or for other construction applications. The granular material is passed through a series of screens to separate it into different size fractions. The amount of material in each of the different size ranges is reported as weight % of the whole sample. The results are the grading characteristics [grading] of the granular material.

Granular material

In reports on granular deposits in the ISR, this generally refers to sand and gravel or crushed bedrock in which grain sizes range from 0.003 to 8 inches [0.075 to 203 millimetres].

Gravel

Rock or mineral grains with diametres between 0.16 and 3 inches [4.75 to 75 millimetres]. In reports on granular deposits in the ISR, sands and gravels are defined as less than 50% fines by weight. If the course part of the sample [part courser than fines] is more than half gravel sized particles the material is called gravel, if the coarse fraction is more than half sand sized particles it is called sand.

Ground ice

Ice found below surface in permanently or seasonally frozen ground. This can be either remains of the glacier that were buried and have not melted or ice that formed in-place after the sand and gravel was deposited. In the ISR, granular deposits commonly contain wedges, lenses or layers of ice called massive ice or ground ice.

Hard bonded

See well bonded.

Ice bonding

Ice in sand and gravel bonds the grains together. The degree of ice bonding is dependent on the type and amount of ice and the type of sediment. Sediments may be called poorly bonded [easy to penetrate] or well bonded [difficult to penetrate].

Ice contact deposit

Glacial sediments deposited in, on, or against melting glacial ice.

Ice content

This refers to the amount of ice in sediments and is reported as volume percent ice by combined volume of soil and ice.

Ice wedge

A wedge shaped body of ground ice. Ice wedges occur as vertical or inclined sheets of ice that are thickest at the top. They originate in permanently frozen sediments by freezing of water in a narrow crack.

Interstitial

Material filling empty spaces. In granular deposits in the ISR this commonly refers to ice filling the empty spaces between grains.

Isopach map

A map showing the thickness of a geological formation. Thickness at test sites is known. Assumed thickness between test sites is demonstrated by lines drawn through points of equal thickness.

ISR

Inuvialuit Settlement Region.

Kame

A hill, mound or short irregular ridge composed of stratified glacial drift. Kames are deposited by meltwater streams flowing in, on or at the margin of melting glacial ice. Their present topographic form reflects melt of buried ice. A cluster of kame mounds and ridges is called a kame moraine, kame field, kame complex or kame group. A cluster of kame mounds and esker ridges is called a kame-esker complex. An irregular, pitted terrace like ridge of stratified sand and gravel deposited between the edge of the melting glacier and a valley wall and left standing after the ice melts is called a kame terrace. Some of the granular deposits in the ISR are in kames.

Kame-esker complex

See kame.

Kame terrace

See kame.

Kettle

A topographic depression, commonly steep-sided and bowl shaped, formed by the melting of a block of glacial ice that was buried in glacial deposits. Kettle depressions commonly occur in glacial outwash, kame fields, kame-esker complexes and kame terraces.

Lacustrine

Refers to the deposits and landforms formed in or produced by a lake.

Lithology

The mineral composition and physical characteristics of a rock.

Los Angeles Abrasion Test

A laboratory test used to determine how granular material will perform if used as concrete aggregate. To determine how resistant the granular material is to physical abrasion, the gravel fraction is run through a small grinding mill. Results are reported as a % of the gravel fraction that breaks down into smaller particles.

Massive ice

See ground ice.

Moisture content test

A laboratory test to determine how much water is contained in the granular material. This is done by determining weight loss when the sample is dried and is reported as weight percent moisture by weight of dry sample. In most cases in the ISR, ground temperatures are below freezing and the water is present as ice Moisture content tests help to determine limitations on use of the granular material and indicates the potential for difficulties associated with extracting the granular material.

Moraine

An accumulation of unsorted, unstratified glacial drift transported and deposited primarily by direct action of ice.

Natural exposure

A natural vertical cut exposing buried sediments. Exposures commonly occur where water--along a river bank or at a beach--has cut a cliff into the sediments or on a slope where loose material can be stripped off to expose buried sediments. In the ISR, natural exposures present an opportunity to evaluate subsurface conditions without resorting to drilling or test-pitting.

Organic impurities test

A laboratory test to detect the presence of organic material. Granular material that contains organics, such as peat or other fine woody material, may not be suitable for use as concrete aggregate.

Organic material

Living vegetation such as moss and shrubs, and decaying vegetation such as peat. Organic material forms a thin cover at surface throughout most of the ISR.

Outwash

Stratified drift deposited in front of, or beyond the edge of a glacier by meltwater streams.

Overburden

In reports on granular deposits in the ISR, this generally refers to the uneconomic organics and fine grained sediments that overlie a granular deposit and must be removed to access the sand and gravel.

Permafrost

Buried soil, sediments or bedrock in which the temperature remains below freezing for two years or more. In the ISR, ground is frozen to a depth of over 300 metres and only the upper 0.2 to 2 metres thaws during the summer.

Petrographic Analysis

A laboratory test to determine the rock types in a granular deposit and evaluate their impact on potential uses of the granular material. The pebbles are visually evaluated and the rock types classified according to their resistance to physical abrasion and chemical attack. The results are reported as the petrographic number [PN] for the sample. The higher the PN the poorer the quality of the granular material.

Petrographic Number

See petrographic analysis.

Plasticity

A measure of the character of fine grained sediments. It is the difference between the plastic limit [the moisture content when the material is wet enough to be formed into a thin thread] and the liquid limit [the moisture content when the material is wet enough to flow].

PN

See petrographic analysis.

Poorly Bonded

Frozen organics or sediments that are easily broken up and extracted are called poorly bonded or friable.

Poorly graded

An unconsolidated sediment that does not have a continuous distribution of particles from coarse to fine or is mostly one grain size. Pads constructed of poorly graded material may shift or compact because spaces between grains are not filled. See well graded.

Post-glacial

Refers to the time interval from when the glaciers melted to the present. Sediments deposited during this time period are called post-glacial deposits.

Probable reserves

Reserves of granular material are considered to be probable if their distribution, thickness and quality is inferred on the bases of both direct [drill holes, test pits and/or exposed sections] and indirect evidence [topographic setting and landform characteristics].

Prospective reserves

Reserves of granular material are considered to be prospective if their distribution, thickness and quality is inferred from indirect evidence such as aerial photographic interpretation [topographic setting and landform characteristics] and general geological considerations.

Proven reserves

Reserves of granular material are considered to be proven if their distribution, thickness and quality has been tested by ground truth information such as drilling, test pitting and/or exposed sections.

Raised beach

See beach deposit.

Riprap

A layer of coarse fragments of broken rock artificially placed to prevent shoreline erosion. This term is also commonly used to refer to the rock suitable for use as riprap.

Sand

Rock or mineral grains with diametres between 0.003 and 0.16 inches [0.075 to 4.75 millimetres]. In reports on granular deposits in the ISR, sands and gravels are defined as less than 50% fines by weight. If the course part of the sample [part courser than fines] is more than half gravel sized particles the material is called gravel, if the coarse fraction is more than half sand sized particles it is called sand.

Sediment

Material that originates from weathering of rocks and forms in layers at the Earth's surface [for example sand, gravel, or mud].

Soil

In reports on granular deposits in the ISR, the term soil is commonly used to refer to all loose material above the bedrock. The term soil is, in some situations, used to refer specifically to the organic material at surface capable of supporting plant growth.

Sorting

The process by which sedimentary particles having some particular characteristic [such as similarity of size shape or specific gravity] are naturally selected and separated from associated but dissimilar particles by agents of transportation, such as the action of running water. A sediment that consists primarily of particles of approximately the same size is called sorted or well sorted. A sediment that consists of particles of many sizes mixed together in an unsystematic manner is called unsorted or poorly sorted

Specific Gravity

See bulk specific gravity.

Stratified

Formed, arranged, or laid down in layers.

Stratified drift

Sorted and layered glacial sediments deposited by a meltwater stream or settled from suspension in a body of quiet water adjoining the glacier.

Sulphate Soundness test

A laboratory test used to determine how granular material will perform if used as concrete aggregate. To determine how resistant the granular material is to weathering the gravel fraction is placed in a sulphate solution. Results are reported as the % of the sample broken down by the sulphate solution.

Talus

Broken rock fragments derived from, and lying at, the base of a cliff or steep rocky slope.

Test pits

Pit excavated, by shovel or bulldozer, to evaluate buried sediments. They are generally excavated during the summer when the surface material has thawed.

Terrace

A long, narrow, relatively level area bounded on one side by a steeper descending slope and along the other by a steeper ascending slope. The term is commonly applied to a steplike ledge of unconsolidated material breaking the continuity of a slope. Where a relatively small section of terrace is separated by erosion from the main terrace it is called a terrace remnant. Some granular deposits in the ISR are in terraces.

Terrace remnant

See terrace.

Thaw pond

See thermokarst pond.

Thermokarst depression

Topographic depression formed by collapse of the land surface as a result of local melting of buried ice in a permafrost region.

Thermokarst pond

Water filled thermokarst depression.

Till

Unsorted and unstratified material deposited directly by and underneath a glacier with no reworking by meltwater. It is commonly a mix of material from large boulders to fine silt and clay.

Tundra

A treeless, level, or gently undulating plain characteristic of arctic and subarctic regions. Commonly marshy and underlain by permafrost.

Water Absorption Test

A laboratory test used to determine how granular material will perform if used as concrete aggregate. The sample is immersed in water and the moisture absorbed reported as % of dry weight. Granular material that absorbs relatively large amounts of moisture is susceptible to freeze-thaw degradation.

Well bonded

Frozen overburden or granular material that is difficult to break up or penetrate due to ice bonding is called well bonded or hard bonded.

Well graded

An unconsolidated sediment with a continuous distribution of grain sizes from coarse gravel to fine sand. Pads constructed of well graded material are stable and will support heavy structures because smaller particles fill the spaces between larger particles minimizing any potential for the pad to shift or compact.

13.0 SELECTED BIBLIOGRAPHY

BBT Geotechnical Consultants Ltd., GVM Geological Consultants Ltd. and Terrain Analysis and Mapping Services Ltd., 1983. Granular Materials Evaluation, Deposits 168 and 211 Tuktoyaktuk Area, NWT.. Report Prepared for the Department of Indian Affairs and Northern Development, Ottawa, May, 1983.

EBA Engineering Consultants Ltd., 1976. Geotechnical Evaluation of Granular Material, MacKenzie Delta Area.

EBA Engineering Consultants Ltd., 1976. Detailed Geotechnical Evaluation of Potential Sources of Granular Material at Devils Lake [Source 326], Lucas Point [Source 303] and Swimming Point [Source 222], MacKenzie Delta Area, N.W.T. Report submitted to the Government of Canada, Department of Indian and Northern Affairs Ottawa, March 1976.

EBA Engineering Consultants Ltd., 1983. Granular Resource Development and Management Plan for Tuktoyaktuk NWT. Report submitted to the Department of Indian and Northern Affairs Ottawa, 1983.

EBA Engineering Consultants Ltd., 1986. Granular Resource Evaluation, Richards Island, NWT. Report submitted to Indian and Northern Affairs Canada, Ottawa, December 1986.

EBA Engineering Consultants Ltd., 1987. Inuvialuit Settlement Sand and Gravel Inventory and Recommendations for Development, Aklavik. Report submitted to Indian and Northern Affairs Ottawa, April, 1987.

EBA Engineering Consultants Ltd., 1987. Inuvialuit Settlement Sand and Gravel Inventory and Recommendations for Development, Holman. Report submitted to Indian and Northern Affairs Ottawa, April, 1987.

EBA Engineering Consultants Ltd., 1987. Inuvialuit Settlement Sand and Gravel Inventory and Recommendations for Development, Inuvik. Report submitted to Indian and Northern Affairs Ottawa, April, 1987.

EBA Engineering Consultants Ltd., 1987. Inuvialuit Settlement Sand and Gravel Inventory and Recommendations for Development, Paulatuk. Report submitted to Indian and Northern Affairs Ottawa, April, 1987.

EBA Engineering Consultants Ltd., 1987. Inuvialuit Settlement Sand and Gravel Inventory and Recommendations for Development, Tuktoyaktuk. Report submitted to Indian and Northern Affairs Ottawa, April, 1987.

EBA Engineering Consultants Ltd., 1991. Paulatuk Granular Resources Inventory and Recommendations for Development. Report Submitted to: Government of the Northwest Territories, Department of Transportation, Yellowknife, Northwest Territories, May, 1991.

French Arctic Consultants Limited, 1992. Holman Granular Inventory. Phase B of Field Mapping of Potential Sand and Gravel Reserves, Sachs Harbour and Holman, NWT. Final Report: March, 1992.

French Arctic Consultants Limited, 1993. Sachs Harbour Granular Inventory. Phase A of Field Mapping of Potential Sand and Gravel Reserves, Sachs Harbour and Holman, NWT. Final Report: March, 1993.

Hayley, D. W. and N. R. MacLeod, 1977. Evaluation and Development of Granular Construction Materials in the Mackenzie Delta region. 79th Annual General Meeting of CIM-1977 - Industrials Minerals Division.

Hardy R. M. and Associates Ltd. and Terrain Analysis and Mapping Services Ltd., 1977. Granular Materials Inventory, Yukon Coastal Plain and Adjacent Areas. Prepared for the Department of Indian Affairs and Northern Development, January 1977.

Hardy R. M. and Associates Ltd., 1977. Granular Materials Inventory Tuktoyaktuk, Northwest Territories. Report submitted to the Department of Indian Affairs and Northern Development, Ottawa, August, 1977.

Hardy Associates [1978] Ltd., 1979. Granular Materials Inventory, Phase 111, Tuktoyaktuk Harbour, NWT.. Report prepared for the Department of Indian Affairs and Northern Development, Ottawa, April, 1979.

Hardy Associates [1978] Ltd., 1980. Granular Materials Inventory Tuktoyaktuk NWT., Sources 160 and 161. Report prepared for the Department of Indian Affairs and Northern Development, Ottawa, March, 1980.

Hardy BBT Limited, 1986. Proposed Geotechnical Investigation Plan, Potential Sand and Gravel Reserves, Inuvialuit Settlement Region, March, 1986.

Hardy BBT Limited, 1986. Interim Report - Phase I, Community Granular Management Plan, Tuktoyaktuk NWT. Report Prepared for the Government of the Northwest Territories Department of Public Works, Highways Division Yellowknife, NWT, July, 1986.

Hardy BBT Limited, 1986. Interim Report - Phase II Field Reconnaissance, Community Granular Management Plan, Tuktoyaktuk NWT. Report submitted to the Government of the Northwest Territories Department of Public Works, Highways Division Yellowknife, NWT, November, 1986.

Hardy BBT Limited, 1987. Phase III Final Comparison of Potential Sources, Community Granular Management Plan, Tuktoyaktuk, NWT.. Report Prepared for the Government of the Northwest Territories, Department of Public Works, Highways Division Yellowknife, NWT, May, 1987.

Hardy BBT Limited, 1987. Reclamation Guidelines for Northern Canada. Report Prepared for Land Resources, Northern Affairs Program.

Hardy BBT Limited, 1988. Plan for the Reservation and Development of Granular Materials in the Vicinity of Tuktoyaktuk, NWT. Report submitted to the Department of Indian and Northern Affairs Ottawa, 1988.

Hardy BBT Limited, 1989. Proposed Geotechnical Investigation of Potential Sand and Gravel Reserves, Inuvialuit Settlement Region. Report prepared for Indian and Northern Affairs Ottawa, March, 1989.

Hardy BBT Limited, 1989. Source 155 North-Development Plan, Community Granular Management Plan, Tuktoyaktuk, NWT.. Prepared for: Government of the Northwest Territories, Department of Public Works, Yellowknife, NWT, September, 1989.

Hardy BBT Limited, 1990. Geotechnical Investigation of Potential Sand and Gravel Reserves, Inuvialuit Settlement Region, 155 South Deposit, Tuktoyaktuk, Northwest Territories. Report prepared for the Department of Indian and Northern Affairs Ottawa, May, 1990.

Hardy BBT Limited, 1990. Geotechnical Investigation of Potential Sand and Gravel Reserves, Inuvialuit Settlement Region, Deposit 467 [Willow River], Aklavik, NWT.. Report prepared for the Department of Indian and Northern Affairs Ottawa, May, 1990.

Hardy BBT Limited, 1990. Geotechnical Investigation of Potential Sand and Gravel Reserves, Inuvialuit Settlement Region, I407 [Caribou Hills] Deposit, Inuvik, Northwest Territories. Report prepared for the Department of Indian and Northern Affairs Ottawa, May, 1990.

Hardy BBT Limited, 1990. Granular Resources Demand, MacKenzie Delta Region. Report prepared for the Department of Indian and Northern Affairs Hull, Quebec, July, 1990.

Hardy BBT Limited, 1991. Report on Evaluation of Granular Resource Potential, MacKenzie Delta Region Prepared for: Department of Indian and Northern Affairs Hull, Quebec, January, 1991.

Klohn Leonoff Consultants Ltd., 1974. Granular Materials Inventory, Parsons Lake, NWT.. Prepared for Gulf Oil Canada Limited

Klohn Leonoff, 1988. Western Beaufort Region Concrete Aggregate Study. Prepared for Indian and Northern Affairs, Ottawa, April, 1988.

MacLaren Plansearch, 1982. Environmental Guidelines Pits and Quarries. Prepared for Land Resources, Northern Affairs Program.

MacLaren Plansearch, 1989. Environmental Guidelines Pits and Quarries. Prepared for Land Resources, Northern Affairs Program.

Nesbitt, T.H.D. and Howell, J.D., 1988. Plan for the Reservation and Development of Granular Material in the Vicinity of Tuktoyaktuk, NWT.. Prepared for Indian and Northern Affairs, Ottawa, December, 1988.

Nesbitt, T.H.D. and Howell, J.D., 1988. Plan for the Reservation and Development of Granular Material in the Vicinity of Paulatuk, NWT.. Prepared for Indian and Northern Affairs, Ottawa, December, 1988.

Nesbitt, T.H.D. and Howell, J.D., 1988. Plan for the Reservation and Development of Granular Material in the Vicinity of Inuvik, NWT.. Prepared for Indian and Northern Affairs, Ottawa, December, 1988.

Nesbitt, T.H.D. and Howell, J.D., 1988. Plan for the Reservation and Development of Granular Material in the Vicinity of Sachs Harbour, NWT.. Prepared for Indian and Northern Affairs, Ottawa, December, 1988.

Nesbitt, T.H.D. and Howell, J.D., 1988. Plan for the Reservation and Development of Granular Material in the Vicinity of Holman, NWT.. Prepared for Indian and Northern Affairs, Ottawa, December, 1988.

Nesbitt, T.H.D. and Howell, J.D., 1988. Plan for the Reservation and Development of Granular Material in the Vicinity of Aklavik, NWT.. Prepared for Indian and Northern Affairs, Ottawa, December, 1988.

Rampton, V. N., 1988. Quaternary Geology of the Tuktoyaktuk Coastlands, Northwest Territories. Geological Survey of Canada, Memoir 423.

Ripley, Klohn and Leonoff International Ltd., 1973. Granular Materials Inventory-Zone 1, Zone 11 and 111 [3 volumes]. Report submitted to the Department of Indian Affairs and Northern Development, Ottawa, 1973.

Ripley, Klohn and Leonoff International Ltd., 1973. Community Granular Materials Inventory Tuktoyaktuk N.W.T.. Report submitted to the Department of Indian Affairs and Northern Development, Ottawa, 1973.

Ripley, Klohn and Leonoff International Ltd., 1973. Granular Materials Inventory Tuktoyaktuk N.W.T.. Report submitted to the Department of Indian Affairs and Northern Development, Ottawa, 1973.

Terrain Analysis and Mapping Services Ltd., 1976. Ya-Ya Lake Esker Complex: Site Development and Restoration Plan. Prepared for Land Management Division, Indian Affairs and Northern Development, Ottawa, 1976.

Thompson, F. J., 1992. Investigation of Geological Constraints on Granular Resource Extraction in the Tuktoyaktuk Coastlands Area N.W.T. Source 155N. Report submitted to the Department of Indian and Northern Affairs, Ottawa, 1992.

Thompson, F. J., 1992. Investigation of Geological Constraints on Granular Resource Extraction in the Tuktoyaktuk Coastlands Area N.W.T. Source 160/161. Report submitted to the Department of Indian and Northern Affairs Ottawa, 1992.