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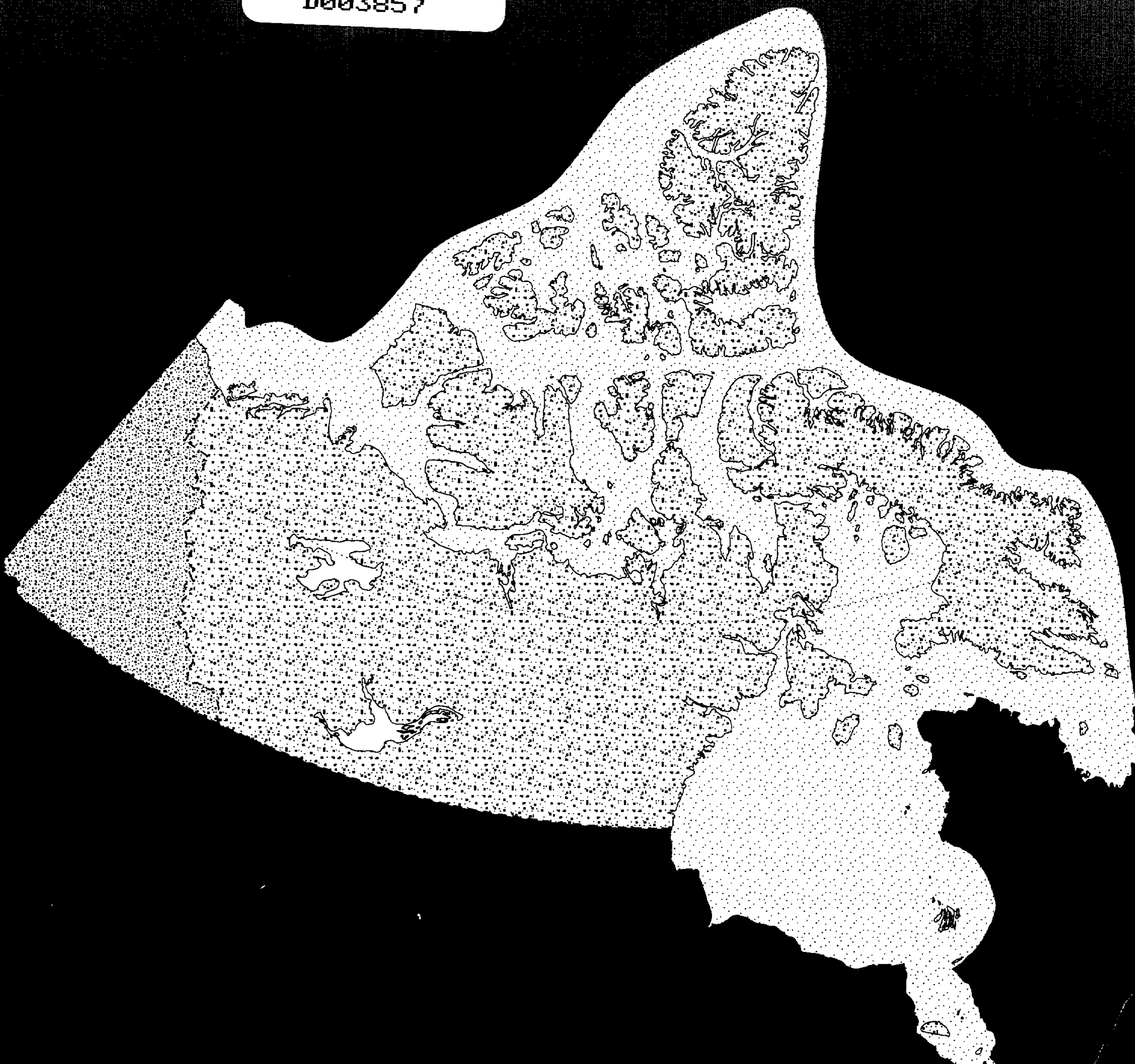
Granular Resources of the Slave Structural Province, N.W.T.



NORTHERN GRANULAR RESOURCES SERIES

Hi Bob! Oct. 15/96

Finally I have written some cover letters for Lynda Dredge and Mike Cherry of the GSC. I looked around for the address of the Terrain Sciences Division building behind Booth St. but couldn't find it, so I put the Booth St. address on the cover letters.

I finally got my work rept. award from UW too. I went to pick it up one day, but they'd mailed them the day earlier, so I got it from home this weekend. I've enclosed a copy of the certificate that I received. It came in a nice folder, on heavy weight paper and everything. I'll have to send Inmet a thank-you letter soon.

That's all for now! Say hi to all for me.

Thanks a lot! Mike

Dr. M. Cherry
Terrain Sciences Division
Geological Survey of Canada
601 Booth St.
Ottawa, ON
K1A 0E8

October 11, 1996

Dear Dr. Cherry,

Enclosed is a copy of the report entitled "Granular Resources of the Slave Province" that I prepared as part of my University of Waterloo Co-op term at DIAND's Land Management Division this past summer. I spoke to you on the telephone in the summer, inquiring about the status of surficial geology mapping of the Slave Province as part of the NATMAP Program. I thought that, being involved with the Slave Province NATMAP project, you may be interested in the subject of the report.

Please feel free to make copies of the report. If you have any questions or comments, please contact me at:

72 Northmanor Crescent
Kitchener, ON
N2N 3C3
(519) 749-7098
email: mbevan@science2.watstar.uwaterloo.ca

Thanks again for your assistance.

Sincerely,

Michael Bevan

Michael Bevan

Dr. Lynda Dredge
Terrain Sciences Division
Geological Survey of Canada
601 Booth St.
Ottawa, ON
K1A 0E8

October 11, 1996

Dear Dr. Dredge,

Enclosed is a copy of the report entitled "Granular Resources of the Slave Province" that I prepared as part of my University of Waterloo Co-op term at DIAND's Land Management Division this past summer. I spoke to you on the telephone on several occassions on the subject of eskers in the Slave Province. Knowing that you have worked extensively studying the surficial deposits in the Slave Province, I thought that you may be interested in the subject of the report.

Please feel free to make copies of the report. If you have any questions or comments, please contact me at:

72 Northmanor Crescent
Kitchener, ON
N2N 3C3
(519) 749-7098
email: mbevan@science2.watstar.uwaterloo.ca

Thanks again for your assistance in the summer.

Sincerely,

Michael Bevan

Michael Bevan

University of
WATERLOO

Co-operative Education Work Term Report Award

This is to certify that

MICHAEL BEVAN

is the recipient of the

Inmet Mining Corporation

award presented in August 1996

for excellence in written communication.

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for the work term of January - April 1996.

Bruce A. Lumsden
Director, Co-operative Education & Career Services

John Thompson
Dean of Faculty

Granular Resources of the Slave Structural Province, NWT

Prepared for
Land Management Division, Natural Resources & Environment Branch, Department of Indian & Northern Affairs

by
Michael J. Bevan

August, 1996

Executive Summary

The Slave Geological Province in the Northwest Territories is primarily undeveloped, but possesses enormous mineral resource potential. The region contains numerous deposits of gold, silver, copper, lead, zinc and diamonds, that may become economical if infrastructure was present. Construction of any development in the permafrost region of the Slave Province requires enormous quantities of granular resources, to ensure stability of the development by preserving the underlying permafrost.

Granular resources are abundant in the Slave Province, in the form of eskers, kames and other glaciofluvial deposits. Eskers are a prime source for granular material, due to their generally high quality, and the relative ease of excavation of the resource. Several limitations to the use of esker as a granular source do exist though. Eskers are important as travel ways for migrating caribou, as denning habitats for many animals that live in the harsh tundra environment, and are the location of numerous heritage sites from ancestral indigenous peoples.

There is currently no granular resources inventory program for the Slave Province. Several reports and studies have been conducted though, to varying levels of detail, and varying scopes. These studies have been summarized, and classified according to a series of granular inventory levels. Collectively, they provide a preliminary inventory suitable for broad planning purposes.

The overall granular resources inventory of the Slave Province is currently at a Reconnaissance level. A few specific studies bring several small areas to a Mapping level. The inventory is considered to be at the higher Site Investigation level for a very few isolated sites.

The need to improve the current level of inventory of the Slave Province before large scale development occurs has been recognized by a recent Environmental Assessment Panel. It proposed that the West Kitikmeot Slave Study make the collection of baseline information on eskers to be a priority, so that timely and informed decisions can be made in future regional resource planning, and development planning.

This report includes specific recommendations regarding enhancement of the existing information, as well.

Acknowledgements

This report would not have been possible without the support of the staff of DIAND's Land Management Division. Mr. Bob Gowan suggested the topic, and provided invaluable assistance and support throughout the duration of the project. His insight, comments and editing are greatly appreciated. Mr. Steve Rozak provided assistance with mapping, graphics, and production of the report. DIAND's Mineral Resources Directorate, especially Mr. Tom Caine, assisted by providing knowledge on the exploration and mining activity in the Slave Province. Dr. Lynda Dredge, of the Geological Survey of Canada's Terrain Sciences Division, provided insight on surficial geology, particularly eskers, in the Slave Province, and Mr. Ron Dilabio, also of the GSC, provided up to date information on the status of the GSC-NATMAP Slave Province surficial geology mapping program.

Table of Contents

List of Figures

List of Tables

1

Introduction

Granular resources are a necessary, but scarce material required for development in Canada's north. Being a low value bulk commodity, transportation distance greatly affects the price of the resource. The costs are further exaggerated in the undeveloped portions of the Northwest Territories, where transportation infrastructure is lacking. It is essential to find a source of aggregate that is very close to the development site, as roads must often be constructed from the borrow area. These roads add to the cost, as well as consuming a significant proportion of the sand and gravel needed for the development project.

The Slave Geological Province (Figure 1.1), located in central Northwest Territories, is a primarily undeveloped region that has very high levels of development foreseeable in the near future. Many gold deposits have been identified, with some presently being mined (eg. Lupin Mine); base metal deposits have been extensively investigated in hopes of economical exploitation (eg. Izok Lake); and, most recently, diamonds have been discovered in several areas, with BHP Diamonds Ltd. having just received conditional approval from the federal government to begin mine construction. With all of this development potential, several projects have been proposed to construct a road through the Slave

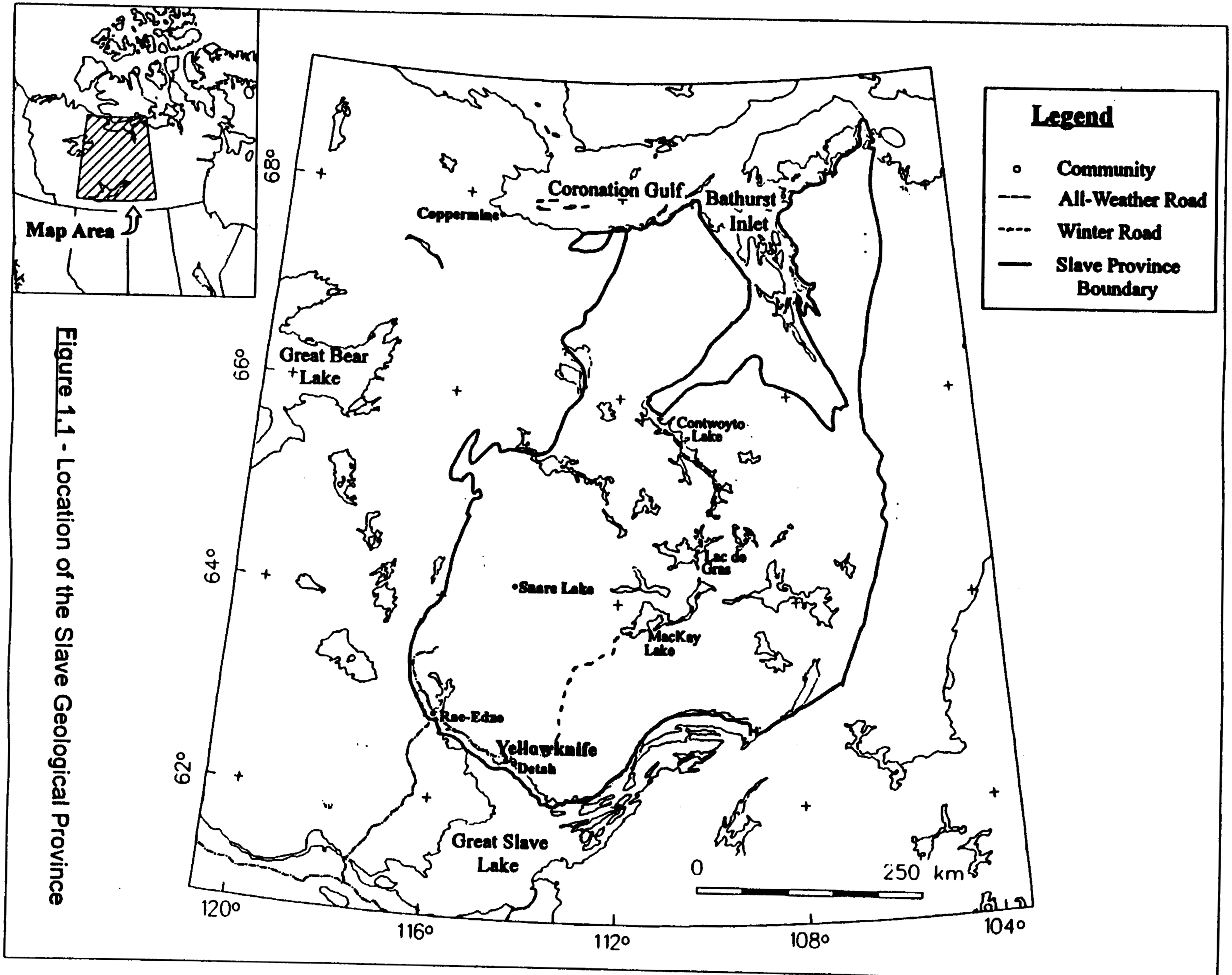

Figure 1.1 - Location of the Slave Geological Province

Province, from Yellowknife in the south to Coronation Gulf on the Arctic coast, a distance of more than 600 kilometres. Any such project will require a vast quantity of granular materials - a resource that is not well known in the region, in terms of location, extent, and quantity.

There is currently no formal program established to develop a comprehensive inventory of the granular resources of the Slave Province. However, a number of studies and projects have been undertaken, or are currently underway, that, collectively, will provide the basis for planning future inventory and resource planning management activities.

This report is a compilation of information currently known about the granular resources of the Slave Province. A background to the Slave Province is given, outlining the regional geology, and current and potential development. These are important considerations in the inventory of granular resources, because most of the development in the region is from mineral exploitation. Surficial geology and the glacial history of the region is presented to provide a brief introduction to surficial sediments, and indirectly, granular potential. The main sources of granular materials are described, and generic granular resource requirements are briefly summarized. Sixteen reports and projects are outlined, and classified into a level of detail with respect to granular resource inventory work. This existing work is reviewed, and several recommendations have been made to improve the granular resource inventory of the Slave Province to a level which adequate for preliminary resource planning and management.

2

The Slave Geological Province

The Slave Geological Province occupies an area of approximately 225 000 sq. km. in the District of Mackenzie, Northwest Territories, between Great Slave Lake and Coronation Gulf (Atkinson et al., 1995). This province of the Canadian Shield has been radiometrically dated to 2.4 to 2.7 billion years, which suggests that it was formed during the Kenoran Orogeny (McGlynn and Henderson, 1972). The Slave Province is also a permafrost environment. The southwestern portion lies in the discontinuous permafrost zone, while the remainder is in the continuous zone. The tree line roughly follows the discontinuous/ continuous permafrost boundary. South of the tree line, vegetation is composed of black spruce, white spruce, high shrubs of willows and dwarf birch, low shrubs of ledum, vaccunium, and arctostaphylos species, sphagnum bogs, and lichen and moss ground cover (Lutra et al., 1985). North of the tree line, vegetation is restricted to limited clusters of stunted spruce, birch, low shrubs, alder, and tundra heath vegetation (Dredge et al., 1995; Kerr et al., 1996). Further north, the trees and shrubs become fewer and smaller.

Canada's National Geoscience Mapping Program (NATMAP) has undertaken a project to further the understanding of geological evolution and mineral potential of the Slave Province. As part of NATMAP, the Geological Survey of Canada has, in the last few years, been updating and improving both surficial and bedrock geology maps for the region. Mapping has been divided into NTS map sheets, and involves airphoto interpretation, and helicopter assisted field traverses.

2.1 Bedrock Geology

Although NATMAP is updating the mapping of bedrock geology at a more detailed level, a more general interpretation is adequate for the purposes of this report. An overview of the bedrock geology of the Slave Province has been prepared by McGlynn and Henderson (1972). The following is a summary of their findings.

Almost two thirds of the Slave Province is composed of Archean sedimentary and volcanic supracrustal rocks of the Yellowknife Supergroup, or their metamorphic and granitized equivalents. Volcanic rocks make up 15 to 20 per cent of these rocks, with the remaining 80 to 85 per cent being sedimentary. These supracrustal rocks are highly deformed and variably metamorphosed. About one third of the Slave Province is composed of granitic complexes, which are believed to extend underneath the Yellowknife Supergroup forming a granitic basement.

The supracrustal Yellowknife Supergroup rocks are often found in a simple sequence of thick accumulations of greywacke-mudstone sediments (interpreted as turbidites), and volcanics of a chemically basic composition. Minor volumes of carbonates, shallow water siliciclastic sediments, and conglomerates are also present, usually in close association with the volcanic sections. The Yellowknife Supergroup rocks are generally found in three poorly defined northerly trending belts, which are separated by large areas of granitic rocks.

Up to one half of the granitic rocks of the Slave Province are mixed gneisses, migmatites and granitic gneisses that appear to be highly metamorphosed and granitized equivalents of sedimentary strata of the Yellowknife Supergroup. The other half of these rocks are batholiths or slightly gneissic granitic rocks of various compositions. The granitic complexes are found in the broad areas between the three zones of the supracrustal rocks, and also as large intrusions into the supracrustal sequences.

The entire province is marked by non-granitic intrusions, as well, including ultrabasic intrusions, basic and alkaline plutons, and diabase dyke swarms and related sills. With exception of the dykes and sills, these intrusions are rare. The dykes and sills have been determined to be of five different ages, with the older ones being restricted to the southern half of the province. The oldest dykes are 2 300 - 2 400 million years old, with the youngest being 1 100 - 1 200 million years old. These young dykes, some reaching over 30 m wide, belong to the Mackenzie swarm, which occur over the whole of the western half of the Canadian Shield.

Caine and Brown (1986) have prepared a summary of important mines and mineral deposits in the NWT and the Yukon. The following is a summary of their interpretations on mineral associations in the Slave Province.

Gold deposits in the Slave Province are found in several different rock types. In the past, most gold was mined from greenstone shear zones (e.g. Giant, Con Mines) in the Yellowknife Supergroup. More recently, significant volumes of gold have been mined from iron formation-hosted gold deposits (Lupin Mine). Lesser amounts of gold have also been mined from mineralized quartz veins throughout the Yellowknife Supergroup.

The metamorphosed volcanic rocks of the Yellowknife Supergroup are commonly the host to polymetallic base metal deposits (copper, zinc, and lead), such as Izok Lake and Hackett River. The base metal deposits tend to occur in clusters, that are believed to be related to centres of past volcanic activity.

Silver is sometimes found in association with some gold and base metal deposits throughout the Slave Province. Silver is also occasionally found as veins in the Yellowknife Supergroup volcanic rocks, near to the contact with granitic rocks.

Diamonds have recently been found in the Slave Province in ultrabasic igneous intrusions known as kimberlites. Diamondiferous kimberlites are confined to continental cratons, such as the Slave Province, and are very rapidly emplaced, explosive volcanic intrusions, taking the shape of a carrot or funnel (BHP, 1995). They are generally weaker rock than the surrounding bedrock, and thus have been eroded over the millions of years since they were intruded into the surrounding country rock. They are commonly found as depression on the bedrock surface, and many of these depressions have since filled with water, forming lakes.

2.2 Surficial Geology

The Slave Geological Province is part of the Bear-Slave Upland physiographic division in the Kazan Physiographic Region (Bostock, 1970). The province is characterized by a featureless to rolling, hilly peneplain, with an overall relief from sea level to about 650 metres (McGlynn and Henderson, 1972). Thousands of lakes, both large and small, are found throughout the entire region, occupying glacially scoured bedrock hollows and isolated depressions in till plains (Kerr et al., 1996). The landscape was moulded and shaped by the recent Wisconsin glaciation, which has been little modified since the retreat of ice some 9 000 to 10 000 years ago (Dyke and Dredge, 1989).

As part of NATMAP, the Geological Survey of Canada's Terrain Sciences Division has been completing surficial geology maps of the Slave Province. Field work includes terrain mapping, measurement of ice flow indicators, and sampling for textural analysis, trace element geochemistry, and heavy mineral and kimberlite indicator analysis.

The GSC has completed surficial geology maps for seven and one half map sheets (of the 26 NTS sheets in the Slave Province), at a scale of 1:125 000. Five map sheets neighbouring the Slave Province have also been mapped (Figure 2.1). The status of the GSC surficial geology mapping program for the Slave Region is shown in Table 2.1. The maps prepared by the GSC identify glaciofluvial, till, organic, and non-glacial sediments, and bedrock, where it is exposed. Geological interpretations of landforms are also shown, and marginal notes describe the glacial history, and the bedrock and surficial geology.

The surface of the Slave Province is typified by glacially eroded and exposed bedrock, and assorted glacial deposits, including till plains, broad esker systems, kames, and outwash plains. Some of these deposits have been somewhat modified by post-glacial reworking by ice dammed lakes, resulting in beach ridges, and aeolian processes, which have removed fine sands from some of the positive features, depositing them in more sheltered areas. Eskers in the region are often found with a coarse cobble lag on the surface due to these winnowing processes. Glaciolacustrine deposits can be found locally, and organic deposits also compose a minor portion of the surficial deposits. Dredge et al. (1995) and Kerr et al. (1996) have performed detailed surficial mapping studies of several mapsheets of the Slave Province. A comparison of the completed map sheets shows that the surficial sediments are similar throughout the Slave Province, with minor local variations. The main types of deposits mapped in the area are summarized below.

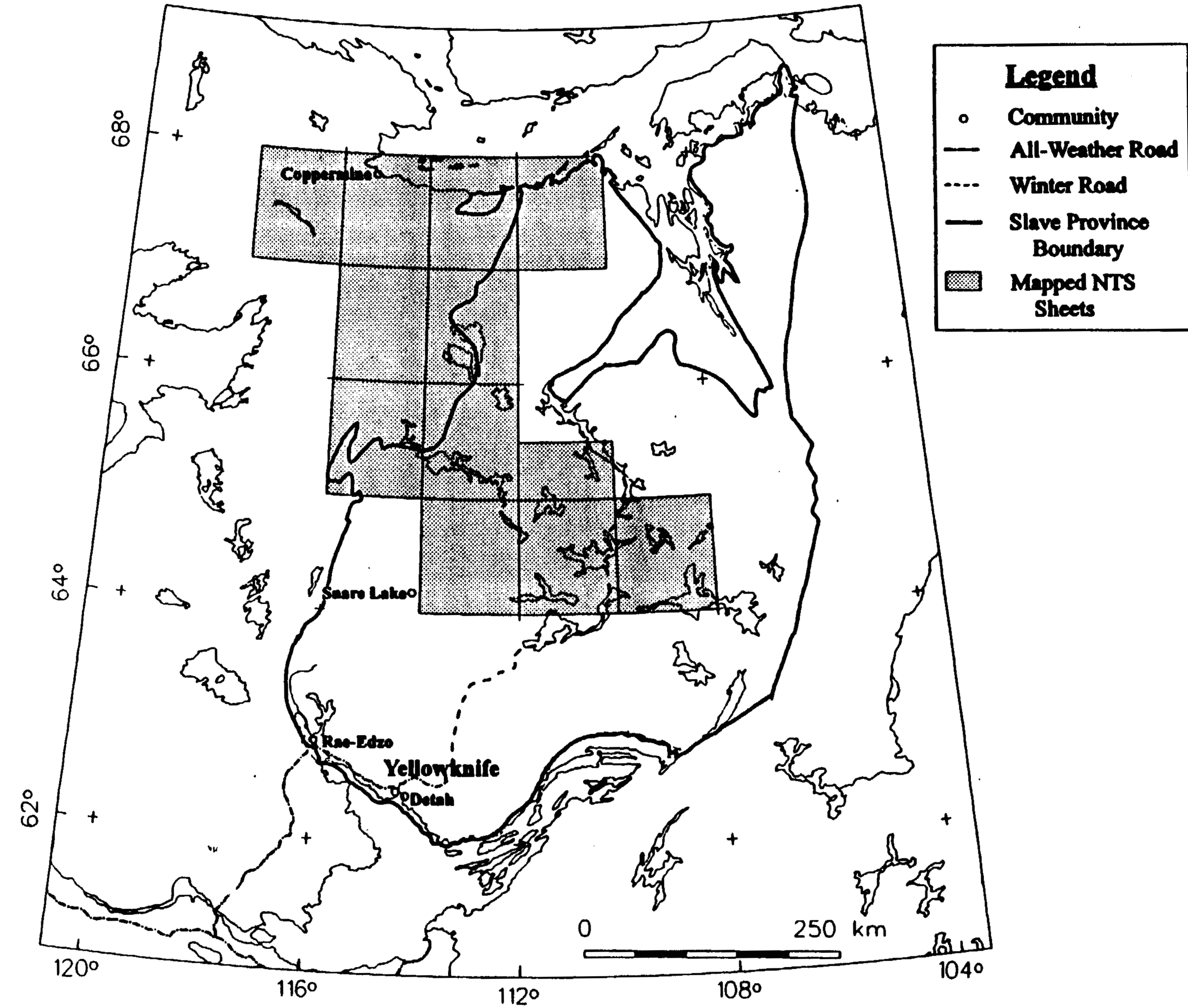

Figure 2.1 - GSC Surficial Geology Coverage

Table 2.1 - GSC Surficial Geology Maps

NTS Sheet Number	NTS Sheet Name	Publication Number[1]	Scale	Reference
76C	Aylmer Lake	Map 1867A (2 sheets); Open File 2798	1:125 000 1:250 000	Dredge et al., 1995a Dredge et al., 1994
76D	Lac de Gras	Map 1870A; Open File 2928	1:125 000 1:125 000	Ward et al., (in press) Ward et al., 1994
76E (south half)	Contwoyto Lake	Open File 3200	1:125 000	Ward et al., 1995
76M	Hepburn Island	Open File 2662	1:125 000	Thomas and Rampton, 1993
86A	Winter Lake	Map 1871A (2 sheets); Open File 2891	1:125 000 1:125 000	Kerr et al., 1996 Kerr et al., 1994
86G	Redrock Lake	Map 1645A	1:250 000	St. Onge, 1988
86H	Point Lake	Map 1890A; Open File 3085	1:125 000 1:125 000	Dredge et al., 1995b Dredge et al., 1995c
86I	Napuktalik Lake	Map 1889A; Open File 3032	1:125 000	Kerr et al., (in press)a Kerr et al., 1995
86J	Hepburn Lake	Map 1645A	1:250 000	St. Onge, 1988
86N	Dismal Lakes	Map 1645A	1:250 000	St. Onge, 1988
86O (west half)	Coppermine	Map 1645A	1:250 000	St. Onge, 1988
86O	Coppermine	Open File 3076	1:125 000	St. Onge, 1995
86O (east half)	Coppermine	Open File 3229	1:125 000	Kerr et al., (in press)b
86P	Kikerk Lake	Open File 3287	1:125 000	Dredge et al., (in press)

[1] Geological Survey of Canada Maps and Open Files

2.2.1 Till Deposits

The most abundant sediment in the Slave Province is till. At present, only one stratigraphic unit of till has been identified, and it is thought to be from the Wisconsin Glaciation. The till is described as consisting of a matrix-supported diamicton, with the matrix varying from silty sand to sand. The stone content averages about 25%, but ranges from 5 to 40% of the total volume. Well developed periglacial features, such as nonsorted and sorted circles, are found on the surface of these tills.

Three subunits have been separated out of the till, based on surface morphology and thickness - till veneer, till blanket, and hummocky till. Till veneers are thin (generally <2 m), and conform to the underlying topography, with bedrock exposures common. They are generally loose in texture and often have high concentrations of cobbles and boulders on their surface. Till blankets are 2 - 10 m thick, and are more compact, with fewer boulders and cobbles than veneers. They drape the bedrock, forming gently undulating till plains or low-relief drumlinoid features. Finally, hummocky till is between 5 and 30 m thick, forming irregular topography, with locally high relief. Hummocky till is commonly associated with surface ablation and stagnant ice, yielding a loose, bouldery texture. This till can also be deposited under active ice, which forms a more compact, less bouldery deposit with a silty sand matrix. Till veneers and blankets are common in the region, with hummocky till being more areally restricted.

2.2.2 Glaciofluvial Deposits

While glaciofluvial deposits are widespread throughout the Slave Province, they are limited in extent. They are predominantly found in the form of eskers and related kames, with outwash fans being less common. Ice wedge polygons are often found on these glaciofluvial deposits. Eskers range from small sinuous ridges to large linear features up to 45 m high, and tens of kilometres in length. Some are flat-topped and sandy, while others are sharp-crested and bouldery. There is often a dendritic network of smaller eskers which feed a large trunk esker. Washed, bare bedrock is frequently found flanking esker ridges, up to one kilometer wide.

The kames are associated with the esker systems, and are usually found adjacent to, or on the washed zones. These features are small, and have internal compositions of sand, with surfaces covered in boulders and sandy till. Morphologically, they range from streamlined forms parallel to meltwater flow, to slightly elongate forms perpendicular to flow, to irregular shapes.

2.2.3 Glaciolacustrine Deposits

Glaciolacustrine deposits are frequently in the form of raised beaches, which are sometimes found on the flanks of eskers. These raised beaches represent still-stand positions in the level of former lakes that were likely glacial in origin and dammed by glacial ice. In some localities, isolated deposits of rhythmically bedded silt and clay are found, up to 5 m thick at one location in the Winter Lake map area.

2.2.4 Organic Deposits

Organic peat deposits are common throughout the Slave Province. They are found in low areas along poorly drained and defined watercourses. Periglacial features such as ice wedge polygons are frequently found in these organic deposits.

2.3 Glacial History

The region of the Slave Province has undergone several glacial episodes, the most recent being the Wisconsin, which began approximately 100 000 years ago, and lasted until only 10 000 to 9 000 years ago. The Slave Province was covered by the Keewatin sector of the Laurentide Ice Sheet (Dyke and Dredge, 1989). Much of the evidence of ice flow direction comes from striations found on bedrock. In some places, there may be two or more striation directions superimposed on one another, but only seldomly can they be differentiated into early and later flows. From this means of investigation, Dredge et al. (1995) and Kerr et al. (1996) have determined that, at least through several map sheets, an early flow direction was towards the southwest. This has been interpreted as relating to the build-up phase of the Wisconsin glaciation. Later, flow appears to have reoriented to a due west direction. Evidence found in re-oriented drumlins and striation sequences suggest that flow in the northern portions of the Slave Province began a progressive shift to the northwest. The eskers in the northern portion of the province trend to the northwest as well, adding support to the theory. This northwest flow is believed to correspond to the Late Wisconsin glacial maximum through to the recession.

3

Development

The Slave Province is an area of little development. There has in the past been many producing mines, of various sizes, mostly extracting gold from the subsurface, but today, only six mines remain. There are also few communities in the Slave Province. Most are small Aboriginal communities, with Yellowknife, the capital city of the Northwest Territories, containing the bulk of the population. While the region is primarily undeveloped today, it has a very high potential for future development, including mines, roads, and hydroelectric power plants.

3.1 Existing Development

The Slave Province is predominantly undeveloped. The 1995 population of the region was 20 000, with Yellowknife being home to 17 350. The remaining population inhabits four established Dene communities - Rae/Edzo, Dettah, N'dilo, and Snare Lake. These communities are all located within 200 km of Yellowknife.

Six operating mines exist within the Slave Province, all retrieving gold from the subsurface, with one mine also producing minor silver. Four of these mines (Giant, Mon, Con and Ptarmigan Mines) are located within 50 km of Yellowknife, one

(Colomac Mine) is just over 200 km north, and the remaining mine (Lupin Mine) is about 400 km north-northeast of Yellowknife. Most of the sixteen past-producing mines in the Slave Province have also been located close to Yellowknife, with its connections to southern cities. Historically, gold has attracted most of the mining interest in the Slave Province, but other commodities, like silver and base metals, have also encouraged intensive exploration.

In most remote areas, the development of natural resources and infrastructure are closely related. The Slave Province is no exception - both are limited. There are only five all-weather roads, totalling approximately 250 km, in the region (GNWT-DOT, 1990). Yellowknife is connected by the the NWT Highway #3 (Yellowknife Highway) to Highway #1 (Mackenzie Highway), with connections further south. An all-weather access road joins Rae-Edzo to Highway #3, and another all-weather road heads north from Rae-Edzo, providing access to a hydroelectric development plant on the Snare River. The Ingraham Trail heads east of Yellowknife for about 70 km, built in the past to provide access to now-abandoned mines.

Ground-based access to other parts of the Slave Province is generally by winter road during a two to three month season, usually from the end of January to early April. Winter roads across lakes, with short land crossings, provide access to several of the remote locations in the Slave Province. A winter road services the Colomac Mine, and the community of Snare Lake, from Rae-Edzo, and another, starting at the end of the Ingraham Trail, services the Lupin Mine on Contwoyto Lake, and several mineral exploration camps both north and south of the mine. While winter roads are relatively economical to build and maintain, they are limited in use to a short period of time, and, if heavily travelled, significant volumes of granular material must be applied to overland sections on an ongoing basis.

Much travel around the Slave Province is by air. Many airstrips of various sizes and conditions exist throughout the region, left behind from abandoned mine sites and exploration camps. Most camps in early exploration phases are supplied by float planes in summer, or, by ski-equipped planes in winter. This is often the cheapest and easiest method of air access, as there are abundant lakes of sufficient size to land planes of all types. Upon more intense exploration and development, a gravel airstrip is usually constructed, to provide uninterrupted, year-round support.

3.2 Potential Development

The majority of the potential development in the Slave Province is directly associated with the mining industry. The level of development depends on several factors such as the prices of mineral commodities, and government mining and environmental policies and regulations.

In the past few years, a new interest has opened in the region - diamonds. Exploration for diamonds has been at a fevered pitch for the past five or six years, with hundreds of kimberlite pipes now identified. Very few of these pipes have been sampled at depth, and it is unlikely that many actually contain economical quantities and qualities of diamonds. Most of the kimberlites identified and studied to date fall in a north-northwest trending band of kimberlite occurrences, passing MacKay Lake, Lac de Gras, and Yamba Lake. Although kimberlites have been discovered and proven to be diamondiferous elsewhere in the Slave Province (including northern Contwoyto Lake, and the northern shore of Great Slave Lake), much of the current exploration and sampling activity is in this "Corridor of Hope".

Three diamond projects are in the process of kimberlite bulk sampling. They are BHP Diamonds, Inc., with their Koala property on the north shore of Lac de Gras; Kennecott Canada Ltd.'s Diavik Project, with pipes around Lac de Gras; and Lytton Minerals Ltd., with the Jericho property near the northern end of Contwoyto Lake. BHP's project has received conditional approval from the federal government to begin construction of the first diamond mine in Canada. It is widely believed that Kennecott and Lytton will soon submit proposals for their own diamond mines, probably to begin operation one and two years behind BHP, respectively.

Bernard et al. (1995) present three potential development scenarios (low, moderate, and high development) for the Slave Province in the year 2010 (Figure 3.1). They predict that two or three moderately sized gold mines will open in the next 15 years, that the Izok base metal mine (and possibly others) will be open, and that at least one diamond mine will be operating. Depending on the level of development, either winter roads or all-weather roads will be constructed from Izok Lake to Coronation Gulf, and from Yellowknife to the Lac de Gras diamond mine(s). Several of the major mines that are presently operating will have depleted their reserves and closed over the 15 year time period, and smaller mines will have opened and closed during this time as well. Winter roads and airstrips will service all of the smaller mines. With high development, two more hydroelectric plants will likely be constructed to service the increased demand by the mines and growing communities.

Development prospects have changed since the above report by Bernard et al. (1995) was prepared, and these changes affect the potential development of the Slave Province. As mentioned above, three diamond projects are expected to open in coming years. This level of diamond-related development corresponds to the "High Development Scenario for 2010" of Bernard et al. (1995), but it may now be expected with a moderate level of development. In an updated high development scenario, a third diamond mine might still be expected in the Lac de Gras region (one of the current diamond mine proposals is at the northern end of Contwoyto Lake, rather than in the Lac de Gras area), as in the scenario of Bernard et al. (1995), making a total of four diamond mines in the Slave Province.

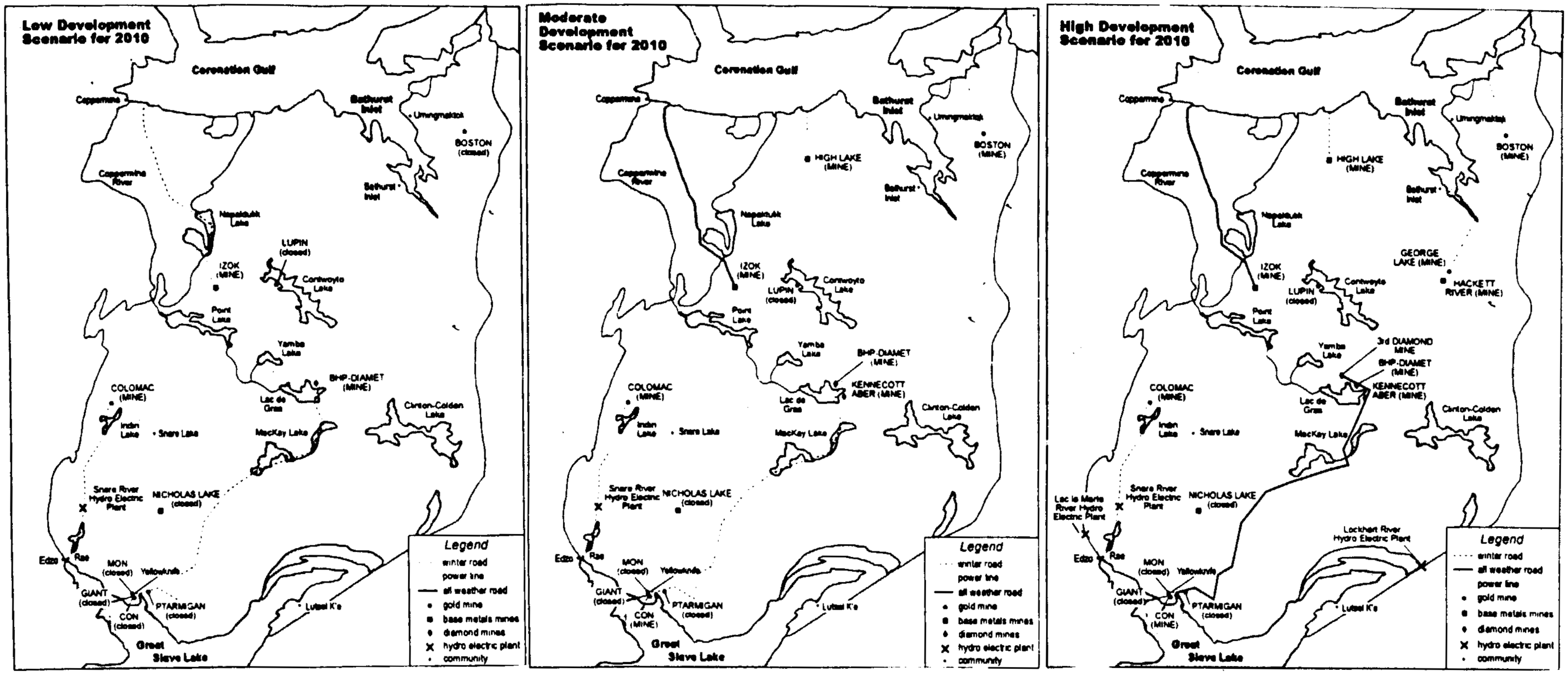

Figure 3.1 - Potential Development Scenarios for 2010 (from Bernard et al. 1995)

Other potential mineral deposits and mine expansions in the Slave Province have been described by Bevan (1996). It is expected that Echo Bay Mines Inc. will increase the life span of its Lupin Mine by opening a satellite mine (called Ulu) some 120 km north of Lupin and trucking the ore to Lupin for processing. The Consolidated Ramrod Gold Corporation, owner of the Colomac Mine, is also looking to open a satellite mine at the Damoti Lake gold deposit located 12 km southwest of the Colomac Mine. Both of these potential satellite mines have undergone extensive exploration in the past year or two, in order to determine their suitability for mining.

Bevan (1996) and Bernard et al. (1995) have considered similar potential development projects, including Boston, George Lake, Hackett River, Izok, Nicholas Lake, and three diamond projects (two at Lac de Gras and one at Contwoyto Lake). Bernard et al. (1995) identified one further deposit (High Lake) likely to be mined in a moderate or high development scenario, and two hydro electric plants (Lac la Martre and Lockhart River) in the high development scenario. Bevan (1996) considered an additional four deposits, two fitting in the low development scenario (Ulu and Damoti Lake), and two in the moderate or high scenarios (Tundra/Fat and Discovery). Another hydro electric plant (Snare Cascades) was identified, which may replace the Lac la Martre plant in the high development scenario.

While the three development scenarios of Bernard et al. (1995) show potential development for the Slave Province, it can also be expected that more development will occur. With infrastructure comes exploration, as can be seen on the mineral deposit maps in Figure 3.2, and Appendix I . Figures 3.2-A and 3.2-B show gold deposits and kimberlite pipes, respectively. As is clear on the Gold Deposit map, exploration is concentrated in several clusters. An interpretation for this is given by the following quotation:

> *"Gold is where you find it, and the best place to look is where it's been found before."*
>
> - Evans Dick, President of Ardic Exploration and Development Ltd. (Gleeson, 1996)

Figure 3.2 - Locations of Selected Minerals in the Slave Province

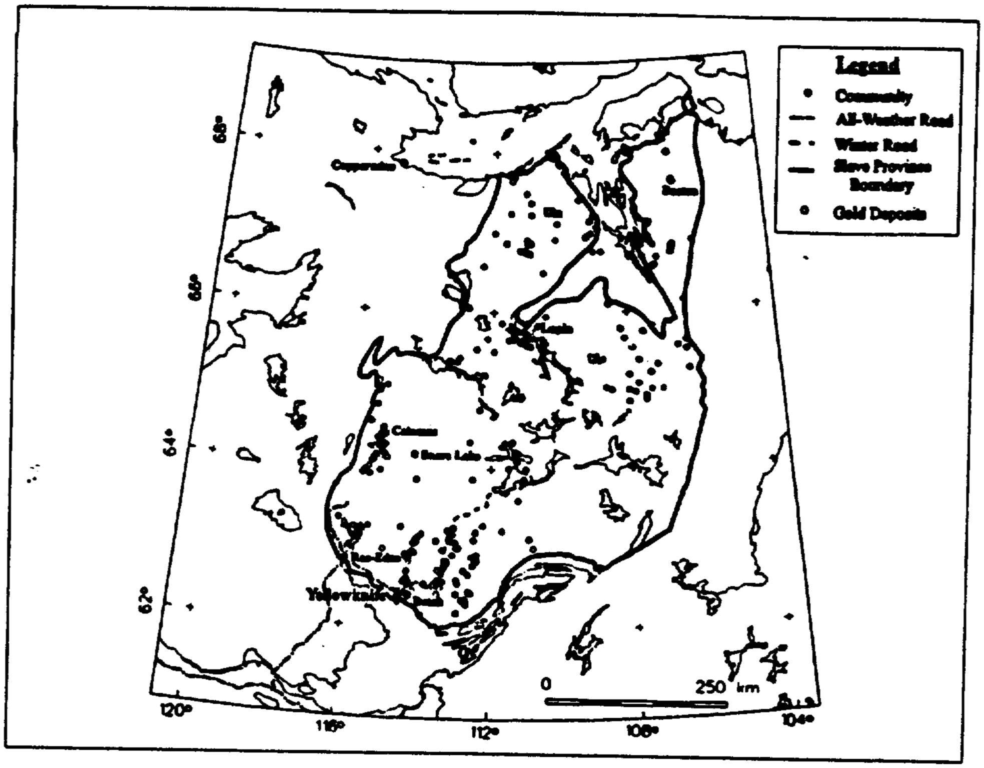

Figure 3.2-A - Gold Deposits

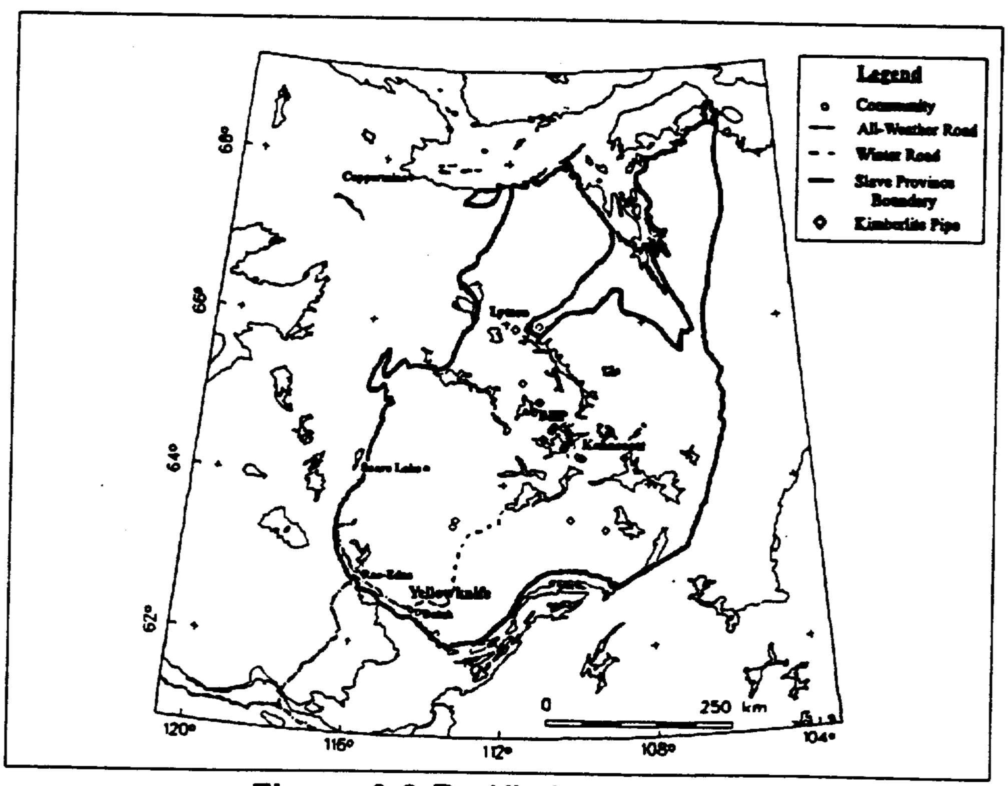

Figure 3.2-B - Kimberlite Pipes

Although gold deposits have been identified in all areas of the Slave Province, the large clusters are found around Yellowknife, Rae-Edzo, Colomac Mine, Lupin Mine, and along the Lupin winter road route (i.e. where infrastructure is already present). This will likely be the case a number of years down the road when diamond exploration has reached a similar level of activity. As is seen on the Kimberlite Pipe map, most kimberlites have been found in the Lac de Gras Region. As diamond exploration increases, and significant finds are made elsewhere in the Slave Province, clusters will likely occur around these finds.

Thus, with any new development in the Slave Province, much more exploration will occur around the development, due to improved access to the area. With this increased access, it is inevitable that new deposits will be discovered, and, some known deposits will likely become economical to produce. This effect will be magnified significantly if all-weather roads are built farther into the Slave Province, as in the moderate and high development scenarios of Bernard et al. (1995), but will also occur with the new development and winter roads in a low development scenario.

3.3 Generic Granular Requirements

While each development project is unique, it is possible to create a generic estimate of the granular requirements for different types of development. Bernard et al. (1995) has presented a basic areal estimate for several types of development, and McDougall (1996) has developed a comprehensive, interactive computer program to calculate granular requirement estimates for development projects.

Bernard et al. (1995) has presented a generic "footprint" for several types of development projects. While the report focuses on the cumulative environmental effects of development in the Slave Province, it also includes very basic estimates concerning the area that would be disturbed (and indirectly the volume of material) to meet borrow requirements. The report predicts that, for a winter road, one km^2 of borrow pit will be required for every 100 km of road. An all-weather road would need one km^2 for every 25 km of road. A 500 ha hydroelectric development would require 2 ha of borrow pit, and a community would need 5% of the total land area for borrow material. These estimates are very rough, as the area of a borrow pit depends on the thickness of borrow material available in the pit. A pit with 2 m thickness of quality material would be very much larger (areally) than one with 4 m of material, when the same volume of granular is removed from both. Clearly, the information on the "footprint" of projects can be refined if better information on granular resource deposits is available.

McDougall (1996) has prepared a computer model for forecasting granular requirements for different types development in the permafrost environment, including roads, airstrips, pads/building foundations, and mine site developments. This interactive model considers the parameters of area, length (if applicable), side slopes, thickness, terrain (flat to rough), and material class (excellent to poor). Some types of development have additional parameters, to allow a more accurate granular estimate for a particular scenario. The system allows the user to use default values for volume calculations, or to override these defaults and enter more specific values for their project. The default values were determined by reviewing granular requirements for existing development, and calculating average values for the parameters. The model uses the data, along with various weighting factors for "terrain factor" and "material class", to calculate a volume of granular material required for such a development. Appendix II contains site parameters, plan and cross-sections for various developments, with a default estimate of required volumes of granular material for the generic values given. Although the above computer model is available for estimating granular requirements, it was not the intention of this report to calculate an overall requirement for the Slave Province.

4

Sources of Granular Resources

Granular resource requirements for various end uses are often very different. Embankment and sub base materials are the easiest to find, and require the least amount of processing, while surface material and concrete aggregates need very specific granular qualities. In the northern permafrost regions, granular material must have a low percentage of fine particles (silt and clay), less than 5% for most uses. This is the most important quality for granular resources in the Slave Province. The materials must be coarse to allow sufficient drainage of water, which prevents buildup of ice. The formation of ice is destructive to any structure overlying it, due to the action of frost heave, resulting from repetitive freeze-thaw cycles of enclosed moisture.

While it is important that formation of ice is prevented within engineered earthfill structures, the granular fill must also preserve any ice in the underlying permafrost. Sufficient thicknesses of granular material must be placed underneath any structure to ensure that the permafrost does not melt. If melting occurs, the result will be thaw settlement. For this reason, great volumes of granular fill are required for all development projects.

supra-, en-, and subglacial flow. Aylsworth and Shilts (1989) have described the eskers of the Districts of Mackenzie and Keewatin, NWT, specifically as "... sharp ridged and up to 40 m high, with conical knobs projecting here and there well above the average elevation of the esker crest. Along their length they may be interrupted in places by bulges where the single ridge splits into multiple ridges which coalesce downstream."

Eskers are known to be deposited by glacial meltwater streams, but there remains some disagreement as to the specific environment. The main discrepancies are the location of the meltwater stream, either supra-, en-, or subglacial; the nature of the conduit, either open channel flow, or closed, full-tunnel flow; and the site of deposition (far back within the conduit, at the ice front in a subaqueous environment or at the ice front in a subaerial environment) Banerjee and McDonald (1975). To date, examples of all the above types have been found, which suggests that each esker is different, and local conditions dictate "how" an esker will be deposited.

Eskers are considered the prime source for granular materials in the Slave Province. Their glaciofluvial environment of deposition has removed most of the fine particles, and has left locally well-graded deposits with sufficient percentages of the various coarse size fractions. Eskers in this region are often many kilometres in length, several metres high and often more than 10 metres wide. This results in a significant, measurable and easily-accessible volume of material available for use in construction. Excavation is usually simple, because of the positive relief of eskers. Typically, there is little overburden, so the required material can be scraped off the top of the feature. In permafrost and muskeg areas, this type of pit development is highly desirable since conventional (below normal ground surface) pits tend to flood, and may be accessible for only one season.

The use of eskers as a granular source does however, raise some environmental issues. Eskers are a unique habitat in the Slave Province. Esker flanks provide well drained soils, shelter, and often a warm surface facing the sun that many plants require to survive in the harsh subarctic climate (Kay and Kay, 1976). Eskers also provide a suitable location for animals to den. Mueller (1995) found that grizzly bears, wolves, red foxes, arctic foxes and arctic ground squirrels "established dens almost exclusively on sandy eskers rather than on rocky uplands or on sedge meadows." Further to the denning habitat for animals, eskers are often used as migratory routes for caribou, because the hard, dry ground is much easier to walk on than the surrounding peat bogs and sedge meadows. The raised elevation over the surrounding area provides relief from insects as well, because there is often a stronger wind to keep bugs away. Finally, eskers have often been used in the past by indigenous peoples as camping, hunting and burial sites. Artifacts can often be found where an esker has previously been used as one of the above sites, and these historical locations must not be disturbed.

Several development considerations must also be evaluated before an esker source is selected and a pit is opened. The presence of massive ground ice may significantly reduce volume estimates, and cause erosional, and/or drainage problems during exploitation. The factors affecting the extent and distribution of bodies of ice within eskers and other coarse-grained sediments are not well understood. Existing pit developments have shown ice to be highly irregular and unpredictable (EBA, 1995).

4.2 Kames

Kames, in general, have been widely studied, as have eskers. They are frequently associated with eskers, as is the case in the Slave Province (see Section 2.2.2), making up complex landforms. Holmes (1946, in Embleton and King, 1968) defined a kame as "a mound composed chiefly of sand and gravel, whose form has resulted from original deposition modified by any slumping incident to later melting of glacial

Granular materials of the quality required for construction in frost-prone areas are typically found in a limited number of landform types. The most important landform in the Slave Province, with respect to granular resources, are glaciofluvial landforms such as eskers, kames, and outwash plains. Other potential sources include features modified by glaciolacustrine processes. Although all of these landforms frequently contain materials of generally high quality granular material, each deposit is unique, and internal morphology and granular quality are highly variable. Where no suitable natural granular material is locally available for a development project, then the alternative is usually a bedrock quarry. Although more expensive than excavating an unconsolidated natural sand and gravel deposit, material of various qualities may be processed from one source, and the quantity is practically unlimited.

The following sections provide a brief description of the main sources of granular resources in the Slave Province. All of these landform types have been the focus of numerous publications, world wide. Eskers have been studied extensively in southern regions, but similar landforms in the northern permafrost regions are much less understood. They have rarely been examined, due to the remoteness of the region, and even then, exposures that reveal their internal structure, such as road cuts, existing borrow pits, and other excavations, are rare.

4.1 Eskers

Many definitions of eskers have been presented, but Banerjee and McDonald (1975) have put forth a simple but informative description: "An esker is a linear accumulation of gravelly and/or sandy stratified sediment that was deposited by a stream confined on both sides by glacier ice. In some cases, though not necessarily, the stream was also confined on the top and/or bottom by glacier ice." This basic definition covers the possibilities of open channel vs. full tunnel flow; and ice against or upon which the deposit accumulated." Kames are made of stratified sediments, and are found taking various forms in the Slave Province, such as hillocks, flat hills and plateaux, and ridges. Kame hillocks are rarely over 10 m in height, and often occur in groups, while kame hills and plateaux occur singly, with flat tops, slopes of 5 - 10 degrees, and varying sizes (up to 12 km^2). Kame ridges have a uniform direction, are from 8 - 20 m in height, and are similar in form to eskers, but have a different structure and origin (Sugden and John, 1976).

Although there are several hypotheses about the formation of kames, it is generally agreed that they are features of a stagnant ice mass. Some of these hypotheses are discussed by Embleton and King (1968).

- Kames may develop as crevasse fillings. As the ice melts, they will gradually be lowered to the ground surface as kames (possibly as kame ridges).
- Debris collects in pools on the surface of the stagnant ice-sheet. As the pool warms, it melts its way to the ground beneath, and forms a kame mound as the surrounding glacial ice melts.
- Supraglacial or englacial meltwater streams carry debris to the edge of an ice sheet, and as it falls over the edge, small delta-like deposits form. As the ice sheet melts, the proximal side of the "delta" collapses, forming the kame. Where many streams exit the ice close together, an elongated kame feature is formed perpendicular to the direction of ice movement.
- Supraglacial or englacial meltwater streams often develop moulins (circular depressions in the ablation zone of a glacier into which meltwater funnels (American Geological Institute, 1976)), which, as they deepen, collect material, and form kames as the surrounding ice melts. These types of kames are often associated with eskers, and sometimes have a thin band of deposits linking the mounds to an esker. These may be the type of kames found by Kerr et al. (1996) and Dredge et al. (1995) in the Winter Lake and Aylmer Lake mapsheets (see Section 2.2.2).

The formation of kames is, by definition, the result of ice collapse and slumping. This frequently results in irregular masses of debris containing till, and other fine-grained materials. The internal structure is usually highly deformed, with erratic pockets of high quality granular material within a mass of tills, and other poor quality deposits. These factors tend to limit the value of kames as sources of granular resources, and although they may contain significant volumes of suitable material, they are often considered secondary to eskers.

Pit development on a kame is similar to that on an esker. Both have a positive relief, and ground ice may be present, potentially causing problems. Although no studies have directly studied the denning habits of animals with respect to kames, similar results to the above mentioned esker study may be expected, possibly with fewer large animal (i.e. bear, wolf) dens. Kames do not have any significant effect on caribou migration routes. Historical sites may be present on kame features, but, to date, they appear to be less prone to contain artifacts.

4.3 Outwash Deposits

An outwash plain is defined as a "plain composed of material washed out from the [glacial] ice" (American Geological Institute, 1976). These plains are also known as sandurs. Outwash deposits may contain sand, gravel, and coarser material, along with fines, and tills. Generally, outwash debris decreases in grain size further away from the ice-front. Outwash plains tend to be poorly sorted, and heterogeneous. They are often marked by kettle holes from melt out of enclosed ice blocks (Smith and Collis, 1993). Where partially confined by glacier ice or topography (eg. valley wall), outwash terraces may be formed.

Significant thicknesses of material can accumulate where outwash is confined (as in mountain valleys), and they may be areally extensive where the landscape is generally flat or gently sloping. However, in areas of scoured, irregular bedrock topography, like the Slave Province, outwash deposits tend to be limited in number, area, and thickness. The general scarcity of unconsolidated sediment (compared to bedrock) may also contribute to the lack of outwash. Most of the coarse grained, unconsolidated material appears to be incorporated into the abundant eskers in the area.

4.4 Bedrock Quarry

Upon processing by blasting, crushing and screening, most types of bedrock make a suitable substitute for natural granular material. Bedrock is exposed at the surface over a major portion of the Slave Province. Even where covered by surficial sediments, the bedrock is often very shallow. Generally, the bedrock of the area (granites, and gneisses - see Section 2.1) is of sufficient quality to be used as aggregate, however, detailed testing must be performed on the rock before it is quarried for use as construction material. Depending on the intended use, specific engineering limits must be met, to ensure the stability of the material.

In the case of a mine site, waste rock from the opening of a drift or portal is frequently used as aggregate for construction of other parts of the mine site. This practice has two benefits - aggregate requirements from a bedrock quarry or other sources are decreased, and waste rock piles are reduced in size, thereby reducing the overall footprint of the site and the extent of reclamation work required on abandonment.

Although more expensive than excavating an unconsolidated deposit such as an esker, kame or outwash plain, the alternative of a bedrock quarry is often the best solution where high quality materials are not available or are not in close proximity to the development site. Such was the case in the construction of the airstrip at the BHP Koala Camp near Lac de Gras (BHP, 1995). Granular requirements for airstrips are very strict, and the company determined that a quarry would be the most efficient and cost effective source of construction material.

5

Granular Investigation Studies

Studies concerning the granular resources of the Slave Province have been completed by government departments, consultant companies, and private industry. The current study has identified and reviewed a total of sixteen reports or studies containing granular resource evaluations and/or assessments. An additional unknown number of investigations have undoubtedly been completed by private industry companies for evaluations and development of proposed mine sites, but there is currently no specific requirement for these studies to be released to any governing agencies or to the public.

Granular investigation studies have varied scopes, and range from preliminary airphoto-based, small-scale mapping to intensive, fine grid, delineation and development drilling. A classification scheme is being developed (Gowan, 1996, pers. comm.) and is presented in Table 5.1. This classification categorizes granular investigations into one of eight levels, with number one being the most detailed. The classification may be applied to individual deposits, to regions, or to granular investigation studies.

The available granular investigation reports and studies are described briefly in terms of purpose and investigation activities, and are classified with respect to the

Table 5.1 - Preliminary Classification of Northern Granular Resource Inventories[1]

Level	8	7	6	5	4	3	2	1
Category	Preliminary	Reconnaissance	Enhanced Reconnaissance	Regional Mapping	Detailed Mapping	Exploration	Delineation	Development
Typical Scale	1:250K-1:1M	1:250K-1:500K	1:125K-1:250K	1:50K	1:10K-1:50K	1:10K-1:25K	1:5K-1:10K	<1:1K-1:5K
Mapping Methodology	Derived from topographic maps, existing surficial geology maps, satellite images or airphotos (non-stereo)	As for preliminary but includes stereographic interpretation of airphotos, systematic image analysis, and/or aerial surveys.	As for reconnaissance but includes some field traverses and site examination.	As for reconnaissance but includes systematic field traverses and site examinations, with sampling and index testing of selected sites.	As for regional mapping but includes sampling and index testing of most deposits.	As for detailed mapping but includes logging of some test pits or boreholes and some materials analysis testing and may include some geophysical surveys.	As for exploration but includes more systematic drilling and/or test pitting and/or geophysical surveys and materials analysis.	As for delineation, but includes drilling, test pitting and/or geophysical surveys on fine grids, extensive materials analysis, and examination of exposed pit walls and quality control testing.
Uses	Broad scale planning. Preliminary granular resources inventory planning.	Broad scale planning. Field program planning	Broad scale planning. Preliminary site investigation planning. Preliminary resource assessment.	Land use planning. Resource management. Preliminary resource estimates.	Land management. Site exploration planning. Resource estimates. Deposit management.	Deposit management. Preliminary reserve estimates. Preliminary development planning.	Deposit evaluations. Development Plans. Contract documents.	Contact documents. Development Plans. Restoration Plans.
Resource Determination	Shows only areas potentially containing granular deposits.	Prospective deposits identified.	Some deposits examined. Some probable deposits identified.	Quality and quantity estimates.	Deposit boundaries identified. Refines quality and quantity information.	Some proven reserves. Quality determined.	Quality and quantity proven. Variations identified.	Precise quality and quantity determined. Performance known.
Examples of Outputs	Field Map sheets	Preliminary Maps.	Reconnaissance Maps.	Resource Maps	Deposit Maps	Site Plans	Development Plans	Production Plans

[1]Source [illegible] ?n, 19[illegible]

above mentioned scheme, in the following pages. This information is summarized at the end of the chapter (see Table 5.2). Figure 5.1 shows the known extent and level of detail of granular resource inventory work in the Slave Province.

5.1 Report: "Granular Material Sources Investigation - Rae-Edzo, NWT"

This report (Collins, 1990) was prepared by the GNWT Department of Public Works as part of their Community Granular Program. It is a field and laboratory evaluation of the existing and potential supply of granular resources in and around the community of Rae-Edzo. Three existing sources are discussed and an additional three potential borrow sources and three potential quarry sites are identified. Estimates of area and volume are given for each of the potential sources, and some test results are presented. A detailed 20-year demand forecast is given for the community, and recommendations have been made on how to meet the projected demand. This study is a "Level 4 - Detailed Mapping" granular investigation.

5.2 Report: "Snare Lake Community Granular Program"

This report (Collins, 1992), prepared by the GNWT Department of Public Works as part of their Community Granular Program. Although a copy of the report was not available at the time of writing, it is assumed that it followed the same method of investigation as the study for Rae-Edzo, and others in the series, reporting on existing borrow pits, identifying potential future sources for granular materials, and evaluating the supply and demand with a 20-year forecast being presented. Five potential borrow sources, and two potential quarry sites were identified. It is believed that this study would similarly correspond to "Level 4 - Detailed Mapping".

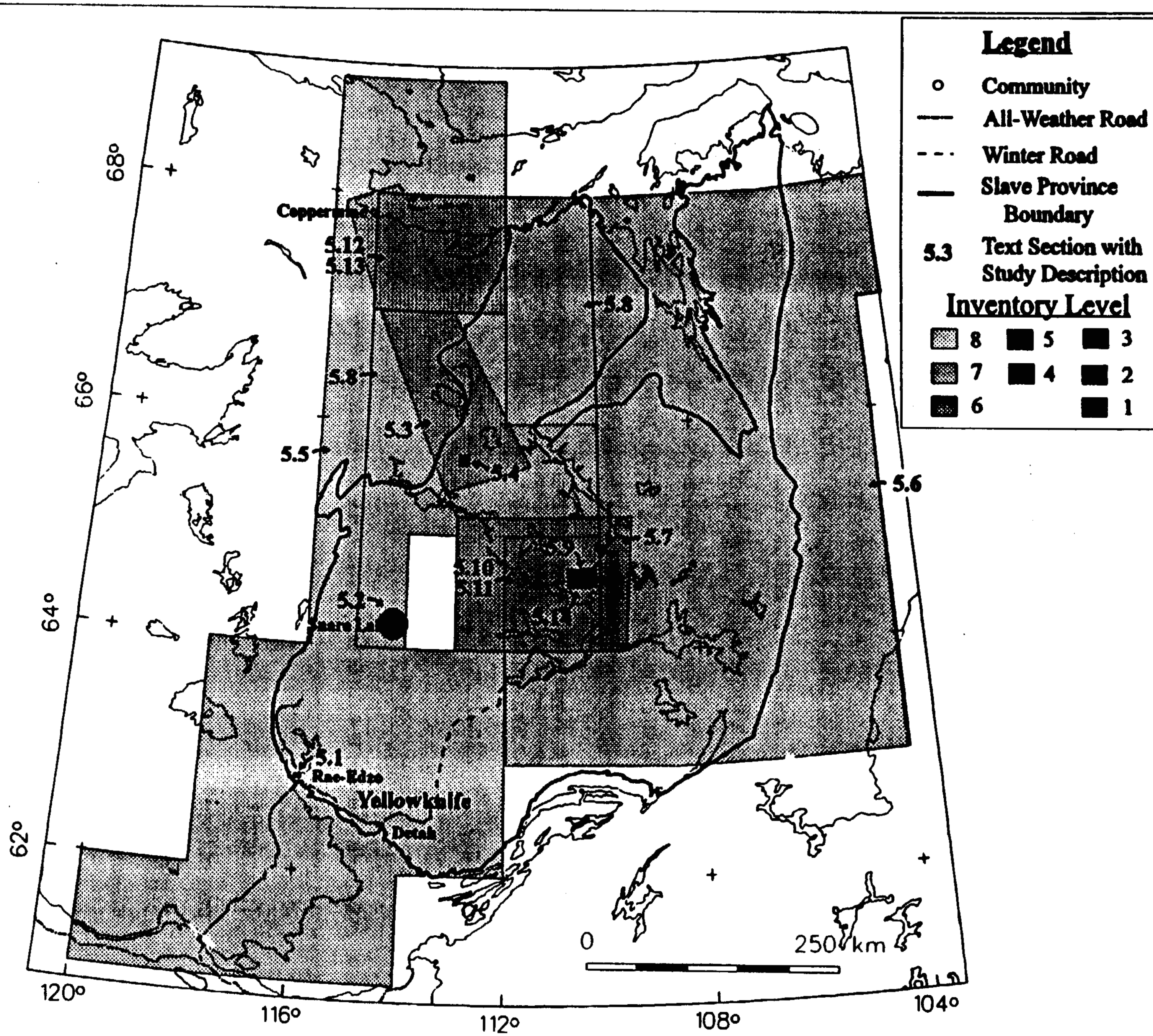

Figure 5.1 - Location and Classification of Granular Resource Studies

5.3 Report: "Izok Project Feasibility Study -- Winter Haul Road"

This report was prepared in October, 1993, by EBA Engineering Consultants Ltd. for Metall Mining Corp. It reports a study of 47 potential borrow sources along the proposed transportation corridor from the proposed base metal mine at Izok Lake to a proposed port site on Coronation Gulf. The sources were identified by airphoto interpretation, and 40 of them were then field checked, test-pitted, sampled and tested to further evaluate them with respect to granular potential. This field program corresponds to a "Level 6 - Enhanced Reconnaissance" study.

5.4 Report: "Izok Project Feasibility Study -- Mine Site Geotechnical Investigation"

This EBA Engineering Consultants Ltd. report was prepared in November, 1993, for Metall Mining Corp. It describes a geotechnical site investigation of the proposed Izok base metal mine at Izok Lake. The study included geophysical surveys as well as extensive geotechnical borehole drilling. The drilling was primarily for an engineering evaluation of the site, although one borehole (11157-25) was drilled through a potential esker borrow site. Detailed borehole logs were completed, and samples were taken for analyses of grain size, moisture content, and various other engineering properties. This study corresponds to "Level 4 - Detailed Mapping" to "Level 3 - Exploration".

5.5 *Report: "Compilation Inventory of Granular Material Resources Information Within the Izok Lake Transportation Corridor"*

This report was prepared for DIAND by J D Mollard and Associates Ltd. in October, 1993. It is a compilation of information from previous aerial photographic studies and associated reports of granular resource prospects within the proposed Izok Lake transportation corridor stretching from Yellowknife to Coronation Gulf, crossing 18 NTS mapsheets. Landform, topography, and rough volumes (small, medium or large) have been interpreted and tabulated. This study did not include re-examination of the previous study areas in stereo, thus, the topographies given should be regarded as approximate. Over 800 prospects were outlined on copies of annotated photomosaics and on photo-reduced mapsheets, which are included in the report. None of the deposits have been field checked by the consultant. Because the original reports included stereoscopic airphoto interpretations, this study corresponds to "Level 7 - Reconnaissance Mapping" on the granular inventory classification of Table 5.1.

5.6 *Report: "Compilation Inventory of Granular Material Resources Information Bordered by Latitude 63° and 68° and Longitude 102° and 112° in NWT"*

This report was prepared in August, 1994, for DIAND by J D Mollard and Associates Ltd. to extend the preliminary inventory for the Slave Province. It is based largely on compilation of known information from previous aerial photographic studies and associated reports of granular resource prospects within the within the study area noted in the title, encompassing 20 NTS mapsheets. However, in contrast to the previous study, other similar features observed on the topographic maps, airphotos, and surficial geology maps have been included. Investigations did not include re-examination of previous reports in stereoscopic vision. Landform, topography, and rough volumes (small, medium or large) have been interpreted and tabulated, with more than 1350 prospects being outlined on photo-reduced copies of the annotated mapsheets, which are included in the report. None of the deposits have been field checked by the consultant. This study corresponds mostly to "Level 8 - Preliminary Mapping" to "Level 7 - Reconnaissance Mapping" on the granular mapping classification of Table 5.1.

5.7 Report: "Tundra Esker Systems and Denning by Grizzly Bears, Wolves, Foxes, and Ground Squirrels in the Central Arctic, N.W.T."

This paper by Mueller (1995) describes the 1994 field activities of the DIAND/GNWT Joint Research on Eskers project, organized by DIAND's Land Management Division and GNWT's Renewable Resources Department to gain baseline information on eskers in the Lac de Gras region, particularly on their ecological importance. The field study had a number of objectives, including preliminary mapping of esker systems, studying the denning habits of the various animals under consideration, and sampling of several types of animal dens frequently found on the eskers. Sediment samples recovered from the den sites were compared using particle size analysis with randomly sampled esker sediments. In terms of granular resource inventory work, this project corresponds to "Level 6 - Enhanced Reconnaissance Mapping".

5.8 Report: "Granular Resources Research: Slave Province, N.W.T."

This report (Harrison, 1994) was prepared for DIAND, and outlines the involvement of DIAND in granular research in the Slave Province. The report describes the work by Mollard (1993) (Section 5.5), which studied the Izok Lake Transportation corridor; a Yellowknife District Deposit Database, which contains records of granular deposit location, status, past usage, etc.; the possibility of using remote sensing and satellite imagery for identification of granular resources; and a field program, attended by the author, as a part of the DIAND/GNWT Joint Research on Eskers project described above (Section 5.7). The field program consisted of test-pit sampling of eskers to determine a possible relationship between denning habitats and granular material quality. The overall study corresponds primarily to "Level 7 - Reconnaissance", with the field investigations being "Level 6 - Enhanced Reconnaissance Mapping".

5.9 Report: "Koala Mine -- Airport Esker Evaluation"

This report to BHP Diamonds Inc. was prepared by EBA Engineering Consultants Ltd. in March, 1995. It details a geotechnical drilling and geophysical investigation of the Airport Esker near the BHP Koala Camp in the Lac de Gras area. Seven geotechnical boreholes were drilled, and a ground penetrating radar survey was completed over the esker. The study entailed extensive subsurface investigations of the esker with respect to granular quality and quantity, and subsurface ice conditions. In addition, exposures of the esker created by trenching and during gravel extraction operations, were examined. Quarry development guidelines were prepared to ensure efficient extraction of granular materials from the esker. This investigation is a "Level 3 - Exploration" to "Level 2 - Delineation" study.

5.10 Project: DIAND 1995 Summer Field Reconnaissance Program

This study was sponsored by DIAND's NWT Land Administration Division, and formed part of the DIAND/GNWT Joint Research on Eskers project. It included airphoto analysis to identify potential borrow sites, detailed site description and sampling of selected sites. This work follows up and compliments that described by Mueller (1995), and includes field work described by Boles (1995). This field program falls in "Level 6 - Enhanced Reconnaissance".

5.11 Report: "Identifying Granular Resources Using Thematic Mapper Imagery, Slave Geological Province, N.W.T."

This report was prepared in August, 1995, by Stephen Boles, for the Land Management Division of DIAND. The report is an evaluation of the use and effectiveness of remote sensing in the identification of granular resources in the Slave Province. The study involved remote sensing image analysis, airphoto analysis, and a brief field checking program for the study area which encompassed the NTS map sheet 76D - Lac de Gras. Field investigations were performed as part of the DIAND 1995 Summer Field Reconnaissance Program. Ninety-two targets were identified, of which 74 were observed in the field, and seven were sampled. Locations and brief descriptions were entered into a database. The overall study corresponds to "Level 7 - Reconnaissance", with the field portions being a "Level 6 - Enhanced Reconnaissance".

5.12 *Report: "Permafrost Research and Monitoring Stations, Northern West Kitikmeot - Slave Geological Province"*

This report, prepared for DIAND's NWT Land Administration Division by the GSC Terrain Sciences Division (Wolfe, 1996) describes summer, 1995, field activities sponsered partly by DIAND, and conducted as an add-on to the GSC NATMAP work in the area (see Section 2.2). It consisted of surficial mapping, permafrost investigations and granular deposit sampling of one and a half NTS sheets bordering the Slave Province on the northwest. While the overall focus was on surficial geology mapping and permafrost research, some samples of granular prospects were taken for grain size, moisture content, and engineering analyses. With respect to the granular prospects that were sampled, the field study has progressed knowledge to "Level 6 - Enhanced Reconnaissance".

5.13 *Report: "Surficial sediments, permafrost, and geomorphic processes, Kikerk Lake and Coppermine map areas, west Kitikmeot, District of Mackenzie, Northwest Territories"*

This paper (Kerr et al. 1996b) represents a GSC Terrain Sciences Division report on field activities performed in the summer of 1995, as part of the NATMAP Program for the Slave Region. While the overall objective was surficial geology mapping and permafrost research, it includes the results of granular studies described in Section 5.12 above. The outcome of this program will be to produce a surficial geology map of the area, similar to those discussed below in the Slave Province NATMAP Project (Section 2.2).

5.14 Report: Geotechnical Investigation of Selected Granular Prospects, Lac de Gras Area, N.W.T.

This report was prepared for DIAND by EBA Engineering Consultants Ltd., in August, 1996. It details a geotechnical drilling program performed in March, 1996, in the area surrounding BHP's Koala Exploration camp near Lac de Gras. Eight geotechnical boreholes (three on the Airport Esker from the Koala Mine study mentioned above, and five on the Misery Esker on the shore of Lac de Gras) were drilled and detailed logs were prepared. Samples were taken and analyzed for grain size, moisture content, and various other engineering properties. The GSC's Terrain Sciences Division conducted a companion study, consisting of several geophysical investigations, including ground penetrating radar. These results were not available at the time of writing. The drilling program corresponds to a "Level 3 - Exploration" to "Level 2 - Delineation" study.

5.15 Project: WKSS/DIAND Esker Management Project

The DIAND NWT Land Administration Division has submitted a proposal to the WKSS (see Section 5.16) for an esker management study. The main objective is "to provide timely baseline information on eskers in the Slave Geological Province in a format which will benefit all." (Traynor, 1996). Through this study, it is anticipated that most major eskers systems and potential granular resources will be identified and mapped, and limitations to use of granular resources (e.g. ground ice, wildlife habitat, heritage sites) will be identified. Field work has begun in August, 1996, and will continue in 1997, at which time, a map of the entire Slave Province will be prepared showing all eskers and potential granular resources within them.

Upon completion of this project, it is anticipated that data of "Level 6 - Enhanced Reconnaissance" will be available for the entire Slave Province.

5.16 Project: West Kitikmeot Slave Study

The West Kitikmeot Slave Study (WKSS) was initiated by GNWT and DIAND in December, 1994, with funding from both levels of government, and from the mining industry, Aboriginal and environmental groups. It is a major study of environmental, social and economic issues related to mineral development in the Slave Province, and intends to collect baseline information to ensure that timely and informed decisions are made concerning development in the region. The WKSS has been incorporated as a society, and has begun funding research projects to help obtain this goal. The Canadian Environmental Assessment Agency (CEAA) has prepared several recommendations for the WKSS in their review of the NWT Diamonds Project of BHP. Specifically related to granular issues is the following Recommendation.

> *Recommendation 29. c) to collect regional baseline information on eskers and other glaciofluvial deposits, in order to provide a basis for development of guidelines and cumulative effects assessment by government.* (CEAA, 1996)

The project described in Section 5.15 is the first project of the WKSS to help fulfill the above recommendation.

Table 5.2 - Summary of Granular Investigation Studies

Project/Area	Sponsor	Author	Date	Purpose	Study Level*
Community Granular Program: Rae-Edzo	GNWT Dept. of Public Works	Collins	1990	Evaluate existing and potential supply	4
Community Granular Program: Snare Lake	GNWT Dept. of Public Works	Collins	1992	Evaluate existing and potential supply	4
Izok Winter Haul Road	Metall Mining Corp.	EBA Engineering Consultants Ltd.	Oct. 1993	Evaluate potential borrow sources along proposed winter road route	6
Izok Mine Site	Metall Mining Corp.	EBA Engineering Consultants Ltd.	Nov. 1993	Geotechnical investigation of proposed mine site	3 - 4
Izok Transportation Corridor	DIAND	J D Mollard & Assoc.	Oct. 1993	Identify granular prospectsfrom previous development proposals	7
East Slave Region	DIAND	J D Mollard & Assoc.	Aug. 1994	Identify granular prospects from previous proposals, maps, etc.	7 - 8
Lac de Gras Esker/Denning Study	DIAND/GNWT Renewable Resources	Mueller	1995	Collect baseline information onuse of eskers as denning habitat	6
Granular Research, Slave Province	DIAND	Harrison	1994	Identify granular information for Slave Province	7 (6)**
Koala Mine - Airport Esker	BHP Diamonds Inc.	EBA Engineering Consultants Ltd.	1995	Develop guidelines for granular extraction	2 - 3
Esker Sampling, Lac de Gras area	DIAND	N/A	1995	Sample potential quarry sites	6
Remote Sensing - Eskers, Lac de Gras	DIAND	Boles	1995	Evaluate the use of remote sensing in ID of eskers, and ground-truthing of results	7 (6)**
Permafrost Research, NW Kitikmeot	DIAND-GSC-NATMAP	Wolfe	1996	Focus mapping program on permafrost and granular issues	6
Surficial Geol. - Kikerk L., Coppermine	NATMAP-GSC Terrain Sciences Division	Kerr et al.	1996	Surficial geology mapping, permafrost investigation, preliminary study of granular deposits	6
Koala Area, Winter Drilling Program	DIAND	EBA Engineering Consultants Ltd.	1996	Geotechnical investigation of two eskers	2 - 3
Slave Province Esker Management Project	DIAND	N/A	1996 - 1997	Identify major esker systems, potential granular deposits, and limitations to graular resource use	6?

*Defined in Table 5.1

**Bracketed number refers to field portion, first number applies to overall study

6

Existing Granular Resources Inventory

Although there is currently no formal regional granular resources inventory program for the NWT, studies of the Slave Province have been completed on an ad hoc basis, at various levels of detail (see Table 5.1). Granular resource inventory work in the Slave Province is still far from complete, but collectively, the previous studies provide a preliminary granular inventory that can serve as the basis for planning future investigations and resource management activities. Recognizing the current deficiencies in the inventory, the recent Environmental Assessment Panel report on the BHP NWT Diamonds project has encouraged the West Kitikmeot Slave Study (WKSS) to make the collection of baseline information on eskers a priority.

Most of the region has undergone a reconnaissance level granular resource evaluation, which is suitable for preliminary regional planning, but only selected areas have been investigated to a regional mapping or more detailed level, which is required before any development is planned. This section attempts to summarize and consolidate the various studies and to assess the current status of the inventory.

6.1 Reconnaissance Level Inventory Work

Reconnaissance inventory work includes Levels six through eight of Table 5.1. It involves the identification of areas and deposits from aerial photographs, maps and satellite imagery, and field work, including aerial surveys, and limited ground-based work. This level of inventory work is suitable for broad scale, regional planning, and preliminary site investigation planning. Surficial geology maps are commonly the basis for preliminary granular resource evaluations. As was discussed in Section 2.2, and shown in Figure 2.1, the extent of surficial geology mapping of the Slave Province is limited, although the GSC is continually improving the coverage.

The "compilation inventory " projects of Mollard (1993, 1994) were completed without the benefit of complete coverage of surficial geology mapping. Had these been available, the above studies may have been able to identify more potential granular deposits, and perhaps to refine the deposit outline and size.

The initial study by Mollard (1993) relies on previous airphoto interpretation studies of existing and proposed transportation corridors, such as for the Izok project. Although this study considered only the area immediately surrounding the corridors, and not the entire mapsheet, over 800 granular prospects were identified on 18 NTS sheets. The following report, covering the Eastern Slave Region (Mollard, 1994), identifies 1350 granular prospects over 20 NTS mapsheets. This study used all available maps and airphotos to identify all potential deposits within the mapsheets. Figure 6.1 shows the extent of both of the Mollard studies, and all of the deposits they identified. The gaps in coverage between the various corridor studies included in the initial report (Mollard, 1993) are evident on this map, as is the absence of inventory work for NTS 86A - Winter Lake. This area was omitted from the Mollard projects because the preparation of a surficial geology map was in progress at the time.

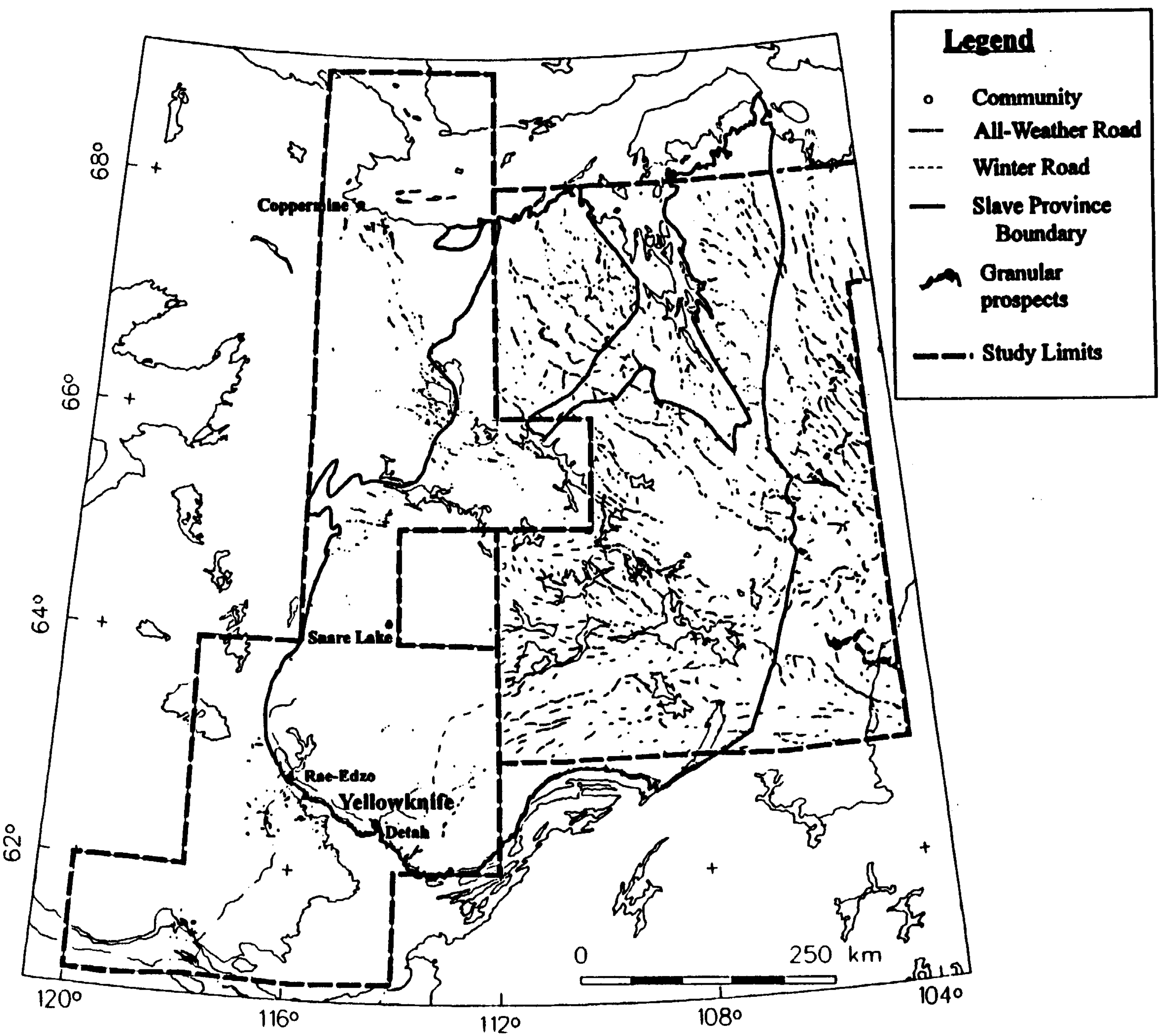

Figure 6.1 - Granular Prospects Identified in Reconnaissance Level Inventory

The area in the immediate vicinity of the proposed Izok winter haul road has been upgraded to a "Level 6 - Enhanced Reconnaissance" inventory by EBA (1993). This study identifies 40 potential borrow sources along the proposed winter road route and presents sample test results. This study is restricted to deposits considered suitable for the construction of a winter road, and does not identify any other potential granular deposits (thus it does not delineate all potential deposits in the corridor).

Much of the Lac de Gras region of the Slave Province has also been upgraded to the higher level of enhanced reconnaissance inventory through studies reported by Harrison (1994), Boles (1995), and Mueller (1995). These studies consisted of airphoto and/or remote sensing interpretation of landforms, field checking of identified eskers, and limited test-pit sampling.

One further region has been investigated to the level of enhanced reconnaissance; this being the Coppermine and Kikerk Lake mapsheets studied by Wolfe (1996) and Kerr et al. (1996b). The entire area has not been upgraded to this level, but a number of granular prospects were identified and sampled.

6.2 Mapping Level Inventory Work

Granular resources mapping includes Levels four and five of Table 5.1. It requires field studies that include systematic examination of all granular resources in an area, with prescribed sampling of most or all potential deposits. This level of inventory is suitable for land and resource management, resource planning, and preliminary resource estimates. In the Slave Province, only three studies, each covering a small area, are known to be completed to this level.

The Community Granular Program of the GNWT Department of Public Works provides mapping level inventory for the area around small NWT communities by identifying both existing and potential granular deposits, and present development plans for the communities. With the completion of investigations for Rae-Edzo, and Snare Lake (Collins, 1991, and 1992), this program is complete for the Slave Province, as the remaining communities of N'dilo and Detah meet granular requirements from the Yellowknife stocks.

A similar level of inventory work has been completed for the proposed Izok mine site (EBA, 1993a), with a potential borrow source being mapped and one borehole drilled and sampled. It is likely that a comparable level of inventory work has been completed for most mine sites in the region, but reports verifying this were not available in the public domain.

6.3 Site Investigation Level Inventory Work

This level of inventory work encompasses Levels one through three as in Table 5.1. It is usually restricted to a particular site of development. The granular resource sources are explored in detail in hopes of opening a borrow pit. Studies of this magnitude are prepared for the purpose of reserve estimates, deposit evaluations, and development planning. Within the Slave Province, the inventory at this level is very limited - only two studies prepared to this level were available in the public domain.

Site investigation work has been performed at the Airstrip Esker on the BHP property near Lac de Gras by EBA (1995, and 1996). Both field programs studied the esker intensively, with a total of ten boreholes, many borehole samples, and a ground penetrating radar (GPR) survey. The Terrain Sciences Division of the GSC has also conducted one GPR survey, and an "ohm-mapper" survey at this esker (paper presently being prepared). The Misery Esker, on the shore of Lac de Gras was also explored by EBA (1996), with five boreholes, and associated borehole samples. The GSC also performed a GPR survey, and an "ohm-mapper" survey on the Misery Esker.

It is anticipated that a similar level of inventory work must exist for several other development sites in the Slave Province, such as Lupin Mine, Colomac Mine, etc. Bevan (1996) suggested that site investigations would have been undertaken for most of the mines built in the Slave Province, some of which are now abandoned. Granular material would have been required for such construction, and potential borrow sources must have been identified and investigated for this purpose. Because there is no regulatory requirement for filing such information, it is not readily available at this time.

7

Conclusions

The Slave Geological Province in the Northwest Territories is one of enormous mineral potential, but little development. The bedrock of the region is host to a wide variety of mineral deposits, including gold, silver, copper, lead, zinc, and diamonds. Many of these deposits remain untapped, due to the lack of infrastructure, and the high cost of construction in the northern permafrost environment. For any development to proceed, vast quantities of granular materials are required for insulation of the permafrost. If underlying permafrost melts, severe damage can be incurred to the overlying structure.

The Slave Province is blessed with an abundance of granular material, predominantly in the form of glaciofluvial landforms, that will likely be capable of supplying the needs of future development. Of these landforms, eskers are the preferred source for granular material, because of the relative ease of extraction, and the generally high quality of material. There are, however, several environmental limitations to unhindered granular extraction from these landforms, including the presence of ground ice, migratory and denning habits of indigenous animals, and historical sites.

A comprehensive granular resource inventory program does not currently exist for the Slave Province, however, a number of reports and studies have been performed that will help to provide a basis for this inventory. These studies and reports have been summarized, and evaluated with respect to the level of inventory work that has been completed.

The level of granular resource knowledge for the Slave Province is currently at a Reconnaissance level, with some areas being investigated to a Mapping level, and a few isolated locations being studied to the site investigation level. Although there do remain gaps in the Reconnaissance knowledge of granular resources (which should be brought up to the Reconnaissance level as soon as possible), the overall status of the granular resource inventory for the Slave Province is adequate for broad scale regional planning, and preliminary site investigation planning.

Work that will improve the current level of inventory of granular resources in the Slave Province is ongoing, by government agencies, such as DIAND and the GSC, industry (primarily mining companies), and the West Kitikmeot Slave Study. The recently released report of the environment assessment of the proposed BHP NWT Diamonds project has emphasized the need for this inventory in recommending that either WKSS or government undertake the work needed to provide baseline information on the Slave Province, including eskers and other potential granular sources. The proposed "Esker Management Study" proposed by the DIAND NWT Region willl make important progress towards satisfying the recommendation.

8

Recommendations

Several recommendations are made with regard to improving the extent and quality of information on granular resources in the Slave Province. They are as follows:

- The initial granular resources compilation, which covered only the potential transportation corridors and other isolated sites, should be re-examined and brought to a level of inventory similar to that of the second report covering the Eastern Slave Region. Also, NTS Sheet 86A - Winter Lake (which was excluded from the above studies) should be evaluated to the same level as the Eastern Slave Region study.

- Other existing granular resources information contained in reports of evaluations of previous or existing development (operating and abandoned mines) should be sought in order to improve the granular resources inventory. Any geotechnical borehole data obtained should be included in the Slave Province Geotechnical Database, created in April, 1996 (Bevan, 1996).

- The "Esker Management Study" proposed by DIAND's NWT Region presents an opportunity to establish a formal granular resources inventory program for the region. If completed as part of the WKSS, it could promote the co-operation of federal and territorial governments, industry partners, and Aboriginal groups, towards obtaining the information needed. DIAND Headquarters should participate to provide specialist advice on inventories and management.

9

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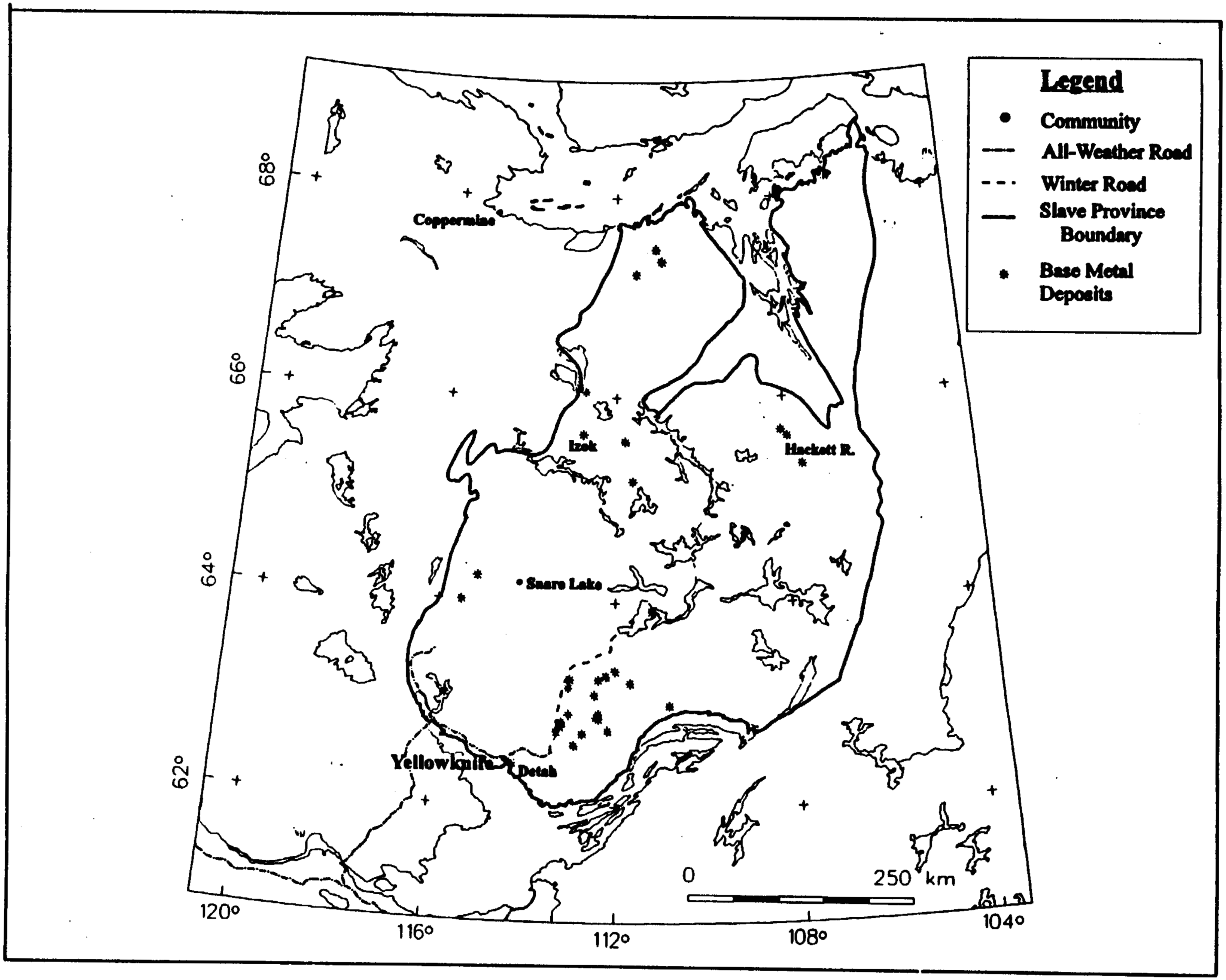
Appendix I - Base Metal Deposits in the Slave Province



Appendix I - Base Metal Deposits in the Slave Province

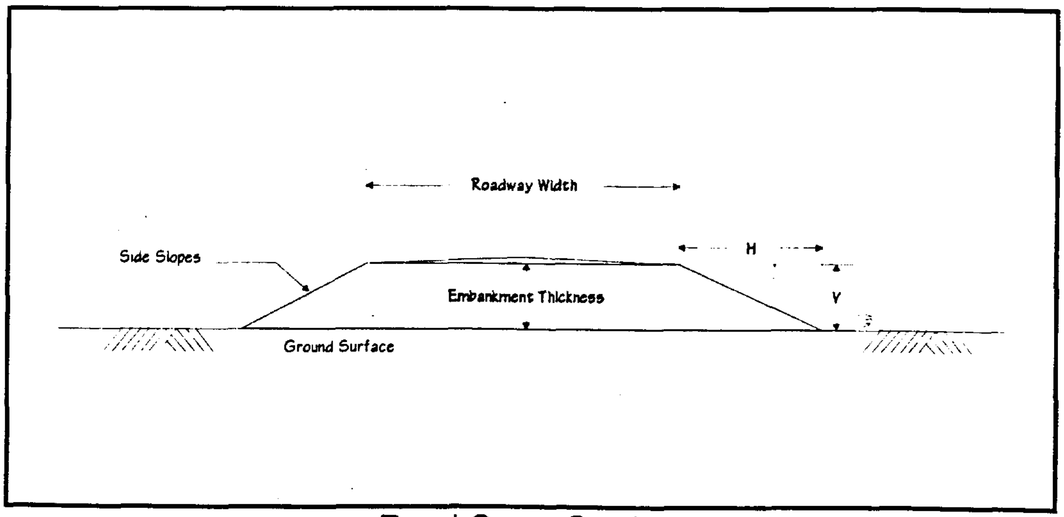
Appendix II - Generic Models for Granular Demand Forecasting

Granular Resource Demand Forecast Model

Menu **Roadway Embankment** Add

Parameter	Units	Default	Override	Actual
Width of Driving Surface	m	8.0		8.0
Embankment Thickness	m	2.0	1.5	1.5
Slopes	H/V	3.0		3.0
Length	km	1.0	3.5	3.5
Terrain Factor	1 - 5	2		2
Material Class	1 - 5	3		3
Calculated Volume	m^3	41,842		99,082

Roadway Parameters
Figure 12



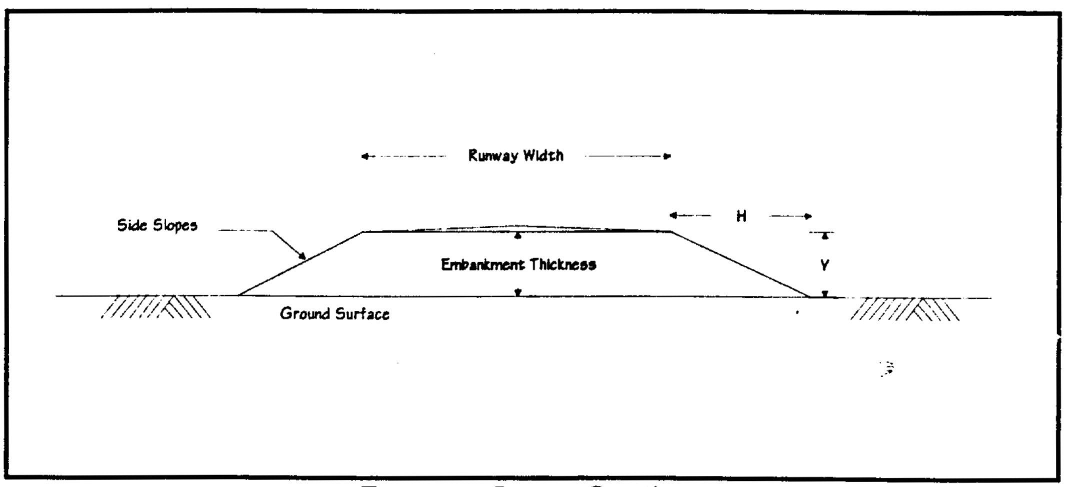
Road Cross-Section
Figure 13

Granular Resource Demand Forecast Model

Menu | **Runway** | Add

Parameter	Units	Default	Override	Actual
Width of Landing Surface	m	50.0		50.0
Embankment Thickness	m	2.0		2.0
Slopes	H/V	3.0		3.0
Length	m	1000		1000
Terrain Factor	1 - 5	1		1
Material Class	1 - 5	3		3
Calculated Volume	m^3	166,882		166,882

Runway Parameters
Figure 14



Runway Cross-Section
Figure 15

4.4. Pads / Foundations

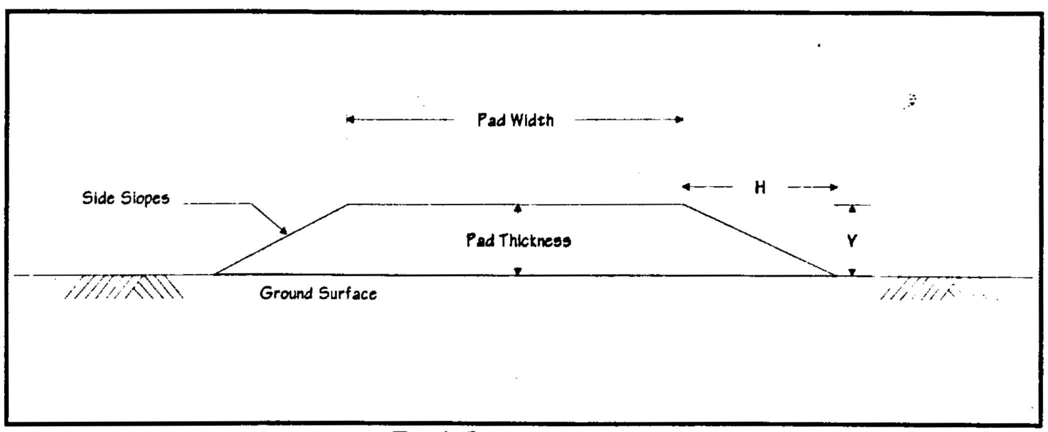
The key parameters for pads or building foundations are shown in Figure 16 and the corresponding cross-section geometry for the pad is shown in Figure 17.

Granular Resource Demand Forecast Model

Menu | **Pad Foundation** | Add

Parameter	Units	Default	Override	Actual
Width of Pad	m	15.0		15.0
Length of Pad	m	15.0		15.0
Thickness of Pad	m	3.0		3.0
Slopes	H/V	1.0		1.0
Terrain Factor	1 - 5	2		2
Material Class	1 - 5	3		3
Calculated Volume	m³	1,383		1,383

Pad Design Parameters
Figure 16



Pad Cross-section
Figure 17

Granular Resource Demand Forecast Model

Menu | **Mine Development** | Cont.

Parameter		Units	Default	Overrid	Actual
Ore Reserves		M Tonnes	20	50	50
Associated Waste		M Tonnes	50		125
Tailing Waste		M Tonnes	17		42.5
Daily Prouduction		Tonnes/d	3700		9100
Infrastructure				None	
Camp & Staging Area		m²	12500		12500
Plant Area		m²	520000		890000
Tailings Dams	Length	m	1000		1000
	Crest Width	m	20		20
	Avg. Height	m	50		50
	% Waste Rock	%	75		75
Air Strip	Length	m	1875		1875
	Width	m	100		100
	% Waste Rock	%	0		0
Water Diversion	Length	km	0		0
Canals	% Waste Rock	%	50		50

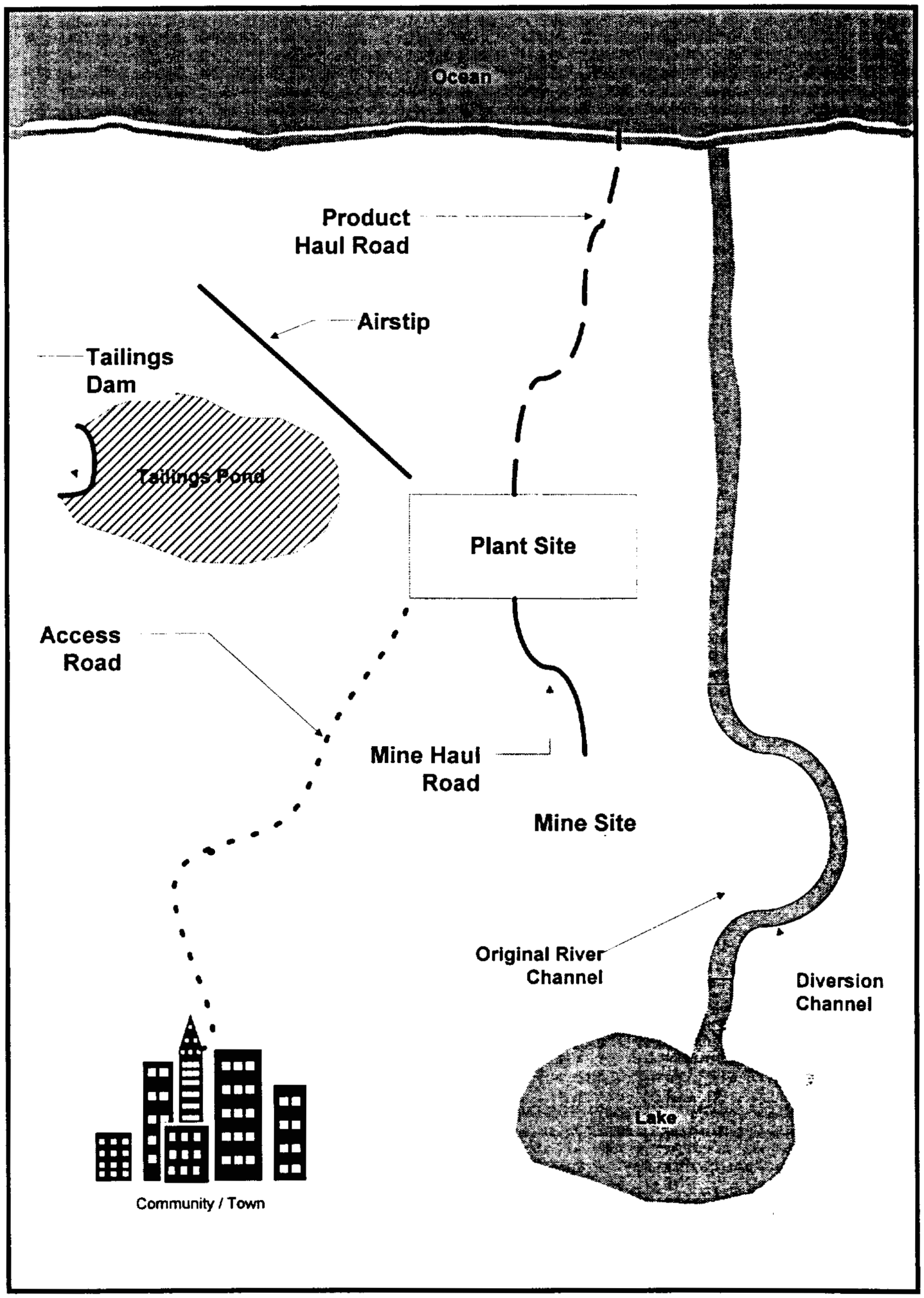
Mine Site Parameters
Figure 27

Granular Resource Demand Forecast Model

Menu | **Mine Development (Continued)** | Add

Parameter		Units	Default	Overrid	Actual
Access Road	Length	km	0		0
	Width	m	10		10
	% Waste Rock	%	0		0
Mine Haul Roads	Length	km	20		20
	Width	m			0
	% Waste Rock	%	50		50
Product Haul Roads	Length	km	5		5
	Width	m			0
	% Waste Rock	%	0		0
Terrain Factor		1 - 5	3		3
Material Class		1 - 5	3		3
Calculated Volume		m³			0

Mine Site Parameters (Page 2)
Figure 28



Mine Development
Figure 25