UNLOCKING NORTHERN RESOURCE POTENTIAL:

The role of infrastructure

PROSPECTORS & DEVELOPERS ASSOCIATION OF CANADA

UNLOCKING NORTHERN RESOURCE POTENTIAL:

The following independent report was prepared by Richard Schodde, Managing Director of MinEx Consulting Pty Ltd, for the Prospectors & Developers Association of Canada (PDAC). The associated GIS modelling work for this study was carried out by Kenex Ltd.

Background information on the author

Richard Schodde has over 30 years of experience in a wide variety of project analysis, business development and strategic planning roles within the international resources industry.

In 2008 Richard founded MinEx Consulting to provide strategic and economic advice to industry and government. His main focus is on the economics of mineral exploration. His client base covers over 50 companies (both Major and Junior), investment groups, and government agencies across 12 countries.

In 2009 he was appointed an Adjunct Professor at the School of Earth Sciences at the University of Western Australia. Richard has published several dozen papers on exploration performance, and is internationally recognized by his peers as a world leader in mineral economics. In December 2015, *Mining Journal* nominated Schodde as one of the top 20 power people in world mining due to his strategic insights and influence on policy in the exploration sector.

Richard holds a First Class Honours Degree in Materials Engineering and a MBA. He serves on the Editorial Board of the Journal of Resources Policy, the organizing committees for the AusIMM and the Melbourne Mining Club.

In this study Richard commissioned Kenex Ltd to carry out the detailed GIS modelling work. Kenex was set up in 2002 in Wellington New Zealand to provide specialist GIS and exploration services to the resources and energy industries.

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Background information on the Prospectors & Developers Association of Canada

The following report was commissioned by the Prospectors & Developers Association of Canada (PDAC) to assess the impact of remoteness on the mining industry, and to identify those districts in Canada where strategic investments in enhanced infrastructure could stimulate the development of new mines.

The Prospectors & Developers Association of Canada (PDAC) is the leading voice of the mineral exploration and development community. With over 8,000 members around the world in all sectors of the mining industry, PDAC's mission is to promote a globally responsible, vibrant and sustainable minerals industry. As the trusted representative of the sector, PDAC encourages best practices in technical, operational, environmental, safety and social performance.

PDAC is known worldwide for its annual PDAC Convention, regarded as the premier international event for the mineral industry. The PDAC Convention has attracted over 25,000 people from 125 countries in recent years and will next be held March 5-8, 2017 in Toronto. Please visit www.pdac.ca.

Our top priorities include:

1. **Enhancing access to capital** for mineral exploration by advocating for renewal and enhancements to Canada's unique super flow-through system.

2. **Facilitating access to land** by encouraging governments to make strategic infrastructure investments to unlock the potential of remote and northern Canada.

3. **Aboriginal affairs:** Improving relationships between companies and Aboriginal communities and enhancing Aboriginal participation in the mineral industry.

4. **Improving global competitiveness of Canadian companies abroad** by strengthening relationships between the Trade Commissioner Service and junior exploration companies.

5. **Championing responsible exploration**

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CONTENTS

EXECUTIVE SUMMARY

Much of Canada suffers from the tyranny of distance. In terms of travel time, some parts of northern Canada are as difficult to access as the Sahara Desert or Siberia. The associated remoteness adversely affects the mining industry, and only the very best projects are economically robust enough to be developed. The high entry cost and mediocre returns on all but the very best projects also discourage exploration in the area.

The transportation infrastructure deficit is the primary driver for the significant cost premium for companies interested in discovering and developing remote deposits. In large part as a result of this cost premium, fewer discoveries have been made in remote Canada than in less remote areas. While 40% of Canada's land mass lies above the above the 60º latitude line, this region contains only 12% of all known deposits. This suggests there are significantly more discoveries waiting to be made, some of which would likely be able to become mines that generate significant economic opportunities for the territory, regional communities and Canada.

Of those discoveries that have been made in remote Canada, a disproportionate number remain "stranded" (undeveloped). Of the 1,079 undeveloped mining projects in Canada, 153 of these are above the 60º latitude line (54 projects in Yukon, 48 in Northwest Territories, 44 in Nunavut and 7 in northern Quebec). Of these, 76% are currently undeveloped. By comparison the national average for undeveloped projects is 61%, and the average for those projects located below the 50º latitude line is 53%.

If strategic infrastructure investments were made in these remote areas there would be a two-fold impact: first, the costs of exploration would decrease, likely leading to more exploration activity and more discoveries. Secondly, the costs associated with developing known discoveries would be reduced, making it economically feasible to move a more diverse range of deposits into production.

PDAC commissioned this study to better understand the economic impact of remoteness in terms of the required increase in ore grade needed to achieve the same economic return as a similarly-sized project in an area of perfect infrastructure. The modelling done for this report suggests that a 10 percentage point improvement in the required grade increases the number of projects that can be developed by 5-7%. From this, it is calculated that such an improvement in required ore grades in the far North would unlock an additional three to four new base metal mines and three to five new precious metal mines in the region.

A 10% reduction in the break-even grade is equivalent to reducing the capex cost by 12-16% or the opex costs by 16-23%. Such gains can be achieved through building better infrastructure. Many undeveloped projects are clustered, creating an opportunity to build infrastructure corridors to service multiple projects. Seven such development corridors have been identified.

PDAC hopes that this information will help bolster federal support for a number of resource-development related infrastructure requests that the three territories have put forward to the federal Building Canada Plan. In addition, PDAC is calling for resource development to be an explicit priority for the proposed Canada Infrastructure Bank promised in the 2015 Liberal Party election platform.

1 INTRODUCTION

1.1 THE AIM OF THIS REPORT

One of the challenges facing the mineral industry in Canada is that much of the northern part of the country has very limited infrastructure—in particular roads, rail, ports and power. The associated higher capital and operating costs are major constraint to mining and economic development in these areas.

The objective of this study is to quantify the impact of remoteness on the economics of mining and from this determine the opportunities to stimulate new mine developments through investing in better infrastructure.

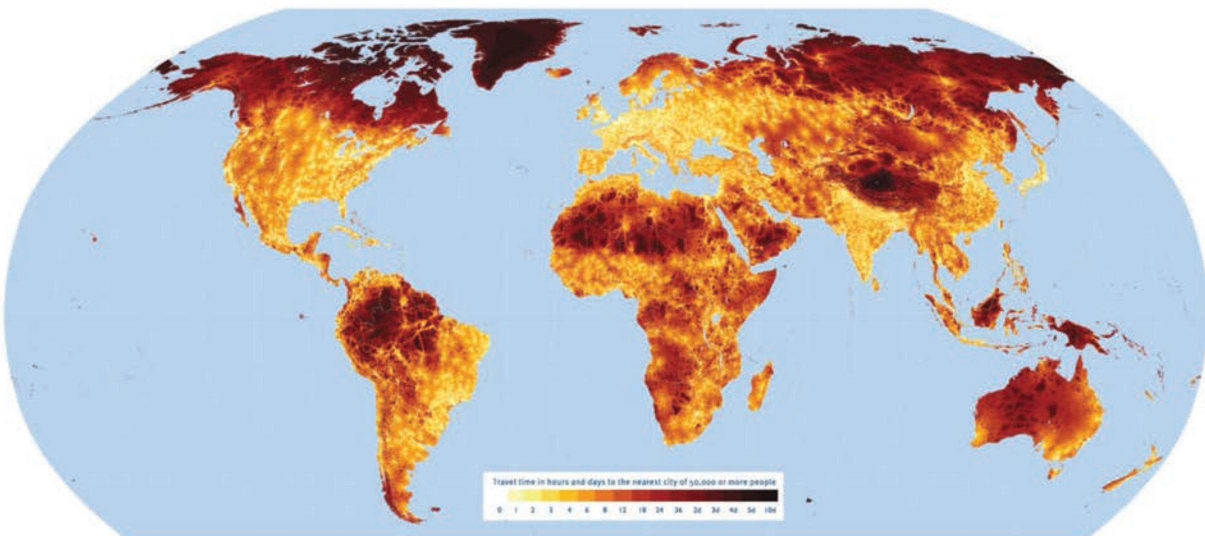
Specifically, the study looked at the percentage increase in ore grade required to achieve the same economic return for the same-sized project located in an area of perfect infrastructure.

2 BACKGROUND

2.1 WHAT DO WE MEAN BY REMOTENESS?

The following remoteness map of the World was compiled in 2008 by the European Commission. It gives a sense of the scale of the challenges facing people living and working in northern Canada versus other regions in the World. It shows the estimated time required to travel by surface transport (road, rail or ship) from a given location to the nearest city with >50,000 people. As can be seen, in terms of travel time, large tracts of Canada are as remote as the Amazon jungle in South America, the Sahara Desert in Africa, Siberia in Russia, the ice shield of Greenland, or the Gobi Desert/Tibet in China.

Figure 1: Travel Time to Major Cities (source: European Commission, 2008)



A similar pattern is noted in a wilderness[1] map generated by the United Nations (UNEP, 1998).

While the above travel-time map is good at highlighting the relative differences in the public's access to goods and services in different parts of the World, it doesn't capture the special issues of remoteness affecting the economics of building and operating a mine. These include the cost of transporting equipment, workers, supplies and fuel to site, as well as (in the case of base-metals)[2] the subsequent cost of transporting the mined material to the customer. It also ignores the cost of building and operating the necessary infrastructure required for the mine, such as roads, ports and power. And, in the case of Canada, there are the added challenges of extreme cold and terrain, both of which can conspire together to restrict land and sea access to only a few months of the year.

A further complication is that the economics of mining are influenced by the size of the operation, with larger mines having a bigger revenue base and longer life to amortize the high cost of paying for the necessary infrastructure required in remote locations. This makes it difficult for small mines to startup in the far North.

1. With "wilderness" measured in terms of remoteness from human influence; with the key variables being distance from settlements, roads and permanent man-made structures.
2. In the case of gold and diamonds, the volume of material produced is very small. Consequently, the cost of transporting it is only a minor component of the overall cost of running the mine.

2.2 METHODOLOGY USED TO ASSESS REMOTENESS FOR MINING PROJECTS

The first step of the study involved compiling data (in a GIS map format) on the various factors that affect the economics of mining across Canada. This included:

- **Geography:** This included topographic information (i.e. whether the area was flat, undulating or mountainous), waterways (both lakes and rivers), and permafrost (which influences the ability to build ice roads in winter).
- **Climate:** Including information on winter temperatures (which influences mining productivity and construction).
- **Land Reservations:** Principally National Parks and land owned by the First Nations.
- **Existing Infrastructure:** This involved several datasets, including towns (and their size), roads (and whether it is a sealed-, dirt- or ice-road), railway lines, power supplies (both generating facilities and transmission lines), port facilities (and the size of ship that can access it), and airports (and the size of plane that it can accommodate).
- **Mineral Deposits:** Both in terms of their primary commodity type (namely gold, diamonds, base metals and bulk minerals), the deposit size and current status (i.e. closed mine, operating mine or undeveloped).

Maps of the key data sets are given in Appendix A.

The next step was to build a financial model to assess the impact of changes in costs on the project's economics. The analysis was based on the following:

- Two broad groups of commodities were assessed. These were:
    - Precious Metals—as represented by gold
    - Base Metals—as represented by copper
- For each commodity three different-sized operations were evaluated, each with different base-case grades and mine lives.
- In the first instance, the model assumed perfect access to infrastructure and zero in-country transportation costs. The capital and operating costs were then adjusted for effects of local terrain, climate, transportation costs and the availability of existing infrastructure.

The analysis then assessed the percentage increase in grade required to offset the additional financial cost of the project being located in a remote area[3]. From this a series of "heat" maps were generated showing the impact of remoteness and infrastructure across Canada. Information on the modelling methodology is given in Appendix B.

The reason for mapping the percentage change in grade rather than the project's Internal Rate of Return (IRR) or Net Present Value (NPV) is that firstly, the percentage grade numbers produced are much less sensitive to changes in assumptions,[4] giving a much more robust and enduring set of results for use in policy analysis. And secondly, plotting the required change

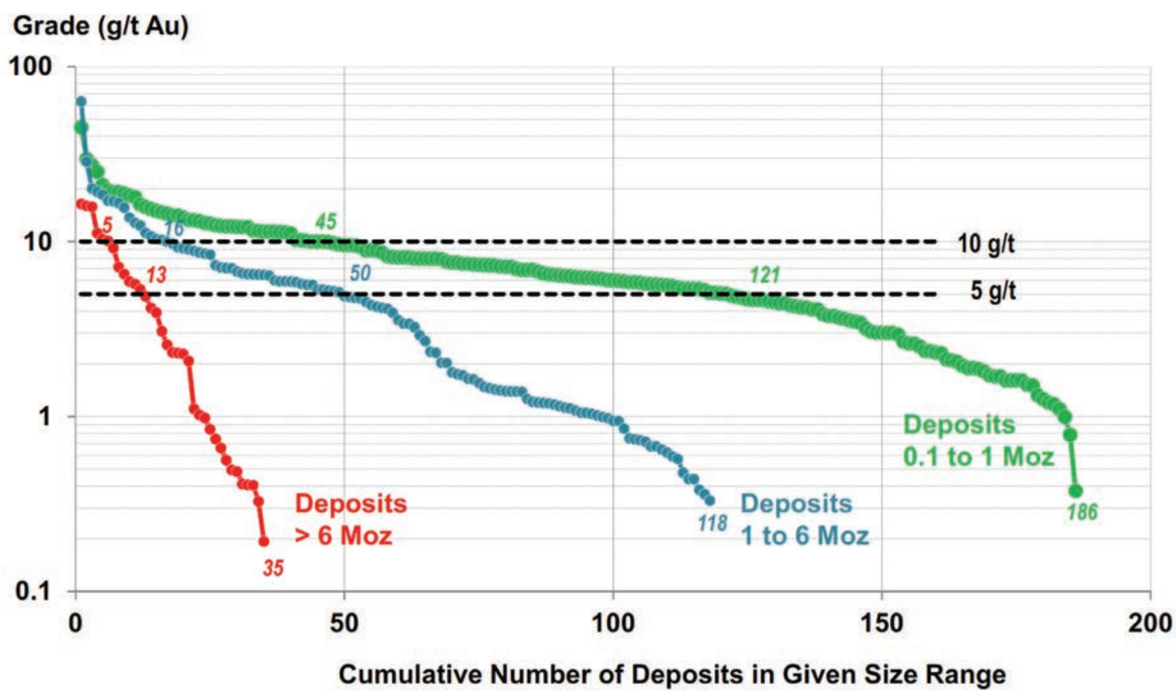
3. In detail, the ore grade was adjusted so as to deliver the same base-case Internal Rate of Return (IRR) for a given project in different locations.
4. For example, a small reduction in the commodity price can change the project's NPV from positive to negative.

in grade enables predictions to be made on the number of new mining projects that could be unlocked through investing in better infrastructure.

In detail (using gold as an example), the author has data on the tonnes and grade of 339 deposits in Canada that contain more than 100 koz of gold. One hundred and eighty-six of these deposits contain 0.1 to 1 Moz (i.e. are "Moderate" sized); of which 121 deposits have an ore grade > 5 g/t Au. However, only 45 of these deposits have a grade >10 g/t (Figure 2). Consequently, doubling the required economic head grade reduces the available pool of gold projects in Canada by (1-45/121 =) 63%. Conversely, any action by the Government that lowers the required break-even grade will greatly increase the pool of potential projects that can be developed.

A well-used axiom in the mining industry is that "Grade is always King", as it can be used to conquer most technical and commercial inadequacies in a given project. Perhaps, given the above, this should be rephrased to say "Grade is always King, but access to good infrastructure is the King-maker!"

Figure 2: Grade distribution of Canadian gold deposits by deposit size



Source: MinEx Consulting © Feb 2016
Note: Based on 339 gold deposits in Canada containing >100k oz Au

2.3 ASSUMPTIONS

The following assumptions were used to model remoteness:

- As previously discussed, two broad commodity groups were assessed. These were:
  - Precious Metals—as represented by gold
  - Base Metals—as represented by copper

The reason for modelling the two groups is that precious metal projects tend to be less affected by remoteness than base metal projects. This is because the unit value (on a per tonne basis) of precious metals is very high, and consequently it is possible (if not preferable) to fly the product out via a plane. In contrast, base metal projects produce large tonnages of low value (copper, nickel or lead-zinc) concentrates, which needs to be trucked overland to the nearest railhead or port for export. This can be expensive and difficult, especially in the far North which has a limited season for trucking and shipping. In addition to the extra transport costs, base metal projects in remote areas may require additional investment in dedicated roads and ports.

For each commodity three different-sized operations were evaluated, each with different base-case grades and mine lives. Details on the size, production rate and Base Case costs are summarized in Table 1. These figures reflect the typical size and grade range[5] for precious and base metal projects.

Table 1: Base Case assumptions used for the three different-sized mines

	Case 1	Case 2	Case 3
Precious Metal (Underground Mine)			
– Mining Rate	0.35 Mt pa	1.75 Mt pa	4.9 Mt pa
– Head Grade	8 g/t Au	6 g/t Au	4 g/t Au
– Annual Production	90 koz pa	320 koz pa	600 koz pa
– Mine Life	8 years	12 years	20 years
– Capex Cost [(a)]	$85m	$194m	$337m
– Opex Cost [(a)]	$88.05/t ore	$44.59/t ore	$28.98/t ore
Base Metal (Open Pit Mine)			
– Mining Rate	0.35 Mt pa	1.75 Mt pa	4.9 Mt pa
– Head Grade	3.0% Cu	1.5% Cu	0.75% Cu
– Annual Production	10 ktpa Cu	24 ktpa Cu	33 ktpa Cu
– Mine Life	8 years	12 years	20 years
– Capex Cost [(a)]	$56m	$132m	$269m
– Opex Cost [(a)]	$76.70/t ore	$41.87/t ore	$28.93/t ore
(a) Assumes perfect access to infrastructure. All costs are in Canadian Dollars			

5. It should be noted that the selected mining rates for the base metal projects was a compromise. In detail, copper projects often have mining rates higher than the maximum 4.9 Mt pa mining rate modelled (albeit at a much lower head grade). However, nickel and zinc/lead mines tend to be smaller in size and have higher grades.

- Unless otherwise specified, all costs reported in this study are in constant 2013 Canadian Dollars.
- The capital and operating costs and were derived from data from the InfoMine Mining Cost Service (InfoMine, 2015). These were benchmarked against detailed data from Preliminary Economic Assessments (PEAs) for 11 recent mining projects in Canada.
- In the first instance, the model assumed perfect access to infrastructure. It also assumed zero in-country transportation costs. The capital and operating costs were then adjusted for distance to ports, effects of local terrain, climate, transportation costs and the availability of existing infrastructure.
- The local capital and operating costs were then adjusted for climate and terrain effects, direct cost of remoteness (specifically the extra cost for transporting workers, materials and product to and from the mine-site) and any need to build additional infrastructure, such as housing, roads, powerlines and seaports and airports (if not currently present in the immediate area). In detail, it is assumed that:
    - To construct the mine, materials and fuel need to be transported to the site. The amount required is 10 kg per annual tonne of ore mined. Depending on the size of mine and deposit-type, a further 5-15 kg of diesel fuel is required (as a first-fill) if the mine generates its own power.
    - Once the mine is operating, materials and fuel will need to be transported to the site on a continuous basis, with the amount varying by deposit type and mine size. For a precious metal mine, the model assumes that amount of material consumed per tonne of ore mined is 5-9 kg, rising by an additional 7-11 kg if diesel fuel is required for power generation. For a base metal mine, the corresponding figures are 4-6 kg and 5-6 kg per tonne of ore mined.
    - The tonnage of product transported from the mine site to port for base metal mines will vary by ore grade mined and the commodity type. For Cases 1, 2 and 3 the annual amount of wet concentrate produced each year is 39,000, 92,000 and 166,000 tonnes pa respectively.
    - The unit cost per tonne of material moved to/from the site varies the transport mode used and the distance travelled. The available options modelled were rail (3¢/t-km), all-weather sealed roads (8¢/t-km), gravel roads (15¢/t-km), ice roads (45¢/t-km plus an annual charge of $15,000/km to build the road) and ocean-going barge (7¢/t-km).
    - In areas of permafrost, depending on the size of the mine, it is assumed that a permanent gravel road will be built if the mine is less than 25-125 km from the existing road network; otherwise, it is assumed that a winter ice road is constructed each year.
    - Depending on the size of mine and local terrain, if the mine was more than 40-150 km away from the existing power grid, it is more economic to build a stand-alone diesel generator than construct a power line to site.
    - If there isn't a large town (of >3,000 people) within a 50 km commuting distance, the model assumes that the workers are flown-in from the nearest provincial capital city and are accommodated in a dedicated camp on-site.

- ◇ If the existing airport is small, it is upgraded to handle the size of plane required to fly-in the workers.
- ◇ If the mine-site is >25km away from an existing airport, a dedicated new airport is built on-site.
- ◇ If the existing seaport is small, it may need to be upgraded to handle exports of base metal concentrates.
- ◇ If there isn't an existing seaport within 50 km of the closest point to the coast from the mine, a dedicated new seaport is built.
- ◇ If an ice road is built, the mine operator will need to stockpile fuel and (in the case of the base metal mine) mine product during those times when the road is closed. It is assumed that the ice road is only open for six weeks per year. This results in a substantial increase in the working capital required.

To simplify the analysis, the economic model assumed over the life of the mine:

- Constant commodity prices (in 2015 US Dollars) of US$1180/oz for gold and US$2.80/lb for copper.
- Constant exchange rate of C$1.00 = US$0.90.
- Two year construction period.
- Constant mining and production rates.
- Constant input costs for fuel, consumables and labour.
- Discount rate of 10% real after-tax.
- A combined Federal + Provincial Tax Rate of 27%.
- 12% Net Profit Royalty Rate.

With regard to the last two items, the model ignored any local variations on tax and royalty rates between the different provinces. This was done of the basis that the primary purpose of the study is to highlight the cost of remoteness on project, rather than discuss which provinces currently have better/worse investment rules.

The issue of remoteness impacts on mining in many ways. In addition to the extra time and travel costs for workers,[6] it is expensive to transport in fuel and consumables to-site, as well as the additional cost of shipping the resulting mined product to market. There also the need to spend extra capital on building the necessary services and infrastructure (such as road, rail, ports, power, water, accommodation, airports for the mine). In many cases in far northern Canada, the existing infrastructure is very limited. The cost of building new infrastructure will vary by location (remote locations are more difficult to access), terrain (building infrastructure in a mountainous area is more expensive and road-making in permafrost-affected areas is very challenging), climate (with colder areas having special issues).

6. In fact, for many mines in the remote parts of Canada, the only practical way is for the company to fly the workers in and provide accommodation on-site.

3 RESULTS

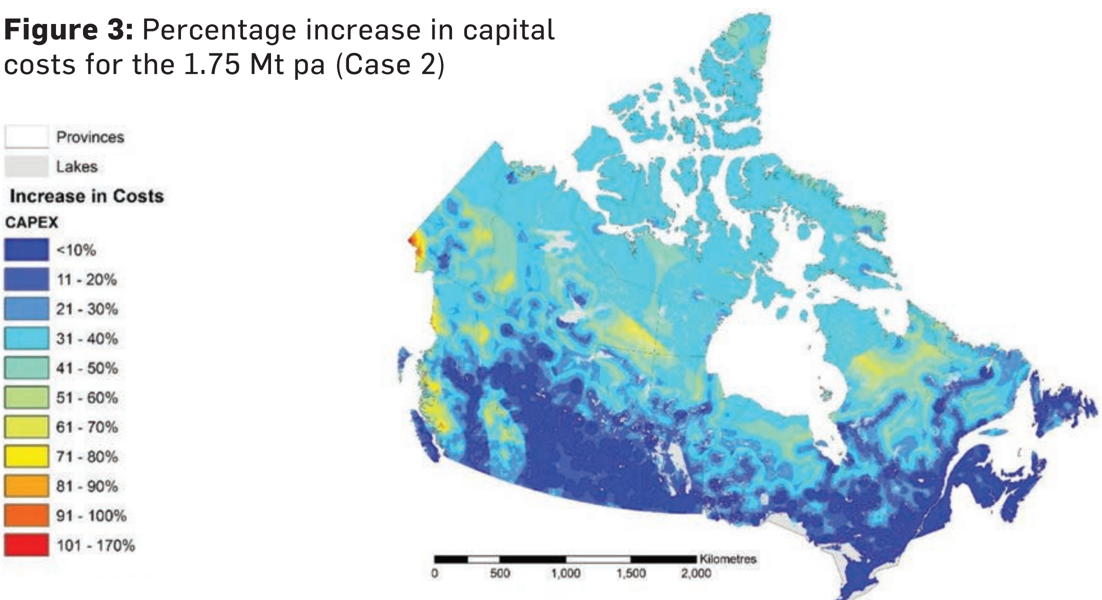
3.1 IMPACT OF REMOTENESS ON CAPITAL AND OPERATING COSTS

Figures 3 and 4 show the impact of remoteness on the capital and operating costs for a 1.75 Mt pa precious metal mine. As can be seen, it is around 40-60% more expensive to build and operate a gold or diamond mine in the far North than a similar-sized mine in southern Ontario. In extreme cases, such as at the top of the mountains of northwestern Yukon and British Columbia, capital costs are doubled.

The cost impact of remoteness is even more pronounced for base metal mines (Figures 5 and 6), with capital costs in the Yukon, Northwest Territories and Nunavut being up to 100-170% more expensive. The main driver for this is the fact that access to the mine is via a winter ice road, which is only open for a few weeks each year. This forces the operator to hold large stockpiles of fuel, supplies and product, with resulting increase in working capital. In addition, there is the need to build dedicated ports (at great expense) to ship out the product. Ice roads are also an expensive mode of transport, with unit costs per tonne-km that are five-times that of an equivalent sealed road. This, plus other access issues, results in operating costs up to 80% higher in areas distant from the coast or existing all-weather transport infrastructure.

Depending on local circumstances, the requirement to build dedicated infrastructure (such as road, power, airports, housing and sea ports) to service the mine results in the capital cost "heat-map" (Figures 3 and 5) being much more locally-variable (i.e. volatile) than the corresponding heat-map for operating costs (Figures 4 and 6)[7].

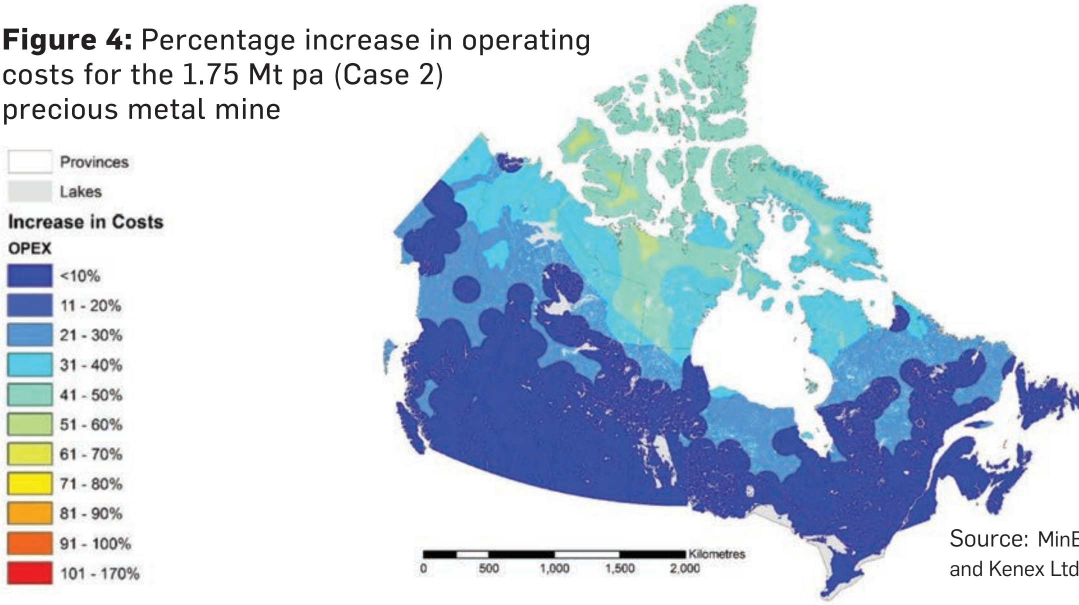
Figure 3: Percentage increase in capital costs for the 1.75 Mt pa (Case 2)



Source: MinEx Consulting and Kenex Ltd © Jan 2016

7. A subtle pattern observed in the capital cost heat-maps is a "donut-effect" for locations 40-120 km away from the existing power grid. This is due to the decision to build a stand-alone diesel power station, rather than install additional power lines. While the capital cost is less, the trade-off is a step increase in operating costs.

Figure 4: Percentage increase in operating costs for the 1.75 Mt pa (Case 2) precious metal mine



Source: MinEx Consulting and Kenex Ltd © Jan 2016

Figure 5: Percentage increase in capital costs for the 1.75 Mt pa (Case 2) base metal mine

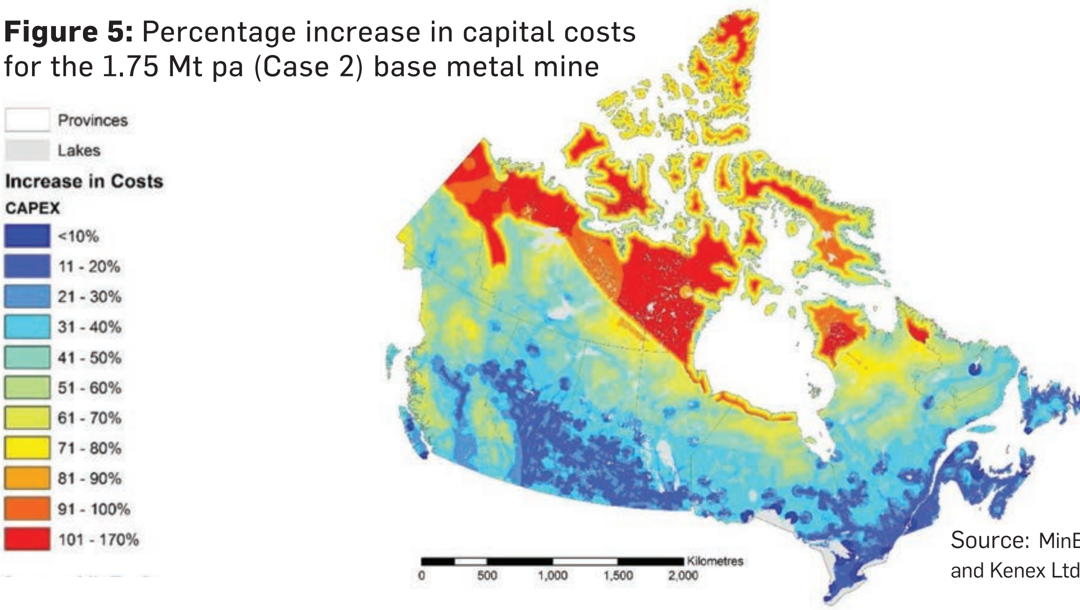


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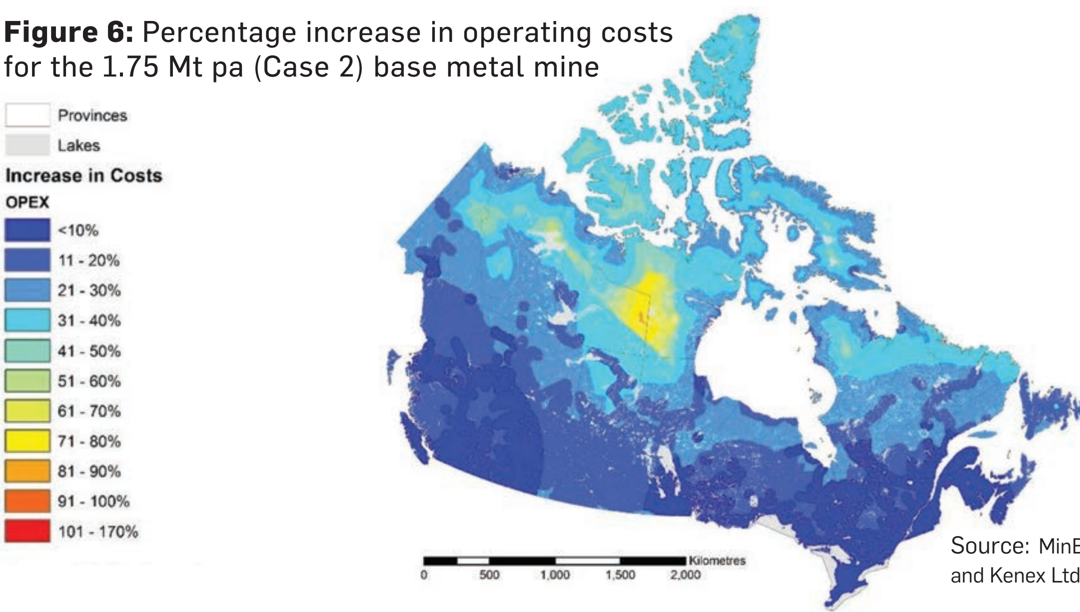
Figure 6: Percentage increase in operating costs for the 1.75 Mt pa (Case 2) base metal mine



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3.2 IMPACT OF REMOTENESS ON THE REQUIRED ORE GRADE

Higher capital and operating costs both impact on the economic viability of mining. To compensate for this, the ore grade needs to be higher. Figures 7 and 8 show the percentage increase in grade required for a 1.75 Mt pa precious and base metal project in remote locations in Canada versus the same-sized project with access to perfect infrastructure (in Southern Ontario or on Victoria island in British Columbia).

For the same mining rate, the economics of base metal projects are much more impacted by remoteness than precious metal projects. This is because of the extra capital and operating costs associated with the need to build roads and ports to transport the metal concentrates. As noted before, in the far North, in areas where ice roads are used, there is the extra cost of stockpiling product when the road is not open.

In detail, to achieve the same return, a 1.75 Mt pa gold or diamond (i.e. precious metal) project in the Yukon, Northwest Territories, Nunavut and northern Quebec need to have grades 40-70% higher than that for an equivalent project in Ontario. For the same-sized copper and lead-zinc (i.e. base metal) project, the grades need to be 50-150% higher in the far North.

3.3 EFFECT OF DEPOSIT SIZE ON THE REQUIRED ORE GRADE

Figure 9 show the grades required for a 0.35, 1.75 and a 4.9 Mt pa base metal project mine. It clearly shows that the impact of remoteness is more severe for small projects than large projects. In particular, for the 0.35 Mt pa case, much of the land above the 60^{o} latitude line (i.e. the southern border of the Yukon, NWT and Nunavut) requires ore grades 100-170% higher than that of a comparable sized project in southern Canada.

For the 4.9 Mt pa case, the two areas in the far North most affected by remoteness are the central parts of the Ellesmere, Baffin and Victoria Islands, as well as the general area surrounding Dubawni Lake, which straddles the border between the NWT and Nunavut. These areas suffer from a complete absence of infrastructure. In the case of the Arctic islands a large investment is required to build a dedicated road to the coast. In addition to the absence of existing infrastructure, Dubawni Lake also suffers from the fact that much of the area is permafrost, which makes it very difficult to build permanent roads. The model assumes that site access is via ice roads during winter.

It should be noted that there some areas in the far North where projects are less affected by remoteness. In addition to the coastal fringe, which doesn't require a large investment in roads, these include the area around Yellowknife in the NWT and along the Klondike highway in the Yukon. This is due to the presence of good existing infrastructure there. Ironically, much of this infrastructure is a legacy of previous mines built in the area several decades ago.

Figure 10 shows the grades required for different-size precious metal mines. As can be seen the impact of size is subtly different to that of the base metal case. The main difference is that, for a given-sized project, the impact of winter ice roads on the required grade is less pronounced.[8] For

8. The mine product can be flown-out all year round; however, fuel and supplies still need to be stockpiled during the off-season.

example, in the Dubawni Lake area the required increase in grade remains relatively constant at around 60% for the 0.35, 1.75 and 4.9 Mt pa cases. With regard to projects located within the far North Arctic islands the required grade slowly increases with increasing mine size. For example, the required grade for a precious metal project located in the centre of Ellesmere Island increases from around 50-55% at 0.35 Mt pa to 55-60% at 1.75 Mt pa to 60-65% at 4.9 Mt pa mining rate. This is primarily driven by the relatively higher operating costs of transporting fuel and supplies to site[9].

In both the base- and precious-metals cases the effect of mountainous terrain is similar. As can be seen for projects located in the Rockies in British Columbia or the Yukon, smaller projects require a greater increase in grades than larger projects. This is due the additional capital cost of building a mine in extreme terrain which, when combined with the short mine life, results in a higher unit capital charge for smaller mines. In other words, it is a function of the mine size and terrain itself, rather than remoteness in general.

Figure 7: Percentage increase in required grade for the 1.75 Mt pa (Case 2) precious metal mine

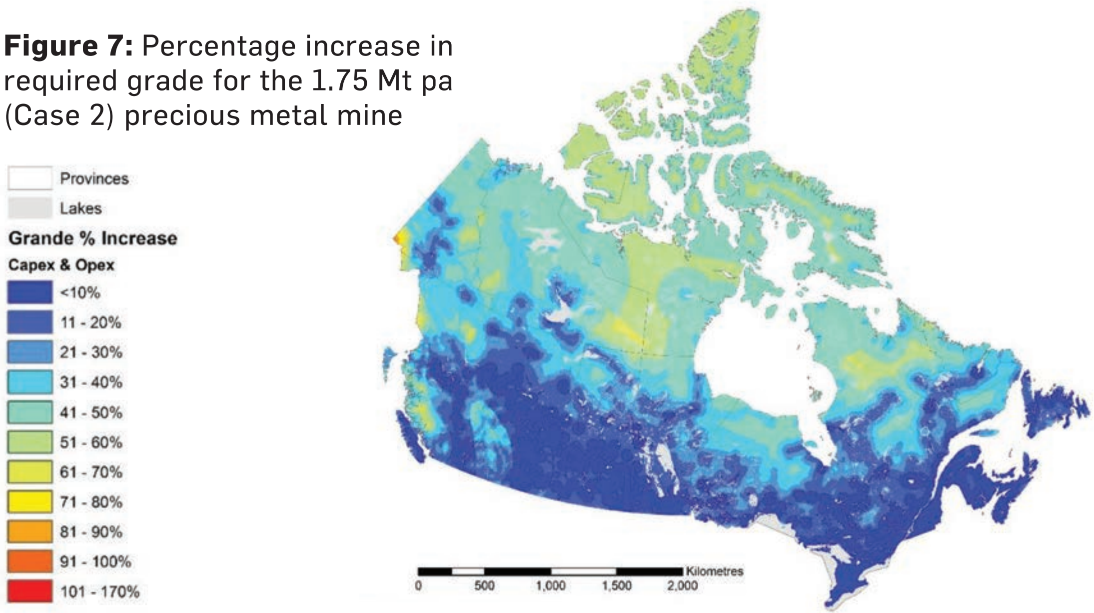
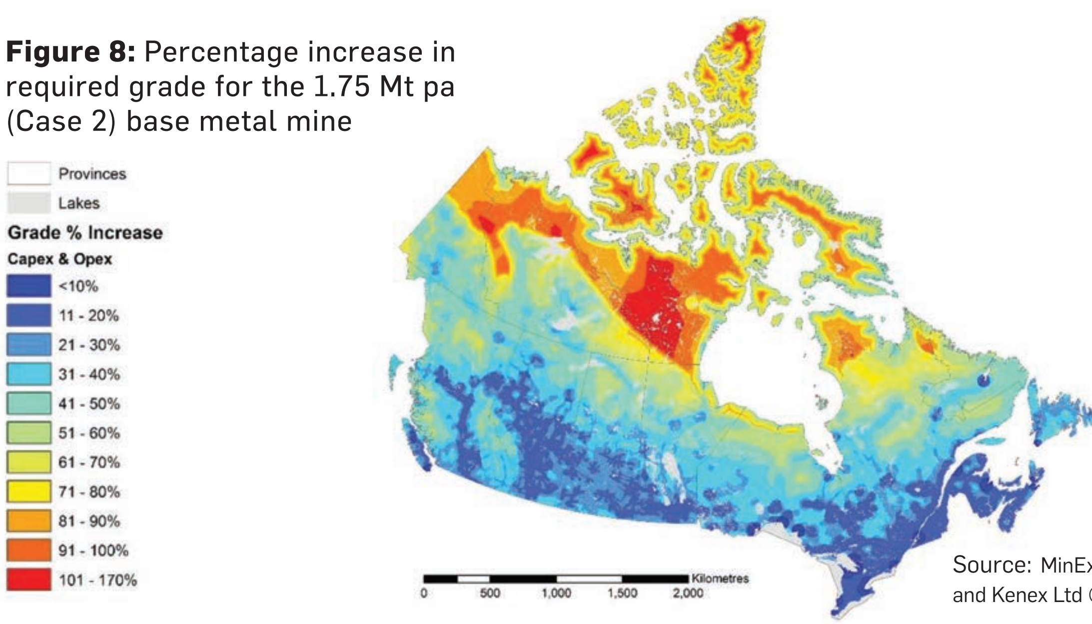


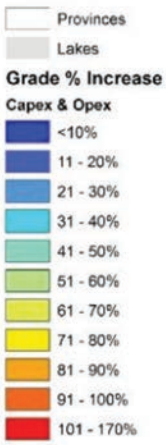
Figure 8: Percentage increase in required grade for the 1.75 Mt pa (Case 2) base metal mine

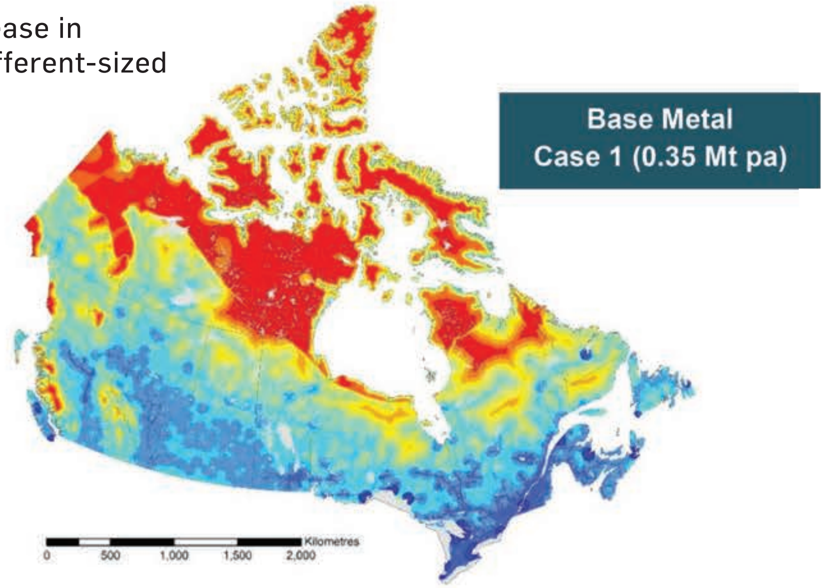


Source: MinEx Consulting and Kenex Ltd © Jan 2016

9. The model assumes that the larger mines have lower head grades; Consequently, more fuel and supplies are required per unit of metal produced.

Figure 9: Percentage increase in required grade for three different-sized base metal mines





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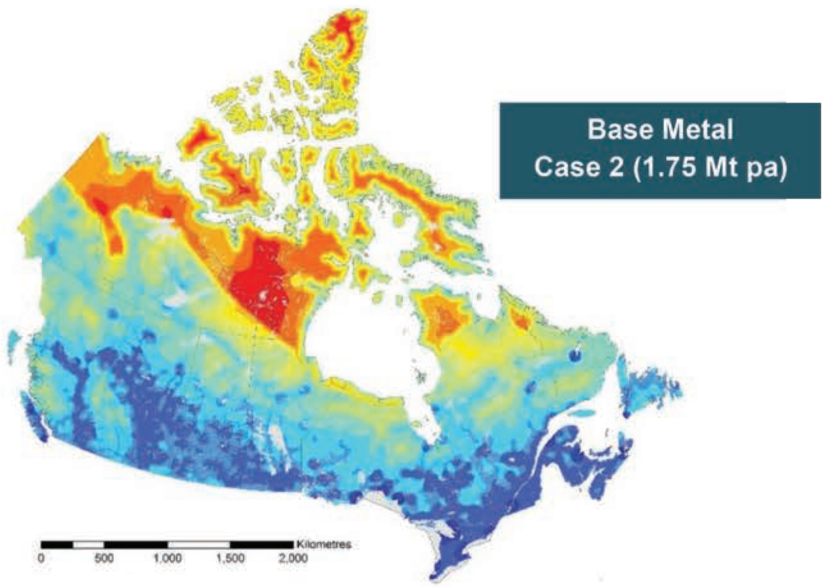


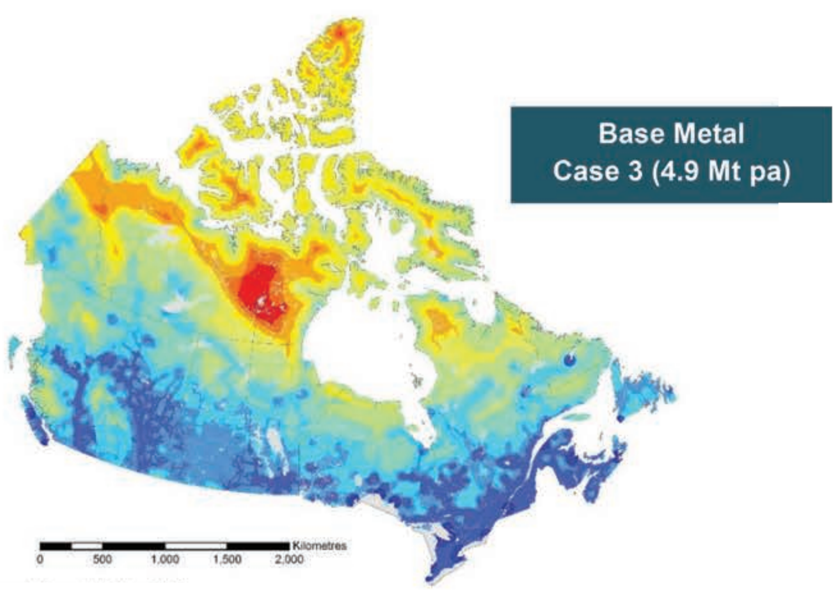
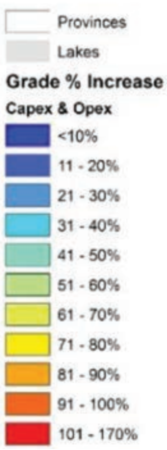
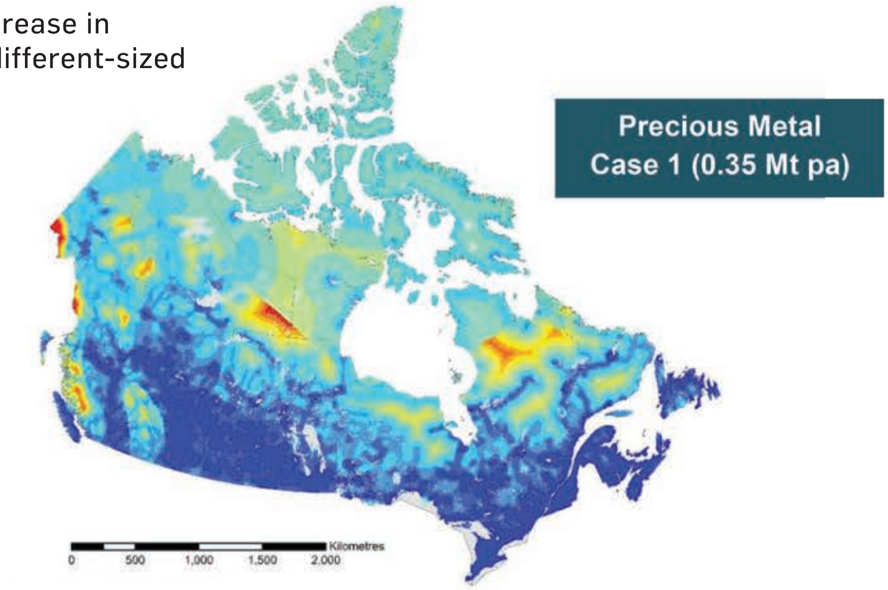


Figure10: Percentage increase in required grade for three different-sized precious metal mines





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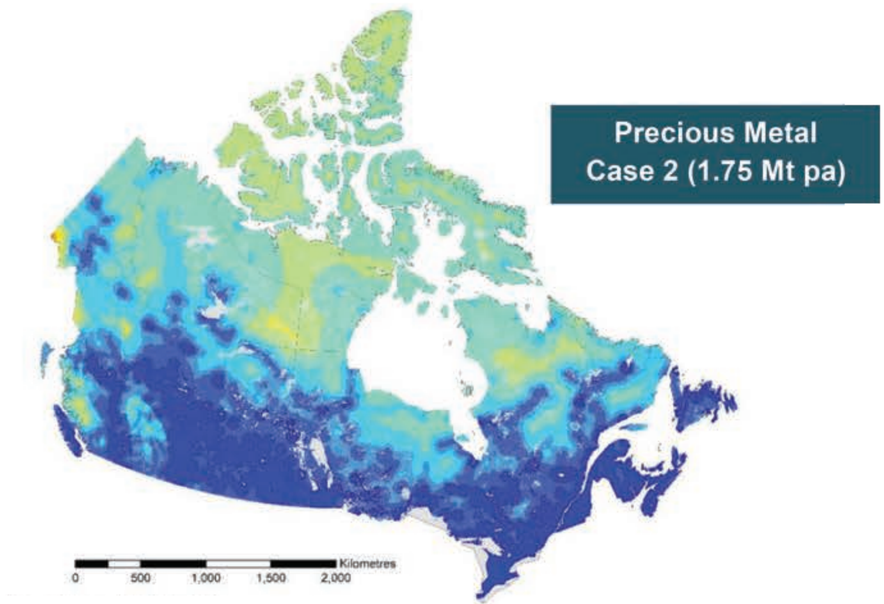
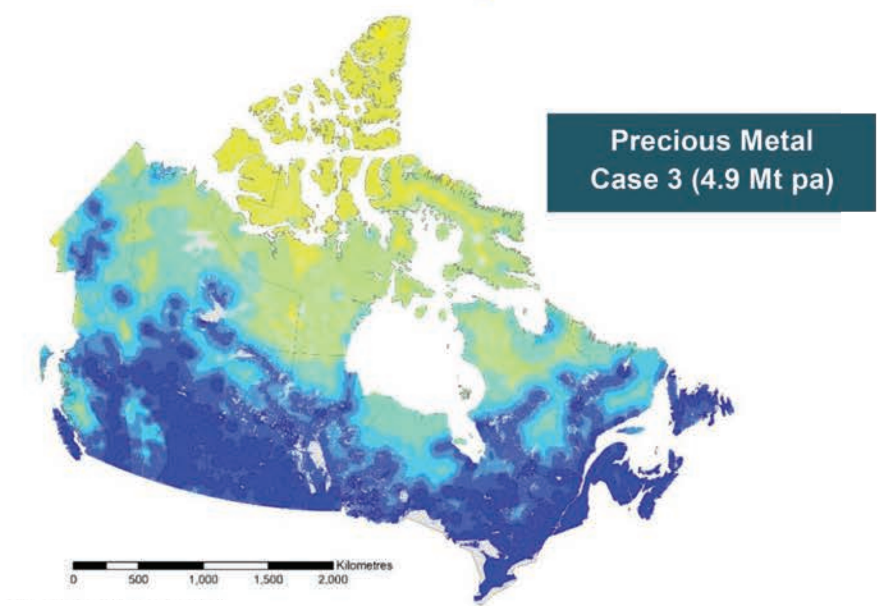




3.4 NUMBER AND STATUS OF MINING PROJECTS IN REMOTE AREAS

A detailed study by the author has identified 1,746 significant[10] deposits in Canada. Table 2 below summarizes the commodity type, size and status of these deposits.
In terms of their status, 667 of the deposits have been developed into mines. This is made up of 107[11] operating mines and 560 that are now closed. The remaining 1,079 deposits, or 62%, of all known mineral deposits in Canada are currently remain undeveloped. This large inventory of projects creates provide a huge opportunity for the local mining industry to grow. However, this is being held back by economic and other issues. Providing better infrastructure will help unlock a number of these opportunities.

Table 2: Number, size, type and status of significant mineral deposits in Canada

	PRECIOUS METALS			BASE METALS			BULK MINERALS				OTHER		TOTAL
	Au	Ag	Diamonds	Ni	Cu	Zn+Pb	Iron Ore	Coal (Met)	Coal (Thermal)	Potash	U_3O_8	Other	
	Moz	Moz	MCt	Mt	Mt	Mt	Mt Fe	Mt	Mt	Mt K20	kt	Mt Al_2O_3	
Size range definitions													
Giant	*>6*	*>300*	*>60*	*>1*	*>5*	*>12*	*>500*	*>500*	*>1000*	*>150*	*>125*	*>5*	
Major	*>1*	*>50*	*>10*	*>0.1*	*>1*	*>2.5*	*>100*	*>100*	*>200*	*>30*	*>25*	*>1*	
Moderate	*>0.1*	*>5*	*>1*	*>0.01*	*>0.1*	*>0.25*	*>10*	*>10*	*>20*	*>3*	*>5*	*>0.1*	
Minor	*>0.01*	*>0.5*	*>0.1*	*>0.001*	*>0.01*	*>0.025*	*>1*	*>1*	*>2*	*>0.3*	*>0.5*	*>0.01*	
Number of deposits in each size range													
Giant	37	0	3	7	5	4	17	7	8	14	3	9	114
Major	127	6	6	16	29	12	40	6	8	5	13	27	295
Moderate	234	4	7	44	110	59	70	12	18	1	24	47	630
Minor	201	10	3	31	176	101	89	7	2	0	37	50	707
TOTAL	599	20	19	98	320	176	216	32	36	20	77	133	1746
Number of deposits by current status													
Closed	232	12	1	18	143	65	34	6	2	0	15	32	560
Operating	36	0	4	5	19	8	6	3	9	6	3	8	107
Undeveloped	331	8	14	75	158	103	176	23	25	14	59	93	1079
TOTAL	599	20	19	98	320	176	216	32	36	20	77	133	1746
Number of undeveloped deposits by size range													
Giant	19	0	1	3	3	2	14	5	7	9	1	7	71
Major	76	3	4	13	15	4	32	5	4	5	8	19	188
Moderate	136	2	6	31	59	27	60	9	13	0	19	33	395
Minor	100	3	3	28	81	70	70	4	1	0	31	34	425
TOTAL	331	8	14	75	158	103	176	23	25	14	59	93	1079

Source: MinEx Consulting © May 2015

Note: Size is based on the pre-mined resource (i.e. current resources + historic production adjusted for recovery losses)
Deposits have been aggregated into Camps (i.e. as is the case for Sudbury there may be several satellite mines with a given Camp)
Undeveloped deposits includes exploration around old/closed mines.

10. With significant defined as a deposit that is Minor/Moderate/Major/Giant in size. See Table 2 for the size-range definitions for each commodity type. *Caution – the analysis may not catch all deposits – particularly those in the smaller size range*
11. This includes 11 mines currently under construction/development.

The following two Figures shows the location of the different deposit types and their current status. As can be seen, undeveloped deposits are spread across the country

Figure 11:
Location of significant mineral deposits in Canada – by commodity type

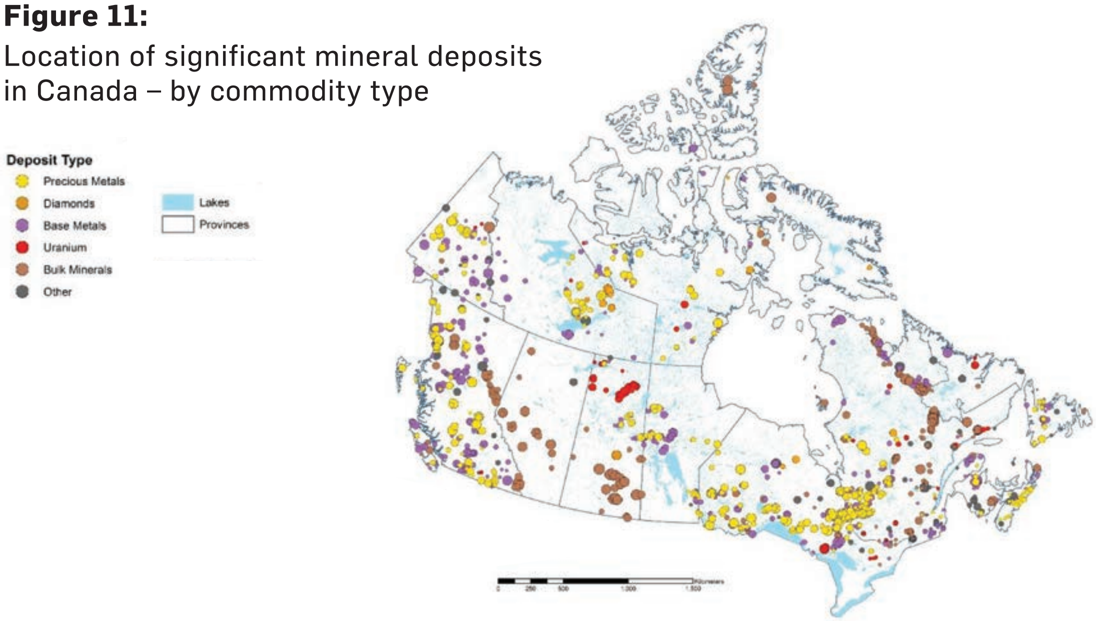


Figure 12:
Current status of significant mineral deposits in Canada

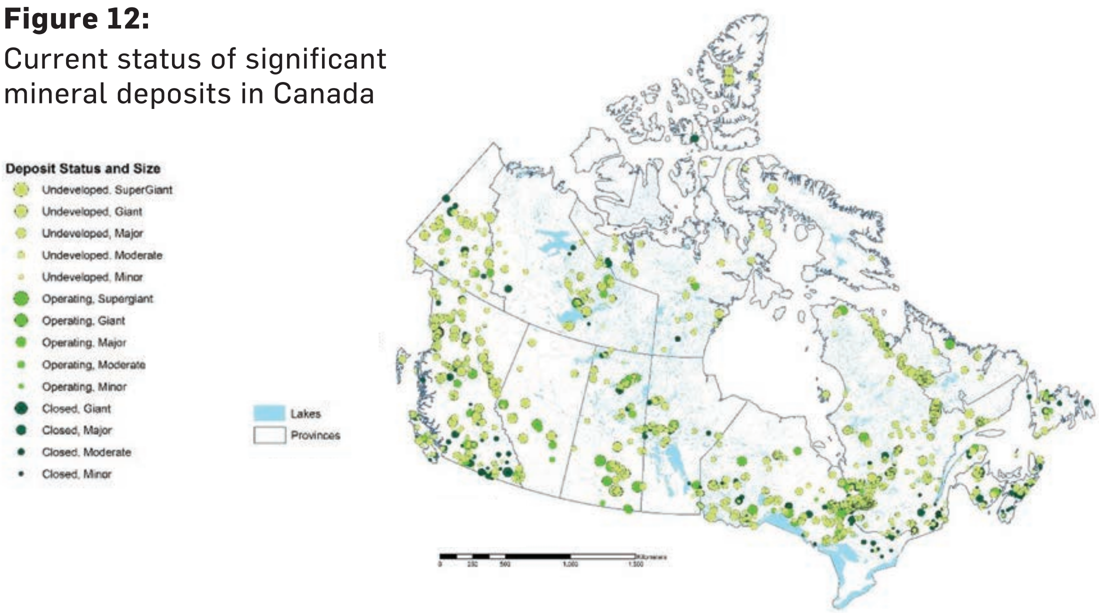


Table 3 shows the number of projects in each Province. While the largest number of undeveloped deposits are in the southern Provinces (especially Quebec, British Columbia and Ontario), it is significant to note that, in percentage terms the northern provinces (Northwest Territories, Yukon and Nunavut) have a disproportionately larger share of the undeveloped deposits, relative to the national average (of 52%). This highlights the tyranny of remoteness in the far North.

Table 3: Number and status of significant deposits by Province

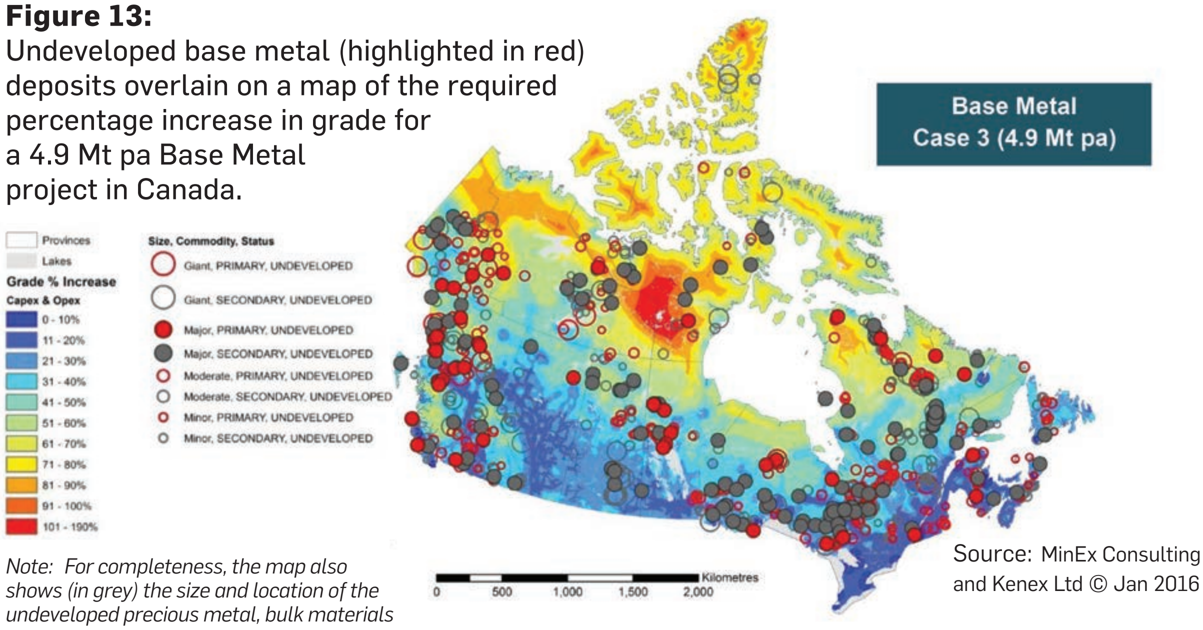
	Closed	Operating	Undeveloped	TOTAL	% Undeveloped
Alberta	1	6	12	19	63%
British Columbia	83	13	159	255	62%
NFld + Labrador	26	5	38	69	55%
Manitoba	38	8	47	93	51%
New Brunswick	10	2	26	38	68%
Nova Scotia	30	-	13	43	30%
Nunavut	7	1	44	52	85%
NW Territories	17	5	48	70	69%
Ontario	102	20	130	252	52%
Quebec	216	32	450	698	64%
Saskatchewan	16	13	58	87	67%
Yukon	14	2	54	70	77%
CANADA TOTAL	560	107	1079	1746	62%

Source: MinEx Consulting © April 2015
Note: Limited to deposits >="Minor" in size
Size is based on the pre-mined resource (i.e. current resources + historic production adjusted for recovery losses)
Deposits have been aggregated into Camps (i.e. As is the case for Sudbury there may be several satellite mines with a given Camp)
Undeveloped includes exploration around old mines - consequently the report number of "closed mines" may be understated
Caution: Analysis may be incomplete - particularly for the smaller-sized deposits

Figures 13 and 14 show the location of the undeveloped mineral deposits overlain on the respective base metal and precious metal remoteness heat maps for Canada, where remoteness is measured in terms of the required percentage increase in ore grade for a 4.9 Mt pa mining operation to be economic[12]. In Figure 13 the red circles refer to different-sized undeveloped base metal deposits, whereas in Figure 14 the red circles refer to different-sized precious metal deposits. In both cases the grey circles refer to undeveloped non-primary metal deposits. As can be seen, there are a several dozen large undeveloped projects in far northern Canada. Of significance is the fact that many of these deposits tend to cluster together and so would greatly benefit from sharing common infrastructure, such as roads, power and ports.

12. A full set of maps for the 0.35, 1.75 and 4.9 Mt pa cases can be found in Appendix C.

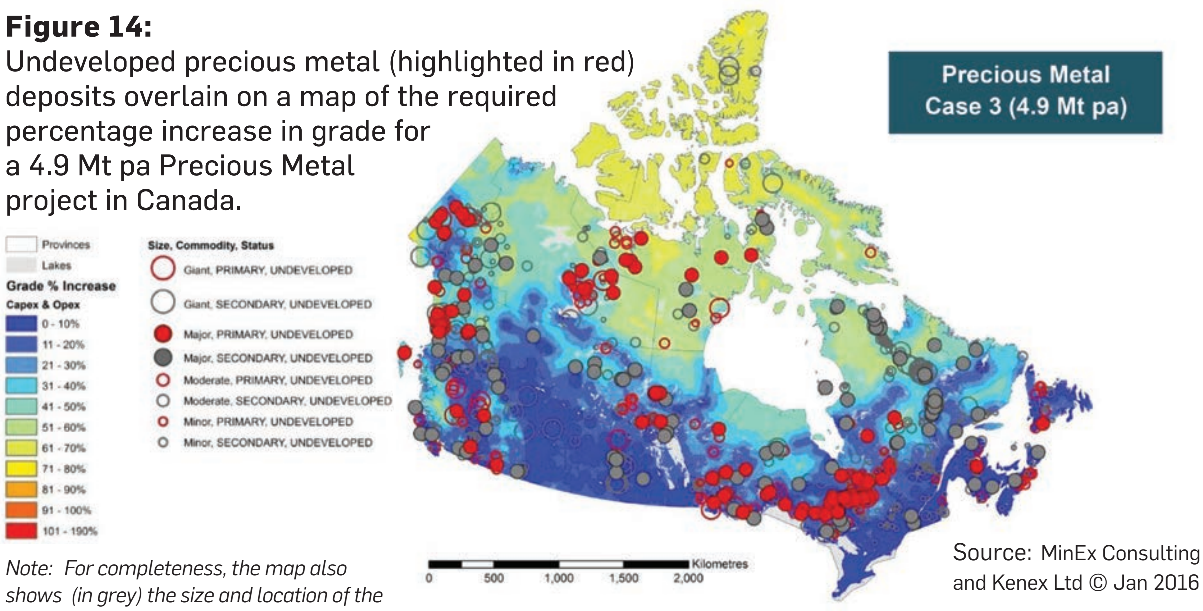
Figure 13:
Undeveloped base metal (highlighted in red) deposits overlain on a map of the required percentage increase in grade for a 4.9 Mt pa Base Metal project in Canada.



Note: For completeness, the map also shows (in grey) the size and location of the undeveloped precious metal, bulk materials and other deposits.

Source: MinEx Consulting and Kenex Ltd © Jan 2016

Figure 14:
Undeveloped precious metal (highlighted in red) deposits overlain on a map of the required percentage increase in grade for a 4.9 Mt pa Precious Metal project in Canada.



Note: For completeness, the map also shows (in grey) the size and location of the undeveloped base metal, bulk materials and other deposits.

Source: MinEx Consulting and Kenex Ltd © Jan 2016

Table 4 shows the number of significant mineral deposits (and their current status) versus latitude. As can be seen, the further north one goes, the fewer the deposits there are and, of these, they are less likely to be developed. For example, above the 75º latitude line the number of known deposits per 100,000 km2 is 0.9 versus 70.8 for those below the 49º latitude line. Similarly, 40% of Canada's land mass lies above the above the 60º latitude line; however, this region contains only 12% of all known deposits, with an average of 5.3 deposits per 100,000 km2. Of these (153/201 =) 76% are undeveloped. By comparison the national average for undeveloped projects is (1,079/1,746 =) 61%, and the average for those projects located below the 50º latitude line is 53%.

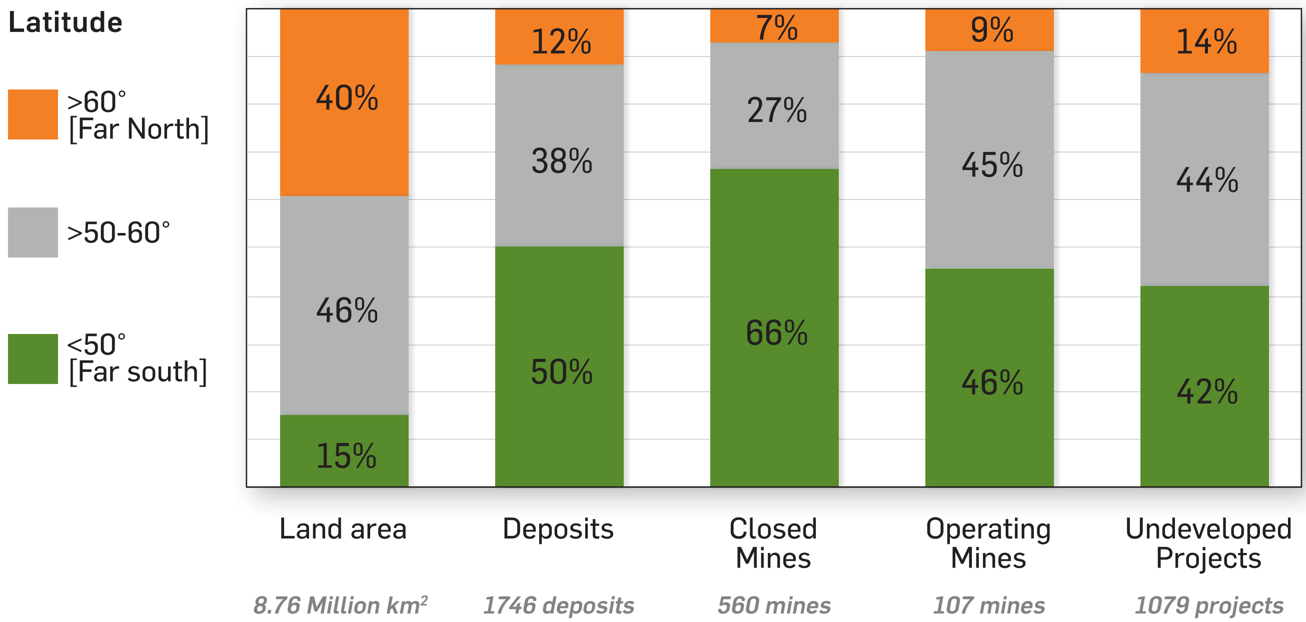
Table 4: Number of significant deposits (and their status) and land area by latitude

Latitude	Closed	Operating	Undeveloped	TOTAL	Land Area	No of Projects per 100,000km²		
						All	Developed	Undeveloped
INCREMENTAL NUMBER OF PROJECTS								
>75	1	0	3	4	429,908	0.9	0.2	0.7
70-74	1	0	4	5	541,317	0.9	0.2	0.7
65-69	5	1	31	37	1,286,184	2.9	0.5	2.4
60-64	31	9	115	155	1,514,994	10.2	2.6	7.6
55-59	43	9	199	251	1,788,513	14.0	2.9	11.1
54-55	40	9	64	113	472,813	23.9	10.4	13.5
53-54	7	5	32	44	494,866	8.9	2.4	6.5
52-53	6	11	57	74	515,066	14.4	3.3	11.1
51-52	21	8	45	74	538,879	13.7	5.4	8.4
50-51	33	6	75	114	529,992	21.5	7.4	14.2
49-50	104	23	127	254	514,024	49.4	24.7	24.7
<49	268	26	327	621	877,126	70.8	33.5	37.3
CUMULATIVE NUMBER OF PROJECTS								
>75	1	0	3	4	429,908	0.9	0.2	0.7
>70	2	0	7	9	971,224	0.9	0.2	0.7
>65	7	1	38	46	2,257,409	2.0	0.4	1.7
>60	38	10	153	201	3,772,402	5.3	1.3	4.1
>55	81	19	352	452	5,560,916	8.1	1.8	6.3
>54	121	28	416	565	6,033,729	9.4	2.5	6.9
>53	128	33	448	609	6,528,594	9.3	2.5	6.9
>52	134	44	505	683	7,043,660	9.7	2.5	7.2
>51	155	52	550	757	7,582,540	10.0	2.7	7.3
>50	188	58	625	871	8,112,532	10.7	3.0	7.7
>49	292	81	752	1125	8,626,556	13.0	4.3	8.7
All	560	107	1079	1746	9,503,682	18.4	7.0	11.4
CUMULATIVE PERCENTAGE OF PROJECTS								
>75	0.2%	0.0%	0.3%	0.2%	4.5%			
>70	0.4%	0.0%	0.6%	0.5%	10.2%			
>65	1.3%	0.9%	3.5%	2.6%	23.8%			
>60	6.8%	9.3%	14.2%	11.5%	39.7%			
>55	14.5%	17.8%	32.6%	25.9%	58.5%			
>54	21.6%	26.2%	38.6%	32.4%	63.5%			
>53	22.9%	30.8%	41.5%	34.9%	68.7%			
>52	23.9%	41.1%	46.8%	39.1%	74.1%			
>51	27.7%	48.6%	51.0%	43.4%	79.8%			
>50	33.6%	54.2%	57.9%	49.9%	85.4%			
>49	52.1%	75.7%	69.7%	64.4%	90.8%			
All	100.0%	100.0%	100.0%	100.0%	100.0%			

Source: MinEx Consulting and Kenex Ltd © Jan 2016 *Note (a) Excludes areas covered by lakes >100km² in size*

The following figure summarizes the relative ratios for mines and projects in the different regions. As can be seen, the far North is severely under-represented in terms of its share of (discovered) deposits and operating mines[13].

Figure 15: Impact of latitude on the percentage of projects discovered and developed



Source: MinEx Consulting © Jan 2016

Rather than simply looking at latitude, an alternative way of assessing remoteness is to look at the required percentage increase in ore grade required for a given project to produce the same economic return. As a general rule, the further north you go, the higher the ore grade required (see Figures 9 and 10).

Tables 5 and 6 show the amount of land area associated with the grade increase required for 4.9 Mt pa base- and precious-metal projects. The two Tables also show the current number and status of deposits in these areas. Not surprisingly, across both commodity-classes, there is a general correlation between the required increase in grade and the percentage number of undeveloped projects. Figure 16 shows that the same general trend applies across the different mine-size ranges. The key observation is that, in very remote areas, economics dictates that only the very best (i.e. highest grade) projects get developed.

The Tables show that, for base-metals 4,409,094 km2 (or 46%) of Canada's land area requires a grade increase of >50% to break-even. The comparable figure for precious metals is 2,778,672 km2 (or 29%).

13. The high percentage of closed mines in the Far South is a historical legacy of the way the mining industry evolved in Canada. The first mines developed were in the South and many of these have now run-out of ore.

Table 5: Impact of increase on grade required on the % of base metal projects that are developed (4.9 Mt pa mining case)

% Grade Increase (a)	Land area (b) km²	Number of Deposits by Current Status (c), (d)				Ratio of Undeveloped to Total
		Closed	Operating	Undeveloped	Total	
0-10%	93,919	4	0	16	20	80%
10-20%	923,268	138	19	126	283	45%
20-30%	1,374,508	71	5	66	142	46%
30-40%	1,303,837	21	5	63	89	71%
40-50%	1,399,056	6	4	49	59	83%
50-60%	1,512,638	4	1	51	56	91%
60-70%	1,286,278	2	2	17	21	81%
70-80%	809,736	0	0	7	7	100%
80-90%	560,207	0	0	6	6	100%
90-100%	133,490	0	0	1	1	100%
>100%	106,746	0	0	0	0	na
Total	9,503,682	246	36	402	684	59%

Source: MinEx Consulting and Kenex Ltd © Jan 2016

Note: *(a) Refers to the increase in grade required for a 4.9 Mt pa mining project in a remote area to have same IRR as a same-sized project in an area with perfect infrastructure*
(b) Excludes areas covered by lakes >100km² in size
(c) Includes minor-, moderate-, major- and giant-sized projects
(d) For purposes of this analysis base metals include other commodities such as tin, tungsten, chromium, molybdenum, niobium and rare earths

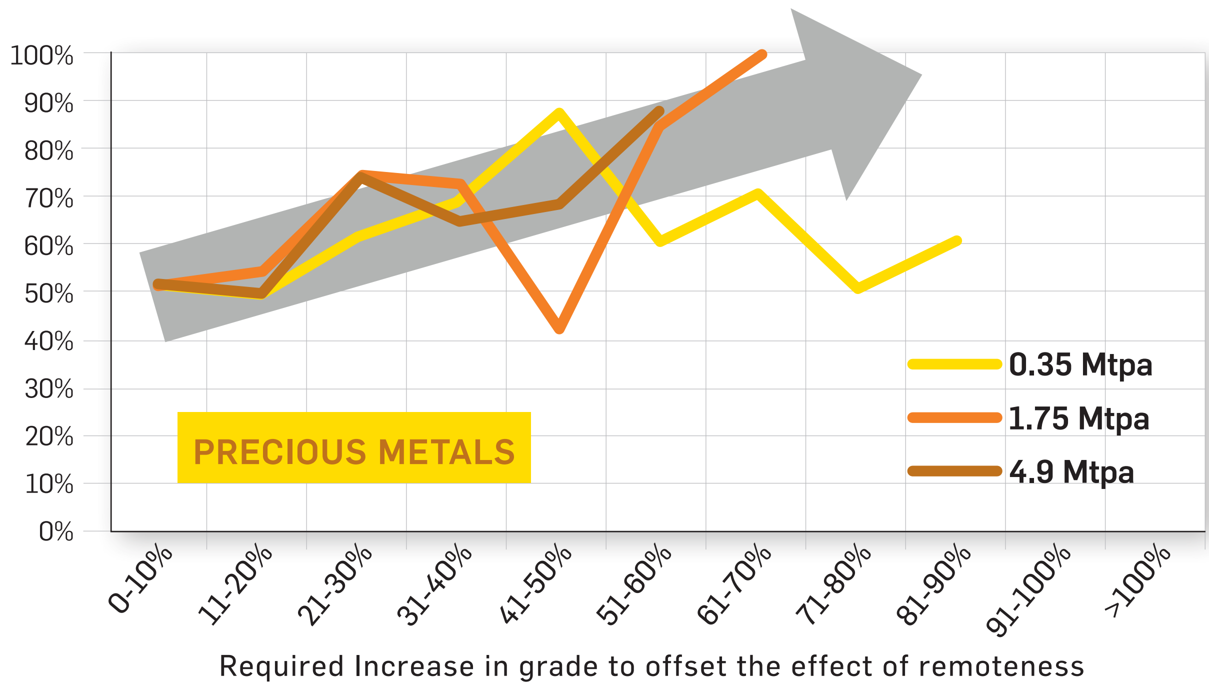
Table 6: Impact of increase on grade required on the % of precious metal projects that are developed (4.9 Mt pa mining case)

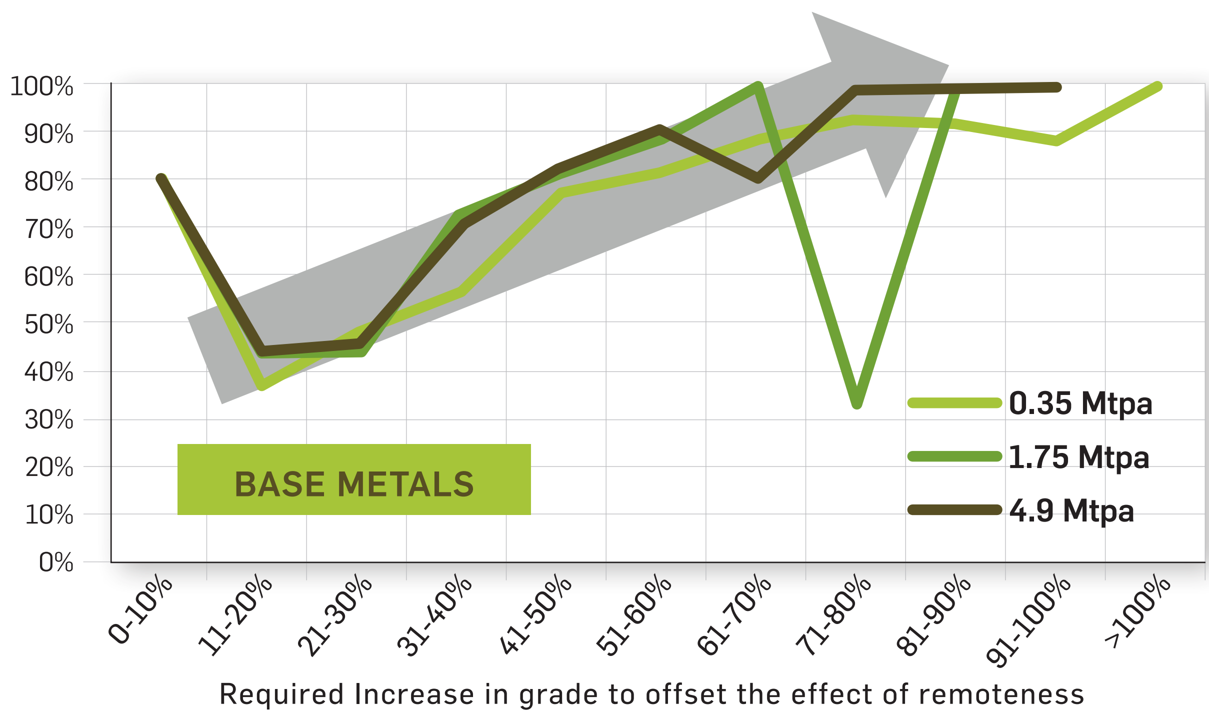
% Grade Increase (a)	Land area (b) km²	Number of Deposits by Current Status (c), (d)				Ratio of Undeveloped to Total
		Closed	Operating	Undeveloped	Total	
0-10%	1,773,246	165	24	196	385	51%
10-20%	1,636,257	41	13	63	117	54%
20-30%	1,167,717	13	0	37	50	74%
30-40%	920,421	10	0	26	36	72%
40-50%	1,227,369	12	3	11	26	42%
50-60%	1,756,876	3	1	21	25	84%
60-70%	1,012,394	0	0	1	1	100%
70-80%	9,403	0	0	0	0	na
80-90%	na	0	0	0	0	na
90-100%	na	0	0	0	0	na
>100%	na	0	0	0	0	na
Total	9,503,682	244	41	355	640	55%

Source: MinEx Consulting and Kenex Ltd © Jan 2016

Note: *(a) Refers to the increase in grade required for a 4.9 Mt pa mining project in a remote area to have same IRR as a same-sized project in an area with perfect infrastructure*
(b) Excludes areas covered by lakes >100km² in size
(c) Includes minor-, moderate-, major- and giant-sized projects

Figure 16: Impact of required grade on likelihood that project will be developed





Source: MinEx Consulting and Kenex Ltd © Jan 2016

Note: Undeveloped Projects includes Advanceed Exploration and Feas/Pre-Feas Projects
All Projects include Operating Mines, Closed Mines and Undeveloped Projects

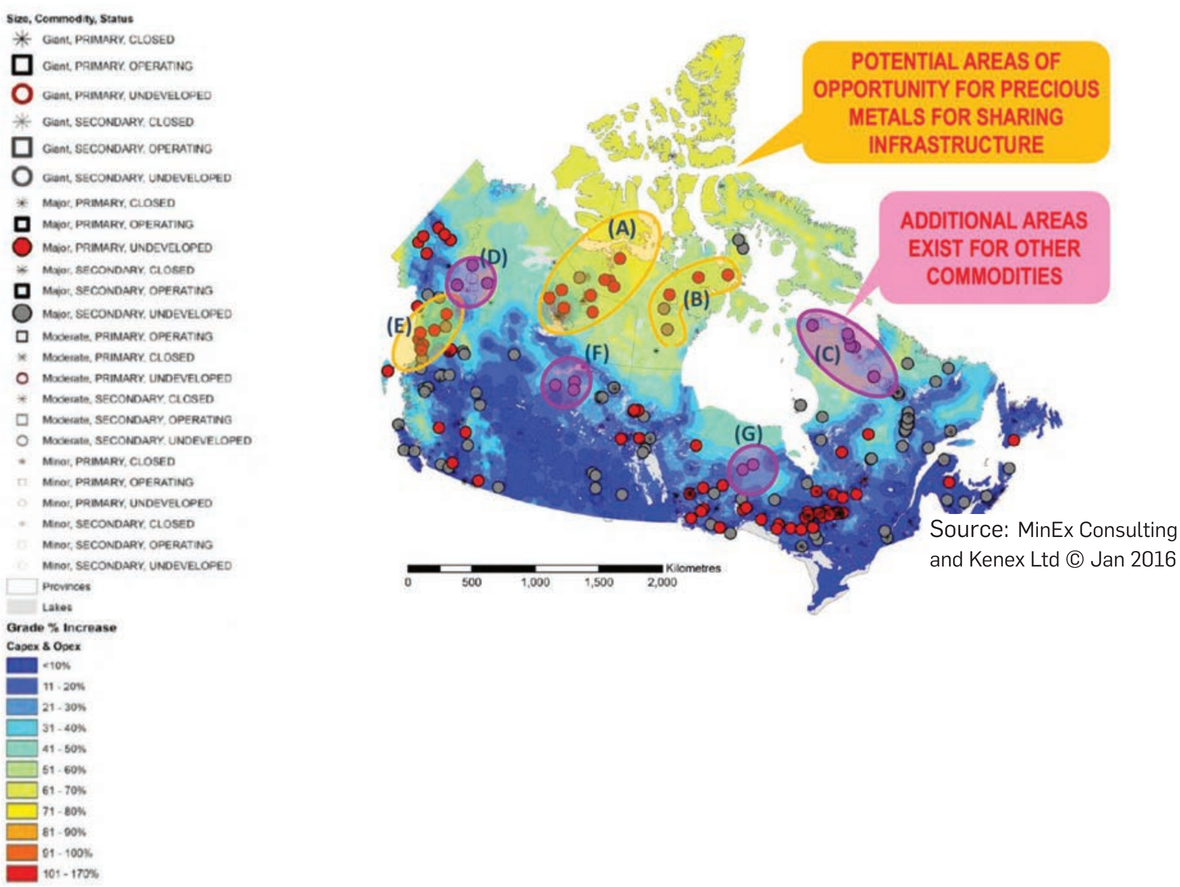
4 OPPORTUNITIES FOR BETTER INFRASTRUCTURE TO CREATE NEW MINES

4.1 AREAS OF OPPORTUNITY

Figure 17 plots up the location of major undeveloped projects (of all commodity types) on the 4.9 Mt pa remoteness map for precious metals. Of significance is the fact that many of these undeveloped deposits cluster together along major geological structures. In remote areas this creates opportunities for government to invest in local infrastructure (principally roads, power and ports) that would be shared across several projects, thereby enhancing their collective likelihood of development. As indicated below, there several such potential infrastructure-development corridors in the far North, including:

- (A) Yellowknife to a port on the Beaufort Sea
- (B) Rankin Inlet to Baker Lake to Repulse Bay
- (C) Schefferville to the top of Ungava Bay
- (D) Selwyn Mountains
- (E) Skagway to Whitehorse
- (F) Fort Mackay to the Saskatchewan Highway
- (G) Ring of Fire in northern Ontario

Figure 17: Potential areas of opportunity



Source: MinEx Consulting and Kenex Ltd © Jan 2016

4.2 POTENTIAL NUMBER OF NEW PROJECTS

Figure 16 shows that, on average, a 10 percentage point increase in the required grade increases the proportion of undeveloped projects by 5-7%. This rate is not sensitive to changes in deposit typer or mine-size. What this means is that an investment in better infrastructure that reduces the required grade by 10% will increase the number of projects (of all types and sizes) that can be developed by 5-7%.

Tables 7 and 8 show the number of mines and projects in the far North, versus their remoteness factor (as measured in terms of the required increase in ore grade) and current status.

Collectively, the Yukon, Northwest Territories and Nunavut host 60 undeveloped[14] base metal and 66 undeveloped precious metal projects. On this basis, a notional 10% reduction in the required break-even grade could result in the construction of three to four new base metal mines and three to five new precious metal mines in the region.

As indicated in Tables 7 and 8, the majority of the undeveloped projects require a break-even grade 30-60% above the base-line grade for an equivalent project in southern Canada. Modelling work by the author indicates that a 10% reduction in the break-even grade will require reducing the capex cost by 12-16% or the opex costs by 16-23%. This can be realized through investing in better local infrastructure.

4.3 SECOND-ORDER EFFECTS AND FLOW-ON BENEFITS

One indirect benefit arising from providing better infrastructure for mining projects is that the resulting lower operating costs means that company can now economically mine lower grade ore. This will result in an increase in the overall reported resource for the deposit,[15] which will result in a larger operation and a longer mine life.

Furthermore, the presence of a large mining operation in a new area often enables other smaller mines to be developed as well for they piggy-back off the access to local infrastructure and services.

Finally, access to better infrastructure will also stimulate other industries in the area, including energy and tourism. All of this will benefit the existing local communities.

14. Made up of 11 base metal projects at the feasibility/pre-feasibility study stage, plus a further 49 projects at the advanced exploration stage. The corresponding figures for precious-metal projects are 16 and 50 respectively
15. This is achieved through adjusting the cut-off grade used for calculating Reserves and Resources. As a general rule of thumb, halving the average gold ore grade mined results in a 3 to 4 fold increase in available ore tonnes, producing a 50-100% net increase in contained ounces (Schodde, 2013). Similar increases occur for other commodities as well.

Table 7: Number and status of base metal operations and projects in Yukon + NWT + Nunavut, broken down by current status and required grade

Required increase in grade to offset impact of remoteness	Land Area (km^2)	Closed Mines	Operating Mines	Feas/Pre-Feas Projects	Advanced Explorn Projects	Total
0-10%	–	–	–	–	–	0
11-20%	–	–	–	–	–	0
21-30%	13,565	1	–	–	1	2
31-40%	98,668	–	–	1	2	3
41-50%	435,121	6	3	4	18	31
51-60%	605,380	4	–	3	11	18
61-70%	698,859	–	–	–	6	6
71-80%	464,115	–	–	1	–	1
81-90%	524,826	–	–	–	6	6
91-100%	574,219	–	–	2	5	7
>100%	246,120	–	–	–	–	0
Total	3,660,873	11	3	11	49	74

Table 8: Number and status of precious metal operations and projects in Yukon + NWT + Nunavut, broken down by current status and required grade

Required increase in grade to offset impact of remoteness	Land Area (km^2)	Closed Mines	Operating Mines	Feas/Pre-Feas Projects	Advanced Explorn Projects	Total
0-10%	1,915	1	–	–	–	1
11-20%	68,264	6	1	2	1	10
21-30%	181,306	5	–	3	19	27
31-40%	398,422	3	1	2	10	16
41-50%	1,995,687	9	3	7	18	37
51-60%	979,517	–	–	2	2	4
61-70%	30,236	–	–	–	–	0
71-80%	3,592	–	–	–	–	0
81-90%	1,721	–	–	–	–	0
91-100%	213	–	–	–	–	0
>100%	–	–	–	–	–	0
Total	3,660,873	24	5	16	50	95

5 SUMMARY/CONCLUSIONS

Large tracts of Canada are very remote and poorly serviced by infrastructure. Much of Canada suffers from the tyranny of distance. In terms of travel time, some parts of northern Canada are as difficult to access as the Sahara Desert or Siberia. The associated remoteness adversely affects the mining industry, and only the very best projects are economically robust enough to be developed. The high entry cost and mediocre returns on all but the very best projects also discourage exploration in the area.

The transportation infrastructure deficit is the primary driver for the significant cost premium for companies interested in discovering and developing remote deposits. In large part as a result of this cost premium, fewer discoveries have been made in remote Canada than in less remote areas. While 40% of Canada's land mass lies above the above the 60º latitude line, this region contains only 12% of all known deposits. This suggests there are significantly more discoveries waiting to be made, some of which would likely be able to become mines that generate significant economic opportunities for the territory, regional communities and Canada.

Of those discoveries that have been made in remote Canada, a disproportionate number remain "stranded'"(undeveloped). Of the 1,079 undeveloped mining projects in Canada, 153 of these are above the 60º latitude line (54 projects in Yukon, 48 in Northwest Territories, 44 in Nunavut and 7 in northern Quebec). Of these, 76% are currently undeveloped. By comparison the national average for undeveloped projects is 61%, and the average for those projects located below the 50o latitude line is 53%.

If strategic infrastructure investments were made in these remote areas, there would be a two-fold impact: first, the costs of exploration would decrease, likely leading to more exploration activity and more discoveries. Secondly, the costs associated with developing known discoveries would be reduced, making it economically feasible to move a more diverse range of deposits into production.

PDAC commissioned this study to better understand the economic impact of remoteness in terms of the required increase in ore grade needed to achieve the same economic return as a similarly-sized project in an area of perfect infrastructure. The key input variables modelled were distance to existing road, rail, power and port infrastructure. Other factors included were elevation, temperature and presence of permafrost.

The results show that that a 1.75 Mt per annum precious metal project in the far North needs to have grades 40-70% higher than for an equivalent project in southern Ontario. For a similarly-sized base metal project, the grades need to be 50-150% higher (base metal projects, of course, require additional investment in infrastructure to transport their (concentrate) products to port). The presence of permafrost and the need to build temporary ice roads in the winter add to the costs.

Modelling shows that a 10 percentage point improvement in the required grade increases the number of projects that can be developed by 5-7%. From this, it is calculated that such an improvement in required ore grades in the far North would unlock an additional three to four new base metal mines and three to five new precious metal mines in the region.

A 10% reduction in the break-even grade is equivalent to reducing the capex cost by 12-16% or the opex costs by 16-23%. Such gains can be achieved through building better infrastructure. Many undeveloped projects are clustered, creating an opportunity to build infrastructure corridors to service multiple projects.

Seven such development corridors have been identified:

- (A) Yellowknife to a port on the Beaufort Sea
- (B) Rankin Inlet to Baker Lake to Repulse Bay
- (C) Schefferville to the top of Ungava Bay
- (D) Selwyn Mountains
- (E) Skagway to Whitehorse
- (F) Fort Mackay to the Saskatchewan Highway
- (G) Ring of Fire in northern Ontario

With regard to the above seven infrastructure corridors, it is recommended that detailed modelling work be carried out at the local level (using local tax and royalty rules and actual costs for nominated projects) to determine the amount of investment required to unlock the specific opportunities available.

Finally, it should also be noted that there are a number of spin-off benefits to government in investing in better infrastructure for the mining sector. These include:

- An increase in the size of available projects. In detail, lower operating costs means that company can now economically mine lower grade ore. This will result in an increase in the overall reported resource for the deposit, which will result in a larger operation and a longer mine life. This has major economic and strategic benefits for the country (namely higher revenues and royalties for longer).
- The presence of a large mining operation in an area often enables other smaller mines to be developed as well for they piggy-back off the access to local infrastructure and services.
- Access to better infrastructure will also stimulate other industries in the area, such as energy and tourism.
- Better access and job opportunities for existing local communities.

PDAC hopes that this information will help bolster federal support for a number of resource-development related infrastructure requests that the three territories have put forward to the federal Building Canada Plan. In addition, PDAC is calling for resource development to be an explicit priority for the proposed Canada Infrastructure Bank promised in the 2015 Liberal Party election platform.

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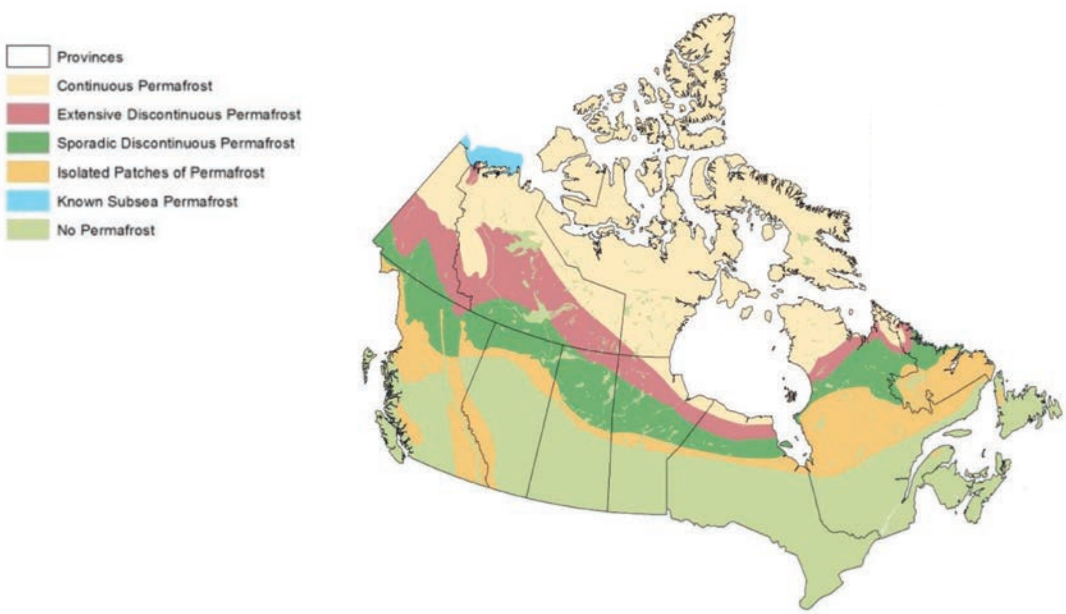
APPENDIX A: Key Data Sets

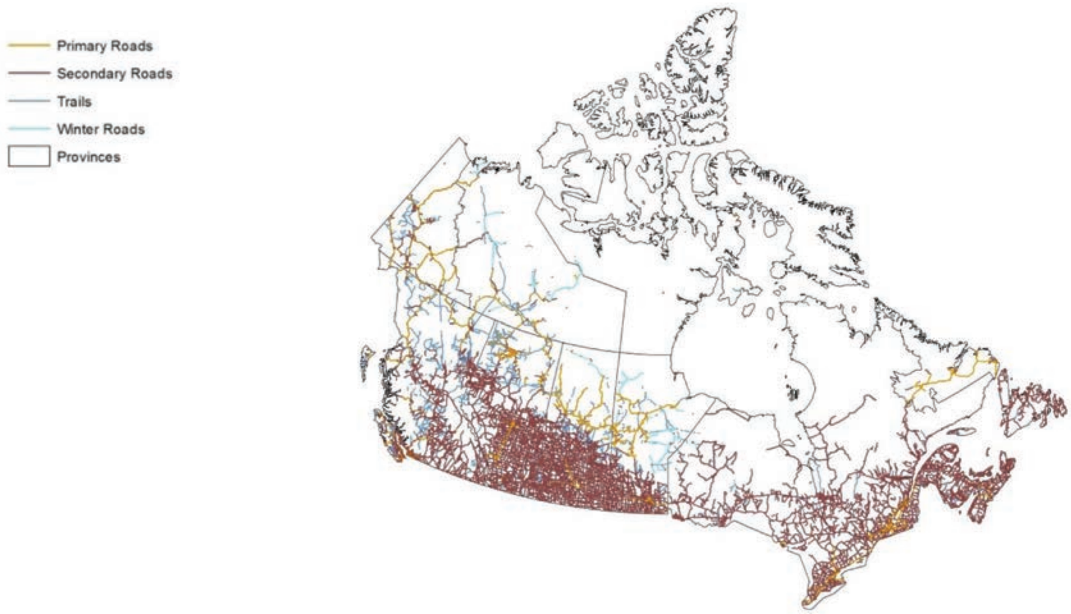
Digital Elevation [Source: NASA, 2011]
It is more expensive to build projects and infrastructure in mountainous areas

Permafrost [Source: Geological Survey of Canada, 2000]
The presence of permafrost affects construction costs for mines and infrastructure. Equipment specifications and worker productivity are also affected by the extreme cold (minimum monthly temperature map used but not shown



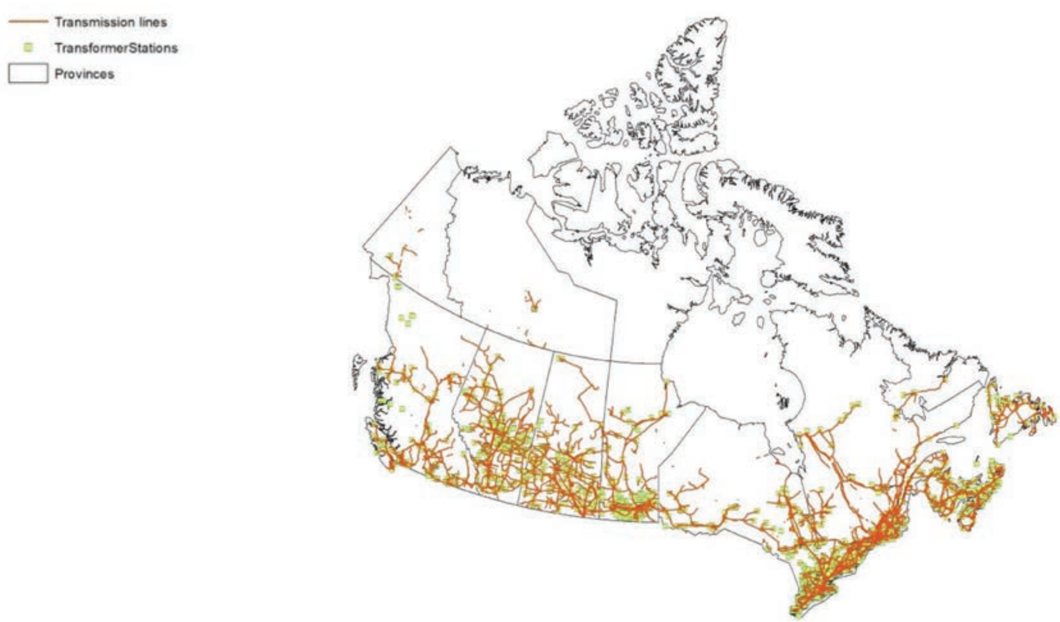
Roads [Source: Natural Resources Canada, 2014]

Roads and rail (not shown) are required to transport equipment and materials to and from the mine. Winter roads are a special case as they only operate for a short time of the year, requiring the company to stockpile materials in the off-season.

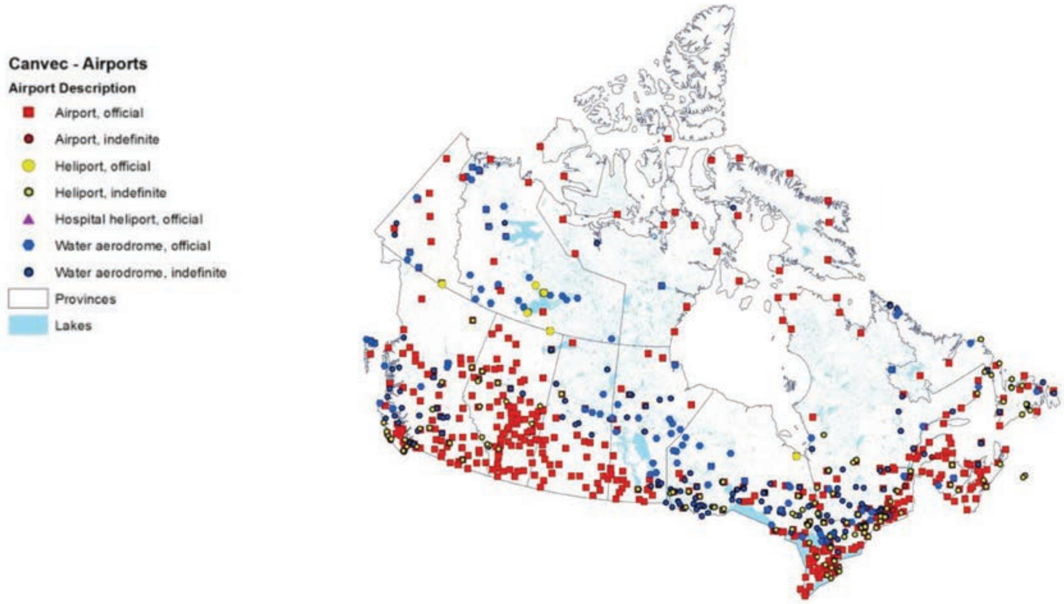


Power [Source: Natural Resources Canada, 2014]

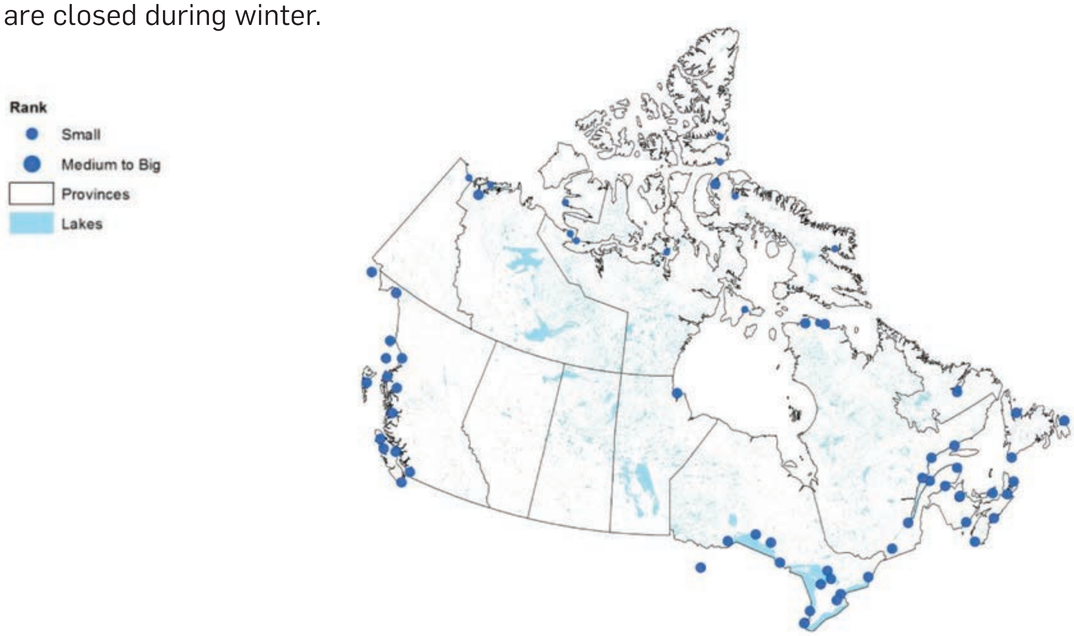
Energy is a large cost item for mines. If the mine is not near the existing power grid the company will need to generate power on-site using expensive diesel fuel, which has to be trucked-in.



Airports [Source: Natural Resources Canada, 2014]
Airport enable workers will travel to the mine site in remote areas. They also provide access for emergency services.



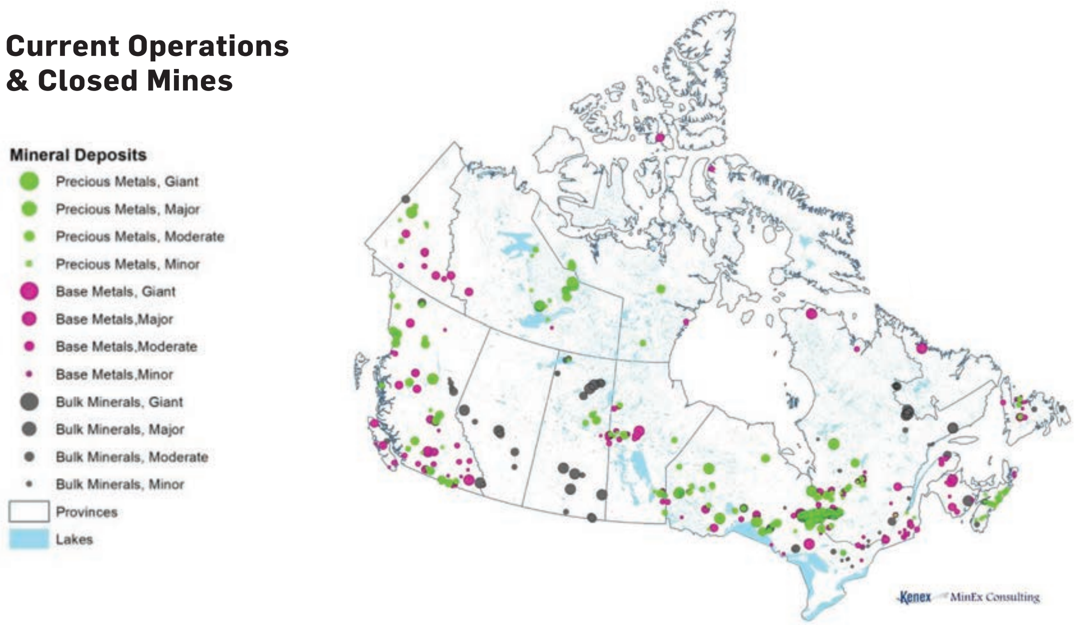
Ports [Source: World Port Source, 2015]
Ports are an important hub for supply of materials to the mine site. In the case of base metals and bulk minerals, they are essential for the export of the mined product. Key variables are the quality of the port facilities (such as storage sheds and ship loaders) and depth of water (as this will affect the size of ship that can be used). Due to ice, some of the ports in the far North are closed during winter.



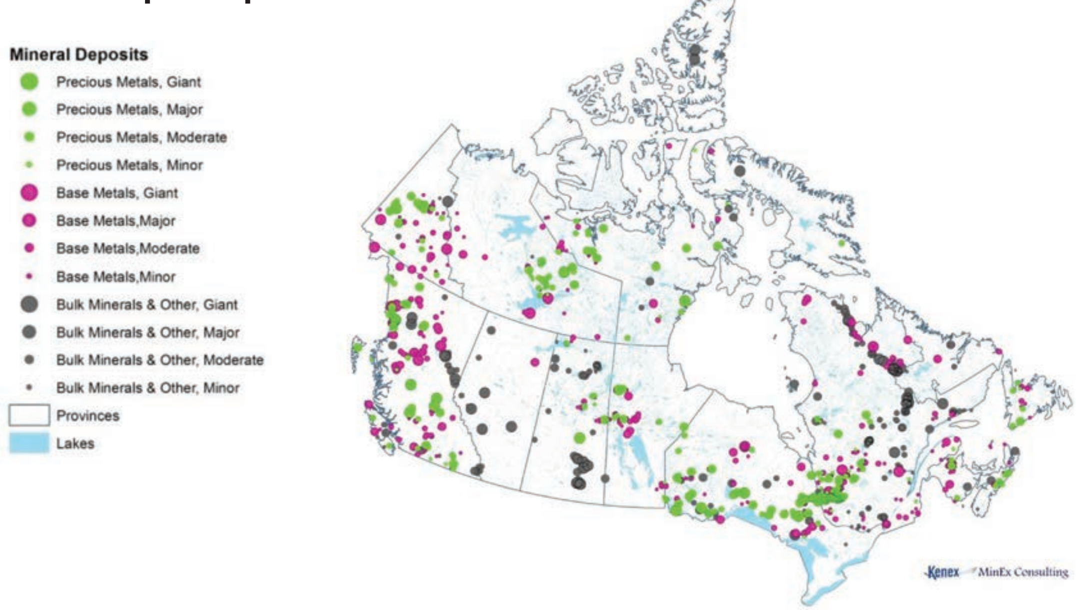
Mineral Deposits [Source: MinEx Consulting, 2015]

The following two maps show the location of 747 existing mines (made up of 107 operating plus 640 closed) and 1,079 undeveloped deposits (including 199 currently at the pre-feasibility or feasibility study stage). The first map shows where mining activities have been historically focused in Canada, whereas the second map indicates where the future opportunities for the industry lie. Several of these projects are in the far North.

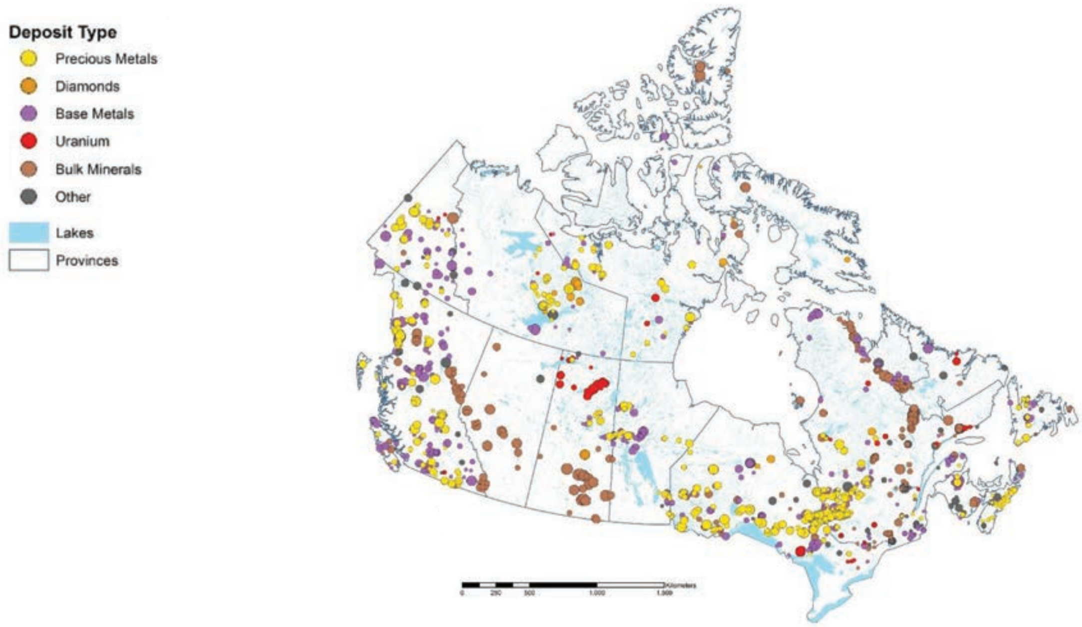
Current Operations & Closed Mines



Undeveloped Deposits



The following map shows in more detail the commodity type for the various (developed and undeveloped) deposits. The bulk mineral deposits in British Columbia, Alberta and Nova Scotia are mainly coal, whereas the bulk deposits in Saskatchewan are potash and those in Quebec and Labrador are mainly iron ore.



APPENDIX B: Background Information on the Modelling Method

he study used spatial modelling techniques. This involved taking into account all the available relevant geographical and infrastructure data in Canada and combining them in a Geographic Information System (GIS) to identify areas lacking infrastructure. Creating a map of remote and undeveloped areas (or "remoteness map") involves a large number of variables and incorporation of multiple data sets. The impact of these factors varies with the commodity chosen and the size of the mining operation.

Due to the large number of factors involved and the complexity of analysis, the use of expert weighted spatial modelling (Fuzzy Logic) was selected as the most appropriate method to create the required output.

The first step involved compiling information on terrain, climate and available infrastructure. This was based on publicly available data for Canada (see Appendix A for details).
The following parameters were then defined as important:

- Infrastructure data:
  - Distance from roads and type of closest roads.
  - Distance from transmission lines and stations.
  - Distance from railroads and type of rails.
  - Distance from ports and airports facilities.

- Topographic barriers: elevation, complexity of the surrounding terrain and slope; waterways and lakes.
- Climatic variables: yearly minimum temperature and its distribution; permafrost distribution.
- Cultural data: population indexes and distribution; national parks and restricted areas
- Size and location of known mines and undeveloped deposits.

The data was managed in a GIS and manipulated using techniques such as buffering, grid extrapolation, grid interpolation, map classification and focal neighbourhood statistics.

Fuzzy logic modelling

The study area for this project consists of the entire land mass of Canada. Modelling was based on a 500 metre by 500 metre grid over the entire country. The grid resolution was chosen as appropriate for a national scale model, balancing the high resolution of the infrastructure and terrain analysis against the practicalities of data management and computer processing and the resolution of the output maps.

Spatial data modelling was undertaken using the Fuzzy Logic technique as developed by Graeme Bonham-Carter of the Canadian Geological Survey (Bonham-Carter 1994, Raines et al 2000). This was done using the Spatial Data Modeller extension (ArcSDM) for ESRI's ArcGIS for Desktop software.

Fuzzy Logic relies on expert opinion to derive weights that rank the relative importance of all the variables considered in the model. The datasets used are reclassified based on their values and the expert's knowledge, and then, as noted in Table B1, a weighting value (0-1) is assigned to each class. The weight expresses the degree of importance of the various classes as predictors of the feature under consideration.

Table B1: Explanation of Fuzzy Logic Weights

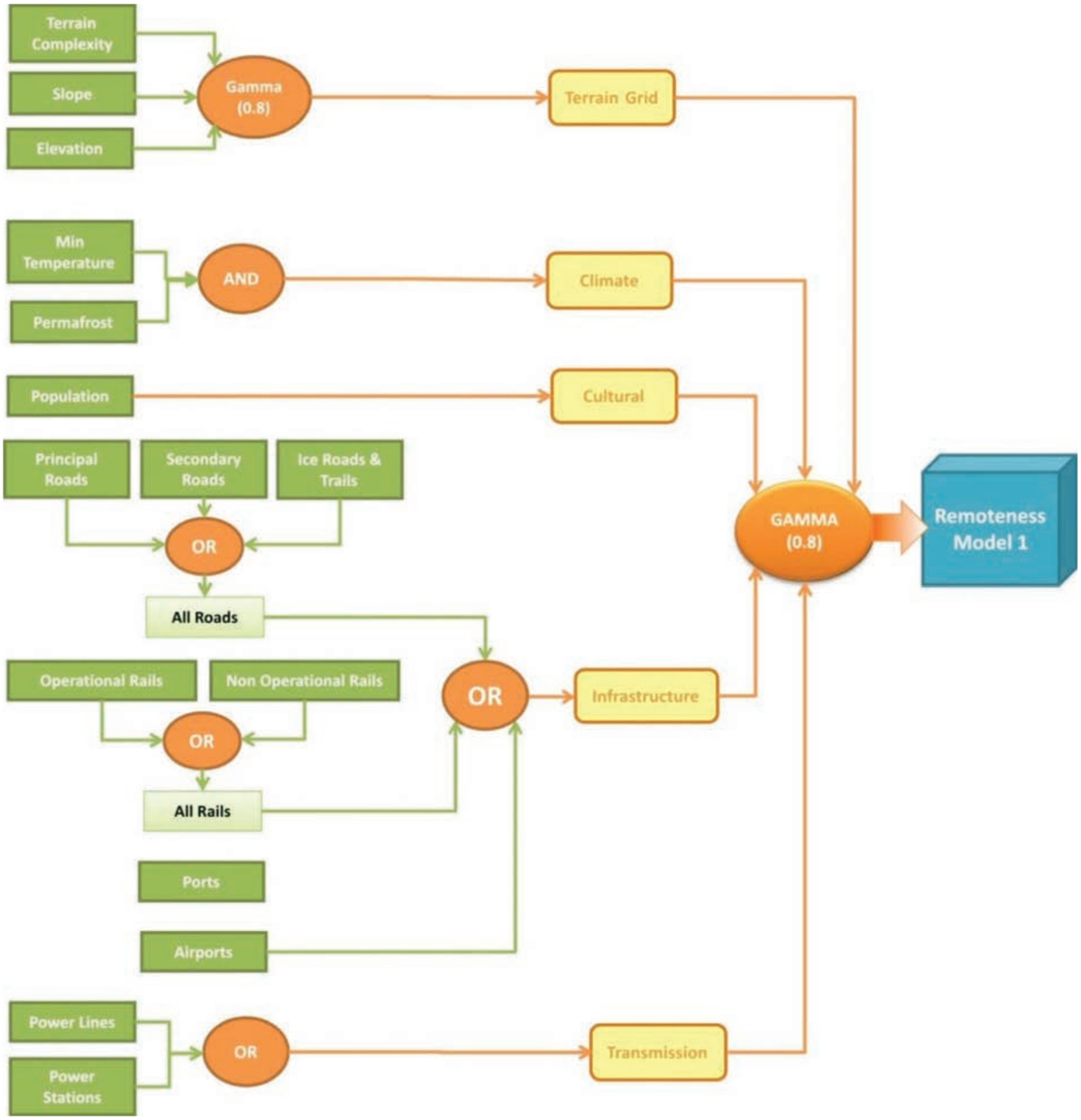
Weight	Description
0.001-0.01	Any predictive map with this weighting will exclude this cell.
0.1	A cell with this weight will only result in a ranked cell if all other predictive maps have high weights
0.5-0.9	A combination of these weights will produce varying degrees of suitability (e.g. if all cells have weights of 0.8 or 0.9 then the output cell will be classified as highly prospective).
1	1 is not used as a weight for any of the predictive maps in this model because it assumes a perfect ability of the data to predict infrastructure locations

Each model generated 22 individual weighted predictive maps, with each map representing a feature and contains classes of values for that feature. Expert opinion was used to weight each class based on its importance. The relative weightings were adjusted depending on the commodity type and mine size. This was based on economic modelling of a standard mine. The predictive maps were combined by a variety of fuzzy logic operators (fuzzy AND, fuzzy OR, fuzzy GAMMA, etc.). The operator determines how the model statistically combines the input maps to create the final map which identifies areas with the highest probability relevant to the feature being modelled. For more details, see Table B2 and Figure B1 below.

Table B2: Explanation of Fuzzy Operators

Fuzzy Operator	Description
AND	The minimum of the fuzzy memberships from the input fuzzy rasters.
OR	The maximum of the fuzzy memberships from the input fuzzy rasters.
PRODUCT	A decreasive function. Used when the combination of multiple evidence is less important or smaller than any of the inputs alone.
SUM	An increasive function. Used when the combination of multiple evidence is more important or larger than any of the inputs alone.
GAMMA	The algebraic product of the fuzzy SUM and the fuzzy PRODUCT, both raised to the power of GAMMA (between 0 and 1).

Figure B1: Diagram of the model procedure



In detail:

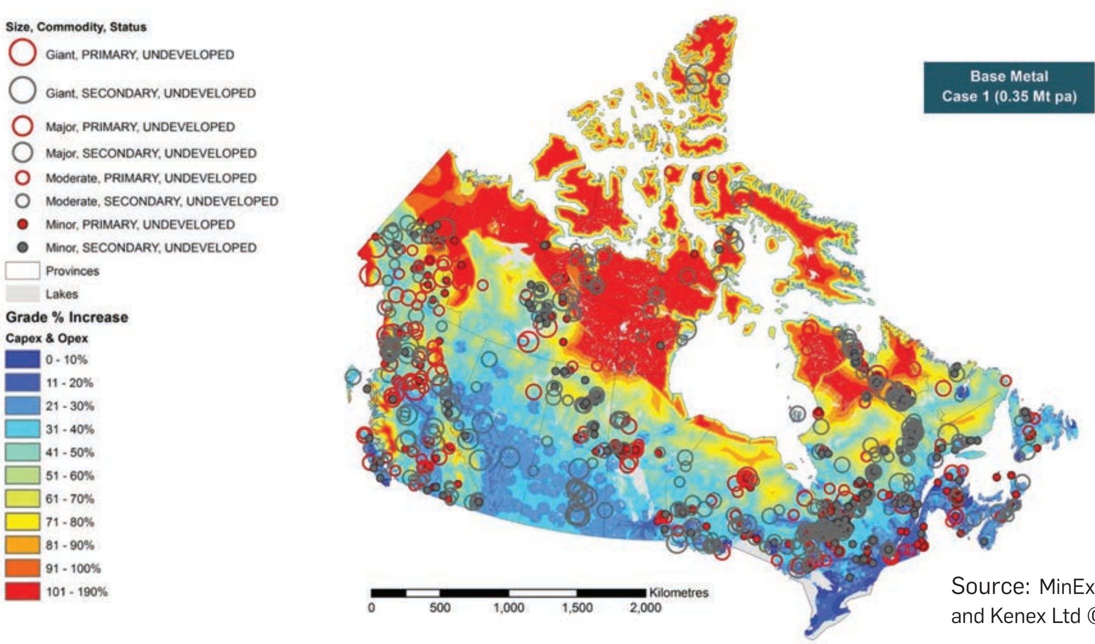
- The predictive maps for road, rail, port and airport were combined together with the Fuzzy operator OR in order to create an inclusive map of the distribution of all the transportation infrastructures in the country. In this map, the value of each cell represents the distance of that cell from any type of transportation network.
- In a similar way, the predictive map for power lines and stations were combined using the Fuzzy operator OR in order to create a map for the transmission network. This map also represents the distance of each cell from any type of power transmission.
- The three terrain maps—elevation, slope and terrain complexity—were combined using the Fuzzy operator GAMMA with value of 0.8. The Gamma operator takes into account not only the weights of the classes in each map but also the combination of the weights between different maps, giving the best overview of terrain conditions for each cell of the map.
- The climate parameters, permafrost and minimum temperature, were introduced in the model to identify areas with challenging climate features. For this reason, the climate maps were combined using the Fuzzy operator AND. This operator prioritizes the lower weighted classes over the others and therefore creates a climate map where each cell represents the least favourable climate condition between the two maps.
- The derived maps—infrastructure, transmission, terrain and climate—were then combined together with the population density map (shown as a cultural map) using the Fuzzy operator GAMMA (with a setting of 0.8). The resulting map is the remoteness map for the entire country; with remoteness measured in terms of the percentage increase in ore grade required to offset the adverse economics of the project being located in a remote and/or difficult area.

APPENDIX C: Remoteness Maps of Undeveloped Deposits in Canada

Appendix C contains heat maps showing the remoteness (as measured in terms of the increase ore grade required for a project to have the same economic return across Canada) for three different sized mining operations (Cases 1, 2 and 3) overlain with the location of undeveloped mineral deposits.

It includes three heat maps for base metal projects (Figures C1 to C3) and three heat maps for precious metals (Figures C4 to C6). In each map the individual undeveloped deposits have been colour-coded to highlight the target commodity (base metal or precious metal) and deposit size (moderate, major and giant).

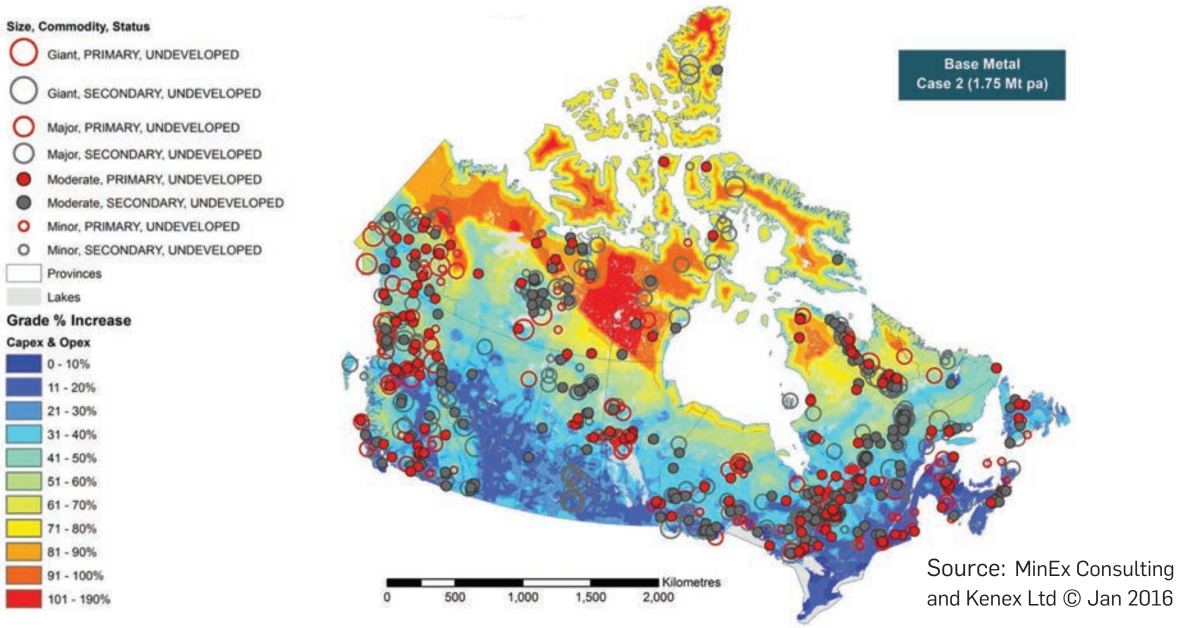
Figure C1: Location of undeveloped deposits overlain on a heap map of the required increase in grade for a 0.35 Mt pa Base Metal Mine (i.e. Heat map of remoteness for minor-sized base metal projects in Canada)



Source: MinEx Consulting and Kenex Ltd © Jan 2016

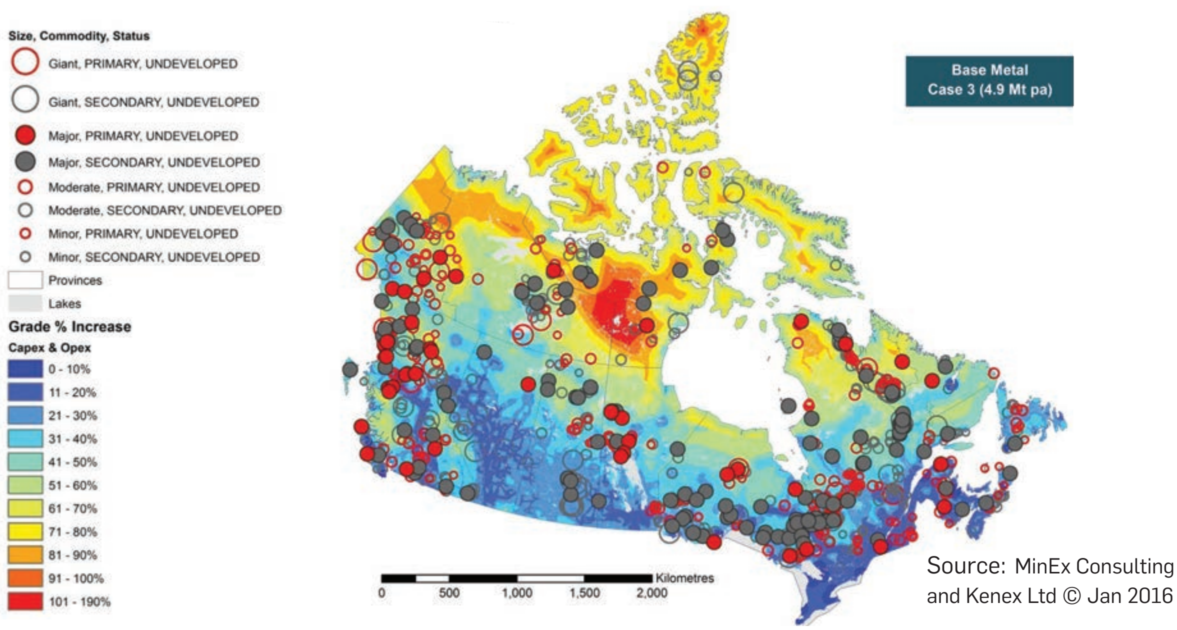
Note: The solid-red circles refer to minor-sized base metal deposits. The open-red circles refer to other-sized base metal deposits. For completeness, the map also shows (in grey) the size and location of the undeveloped precious metal, bulk mineral and other deposits.

Figure C2: Location of undeveloped deposits overlain on a heap map of the required increase in grade for a 1.75 Mt pa Base Metal Mine (i.e. Heat map of remoteness for moderate-sized base metal projects in Canada)



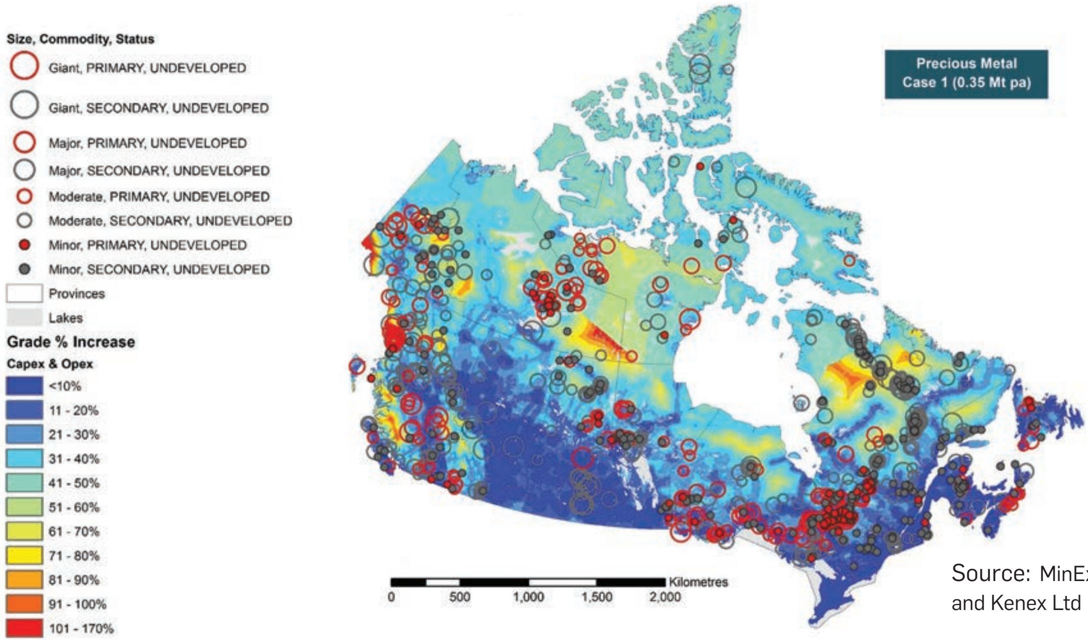
Note: The solid-red circles refer to moderate-sized base metal deposits. The open-red circles refer to other-sized base metal deposits. For completeness, the map also shows (in grey) the size and location of the undeveloped precious metal, bulk mineral and other deposits.

Figure C3: Location of undeveloped deposits overlain on a heap map of the required increase in grade for a 4.9 Mt pa Base Metal Mine (i.e. Heat map of remoteness for major-sized base metal projects in Canada)



Note: The solid-red circles refer to major-sized base metal deposits. The open-red circles refer to other-sized base metal deposits. For completeness, the map also shows (in grey) the size and location of the undeveloped precious metal, bulk mineral and other deposits.

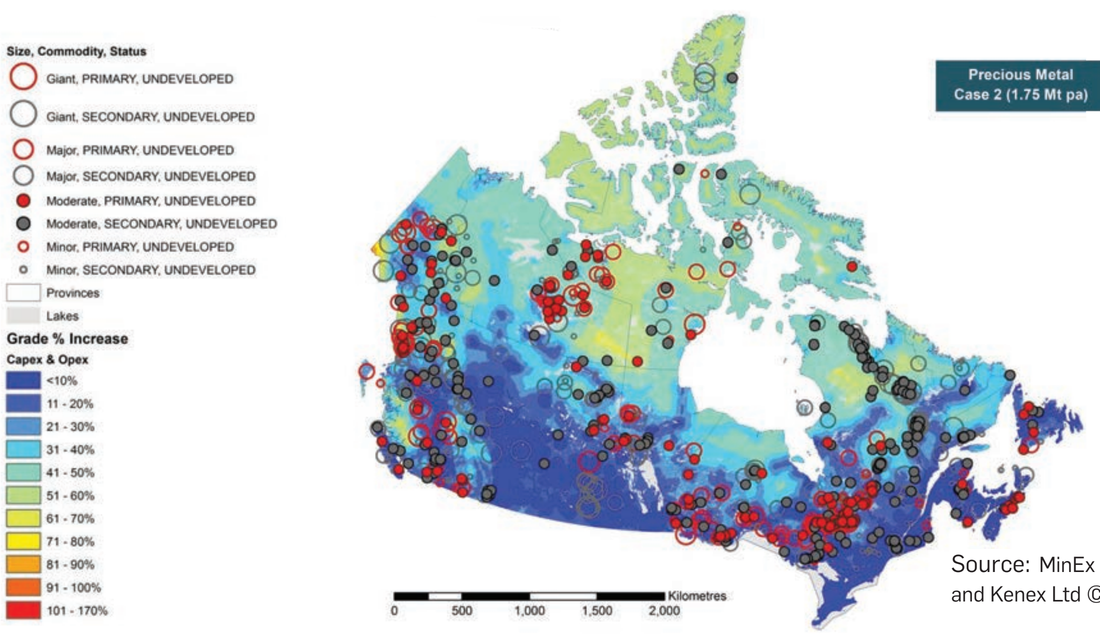
Figure C4: Location of undeveloped deposits overlain on a heap map of the required increase in grade for a 0.35 Mt pa Precious Metal Mine (i.e. Heat map of remoteness for minor-sized precious metal projects in Canada)



Source: MinEx Consulting and Kenex Ltd © Jan 2016

Note: The solid-red circles refer to minor-sized base metal deposits. The open-red circles refer to other-sized precious metal deposits. For completeness, the map also shows (in grey) the size and location of the undeveloped precious metal, bulk mineral and other deposits.

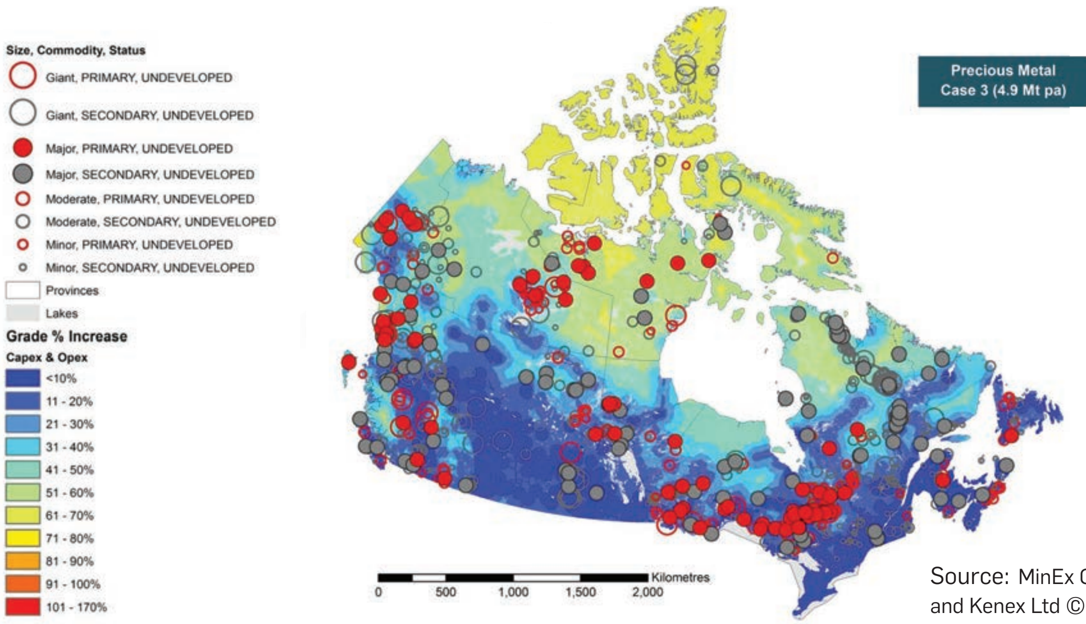
Figure C5: Location of undeveloped deposits overlain on a heap map of the required increase in grade for a 1.75 Mt pa Precious Metal Mine (i.e. Heat map of remoteness for moderate-sized precious metal projects in Canada)



Source: MinEx Consulting and Kenex Ltd © Jan 2016

Note: The solid-red circles refer to moderate-sized base metal deposits. The open-red circles refer to other-sized precious metal deposits. For completeness, the map also shows (in grey) the size and location of the undeveloped precious metal, bulk mineral and other deposits.

Figure C6: Location of undeveloped deposits overlain on a heap map of the required increase in grade for a 4.9 Mt pa Precious Metal Mine (i.e. Heat map of remoteness for major-sized precious metal projects in Canada)



Source: MinEx Consulting and Kenex Ltd © Jan 2016

Note: The solid-red circles refer to major-sized base metal deposits. The open-red circles refer to other-sized precious metal deposits. For completeness, the map also shows (in grey) the size and location of the undeveloped precious metal, bulk mineral and other deposits.

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