SLAVE GEOLOGICAL PROVINCE ROAD CORRIDOR STUDY
GIS Multi Criteria Analysis and Least Cost Path Routing

Slave Craton, NWT & NU, Canada

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Prepared for:

GNWT Industry, Tourism, and Investment
Mineral Resource Planning Division
and Department of Transportation

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TECHNICAL REPORT
GIS Multi Criteria Analysis and Least Cost Path Routing

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1. ACKNOWLEDGEMENTS

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2. DISCLAIMER

This report is based on the subjective judgements of several geoscientists and principally the first author. Decisions were made within a limited time frame using limited information sources. Any subjective, knowledge-based assessment will be handicapped by various limitations and biases, and these should be recognized. The subjective analysis will only be strengthened by the input of additional knowledgeable geoscientists. Our end product is a map showing interpreted mineral potential of the Slave Geological Province and surrounding region. It should not be used solely, but in conjunction with other materials, whether for deciding road routes or for planning mineral exploration programs. The information contained, and forming the basis of our interpretations, is as current as could be reasonably obtained. This cannot be considered a static document. New information is expected to be released that will have an effect on the analysis outlined here. This new information will come from ongoing and future exploration results, new digital geological compilations, and the always-changing land tenure situations. The user is thus cautioned against applying the mineral potential map too broadly, or in isolation, or very far beyond its publication date.

Note that the maps included in this report have been scaled down from the original 1 : 5 000 000 scale plots.

3. EXECUTIVE SUMMARY

An all-weather road through the Slave Geological Province (SGP) to tidewater in Nunavut has been intermittently considered by Government of the Northwest Territories (and/or Federal Government agencies) since the 1950s and by the private sector since at least the 1970s (Arthur Andersen LLP et al., 1999). The recently developed GNWT Mineral Development Strategy (GNWT, 2013) restated this commitment to invest in infrastructure to improve access to mineral potential. This study follows the 2014 GNWT Mineral Development Strategy Implementation Plan (GNWT, 2014) directive to undertake a resource access corridor study to help planning and prioritization of infrastructure to support resource development.

The Slave Geological Province Road Corridor Study (SGPRC) has at its core a series of maps illustrating the interpreted highest mineral potential in the study area. These maps are meant to be considered in concert with the results of other studies, to determine the best road routing. The data on which these maps are based are in a state of change, meaning that the results cannot be considered static or final.

The mineral potential maps make use of two major sets of data: the databases of known mineral occurrences throughout NWT and NU (the NORMIN and NUMIN databases, respectively), and geological map compilations of the SGP (Stubley, 2005) and surrounding areas (Wheeler et al., 1997). Along with mineral tenure and mapped fault locations, these data were evaluated by mainly subjective means, converted to numerical scores, and through Geographic Information System (GIS) analysis, represented on "heat maps".

The mineral occurrence data were evaluated through partly objective but dominantly subjective criteria. The level of development associated with each occurrence, the commodities present, known resources or reserves, and current status of the more advanced projects were all considered. A numerical score was assigned to each of 2813 occurrences. Likewise, geological bedrock units (64 units) are converted to numerical scores based on their subjectively judged importance and/or favourability in mineral exploration.

The four variables (mineral occurrences, bedrock geology, mineral tenure and faults) were individually scored, and converted from a vector data format using GIS software into a raster data format based on 100m by 100m grid cells covering the study area. Raster maps of each variable were standardized to create criteria layers and displayed on a "blue to red" colour scale as thematic "heat maps". Next, the four variables were rated against each other, using a pair-wise comparison matrix. Through the resulting matrix calculations, relative weightings were obtained for each variable. The scores for each variable were used in the GIS analysis with their relative weights, to evaluate every cell in the study area. The result is a "heat map" displaying interpreted mineral potential (Figure 1). Using additional GIS analysis functions with the mineral potential raster data it was possible to obtain a preferred route placement of an all-weather road through the areas of mineral potential (Figure 2).

The mineral potential map shows relatively thin, roughly north-trending belts through the western, central, and eastern SGP that correspond largely to the position of volcanic greenstone belts. In particular, the eastern belts, and northern part of the central belt are interpreted to have high potential. There are some broad areas of relatively high mineral potential at the northwest margin of SGP, in the northern Bear Province. These are at least partly an artefact of the lower resolution of digital geology available for this area.

The optimal route map shows that the highest mineral potential areas are best served by a north trending route branching off NWT Highway 4 near its east end at Tibbitt Lake.

The main conclusion from this study is that the interpreted highest mineral potential lies in the volcanic greenstone belts, while the mineral occurrences lying within those belts serve to enhance certain areas. This is unsurprising, given that the bedrock geology was weighted strongly in this interpretation, and volcanic rocks were considered the most favourable bedrock type. Outside of the greenstone belts, the Lac de Gras and Gacho Kue areas have high potential as well.

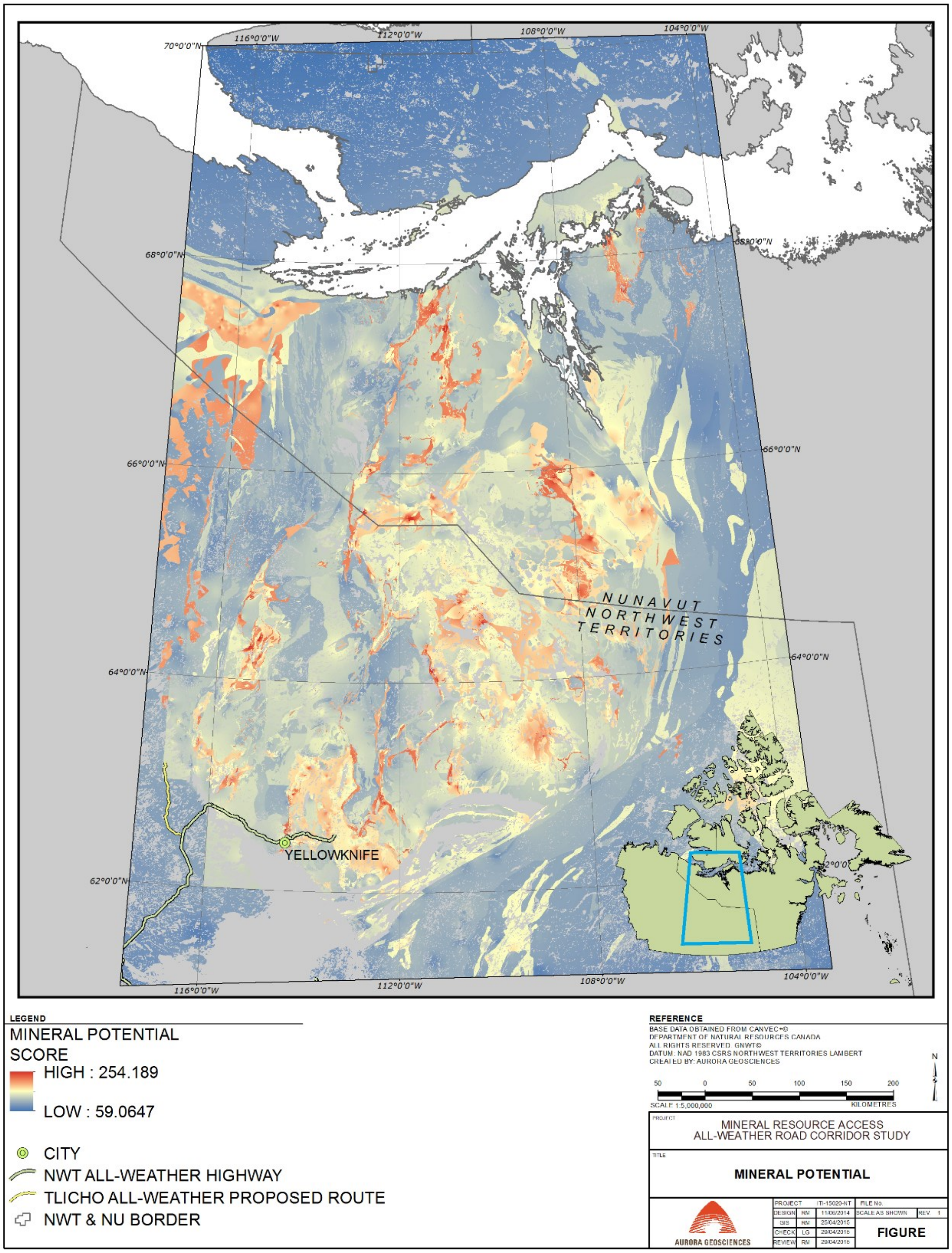

Figure 1. Interpreted Mineral Potential Map

Interpreted mineral potential of the Slave Geological Province and immediate environs expressed as a heat map. Yellowknife and the existing and proposed NWT Highways system are shown. Higher potential areas are in reds. Legend is further explained in text.

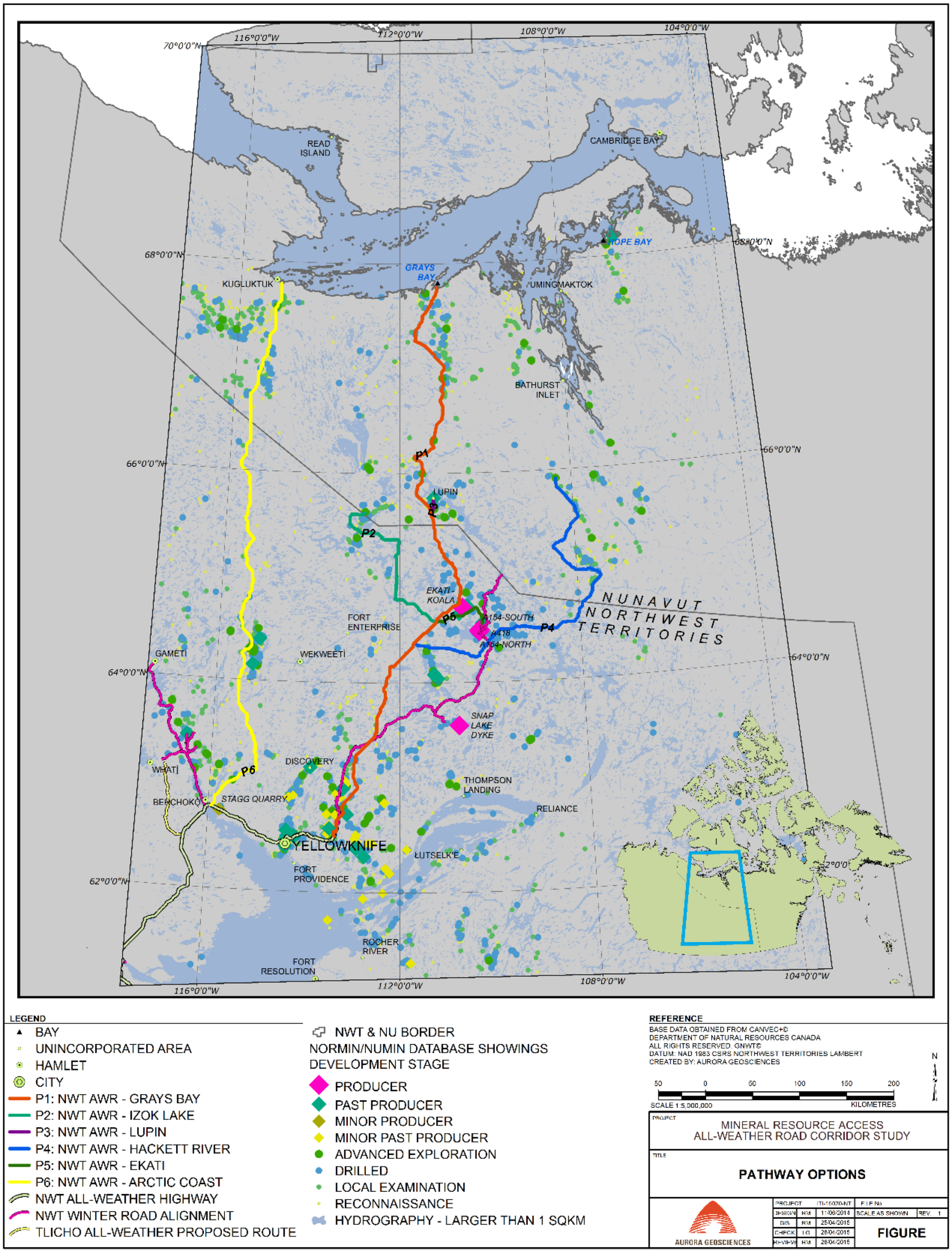

Figure 2. GIS Analysis Generated Optimal Road Paths

GIS analysis-generated optimal road paths originating from the existing NWT Highway system through to various destinations (see legend). These paths are constrained to avoid waterbodies of 1 km^2 in area and greater. Yellowknife and the existing and proposed NWT Highways system are shown. Methodology and Legend are explained in the text.

4. INTRODUCTION

This report summarizes a road corridor mapping project undertaken by Aurora Geosciences Ltd. (Aurora) for the Government of the Northwest Territories (GNWT). The project "Slave Geological Province Road Corridor Study" (SGPRC) was awarded to Aurora through a Standing Offer Agreement.

Mineral potential is determined using an Analytical Hierarchic Process (AHP) through which four variables are individually evaluated and then compared with each other in a pair-wise matrix to calculate relative weightings of importance. Computation of the matrix throughout a high resolution raster map of the study area results in colour-coded "heat maps" graphically illustrating the interpreted mineral potential of the Slave Geological Province (SGP) and adjacent areas. The maps are intended to contribute to road routing decisions.

The mineral potential map is accompanied by input thematic maps of the mineral occurrences, bedrock geology, mineral tenure and faults. Surficial geology, eskers, hydrology and wetlands, basic infrastructure, and gross value of minerals-in-place maps are also presented. The hydrology and wetlands data are also used as exclusionary layers, to enhance the optimal road routing map.

Background

An all-weather road through the SGP to tidewater in Nunavut has been intermittently considered by GNWT (and/or Federal Government agencies) since the 1950s and by private sector since at least the 1970s (Arthur Andersen LLP et al., 1999). All weather road proposals originating in Nunavut, such as the Bathurst Inlet Port and Road Project (Hamel, 2013) and the more recent Izok Corridor Project of MMG Minerals have seen some level of technical study, and environmental review, although both are currently on hold (MMG website April 7, 2015; mmg.com). Currently in the NWT, a network of both public and private seasonal ice roads, branching off from territorial highways #3 and #4, service communities and mines in the study area.

The SGPRC supports the GNWT Mineral Development Strategy (GNWT, 2013), specifically *Pillar 1, Goal 1.3: investment in infrastructure and energy development in the NWT improves access to mineral potential.* A follow-up implementation plan (GNWT, 2014) recommended that the GNWT "*undertake a resource access corridor study that will help coordinate planning, assist with the overall prioritization of investment decisions and mitigate environmental effects of resource development projects*".

The foundation of the SGPRC is a qualitative analysis of the mineral development potential of the SGP to assist with the planning of an optimal all-weather road corridor linking the Northwest Territories highway system with the Nunavut's Arctic Coast.

Scope

The original project document (Appendix I) required a desktop study to:

- identify the areas of high mineral development potential in the Slave Geological Province (SGP);
- map current mineral leases and mining claims in the SGP;
- map current and potential future mines and identify inferred and proven mineral resources

The original study area was, by mutual agreement of GNWT and Aurora, increased both in physical area (Figure 3), and, at least in a qualitative sense, the character and number of parameters to be considered. The key deliverable, however, remained constant: a map (or maps) showing potential road routes through the SGP, optimizing access to the highest value mineral showings and occurrences, which could connect the NWT highway system to the Lac de Gras area and to the proposed Izok Corridor Project. It was understood that the proposed road corridor options would be based on currently available mineral resource and geological information, and informed opinion and judgement of geoscientists.

The original project document requested Aurora to compile data, interpret the data and produce a set of "heat maps" of mineral potential and final report. Data to be compiled included indicators of mineral potential for:

- geology;
- mineral showings;
- occurrences and deposits, including any resource statements outlining inferred and proven resources (historic or current);
- past claim staking activity;
- historic assessment expenditures;
- mineral leases and mining claims.

In the current study, these indicators have all been considered except for historical assessment expenditures. This information was not specifically compiled because of: time limitations in gathering the dispersed data; difficulty in assigning dollar values on a per area unit basis (since exploration dollars are not typically spent uniformly across claims); and the fact that historic expenditures are generally captured in the level of exploration an area has seen, and thus reflected in the NORMIN and NUMIN database entries.

A few additional factors peripherally affecting mineral potential have been considered, as were a number of factors impacting road routing. These include:

- commodity and gross metal/mineral value in-place
- hydrography
- wetlands

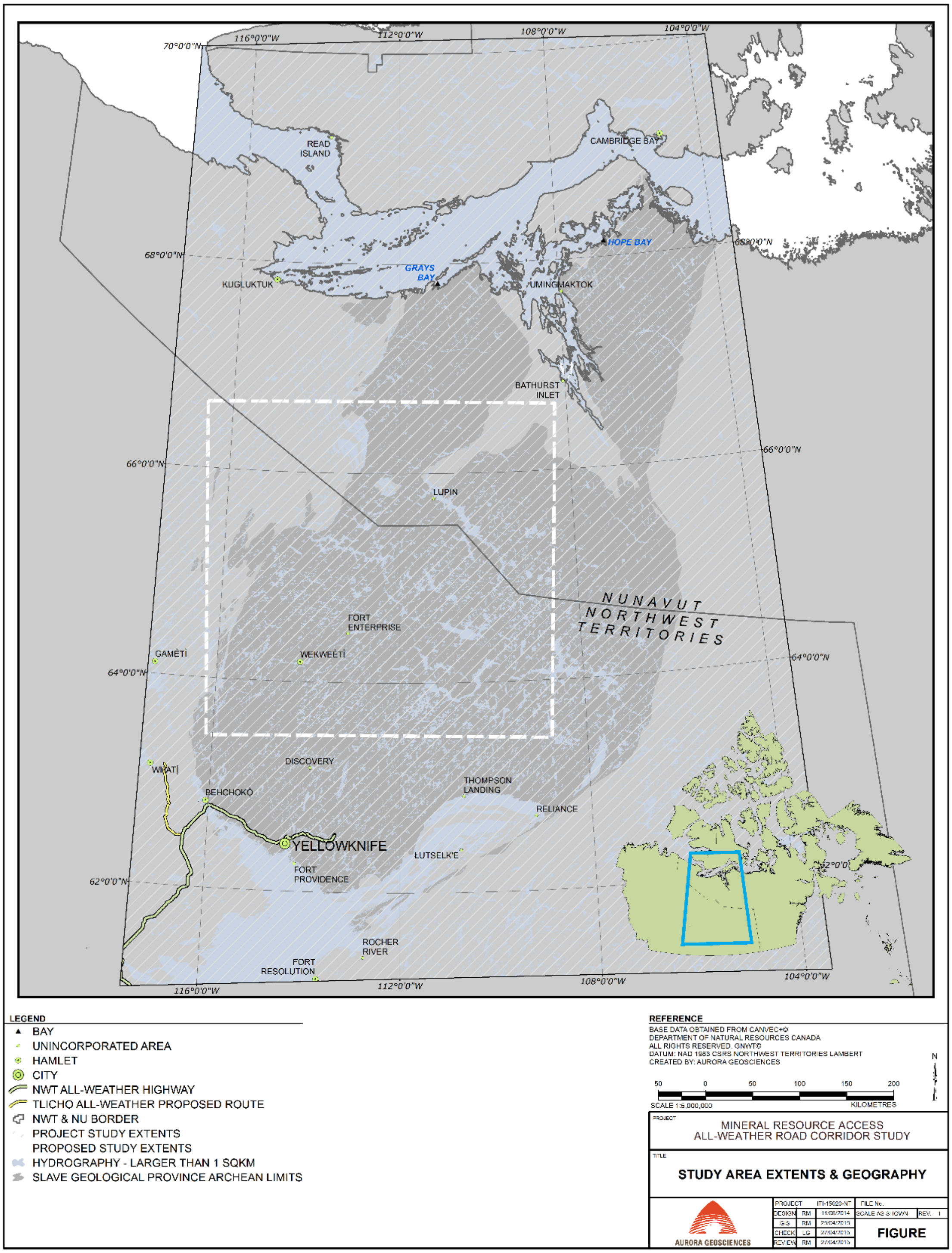

Figure 3. Project Study Area

Project study area (black box with hatching) and geographic features. The original proposed study area is in dashed white line. Grays Bay is the proposed terminus of the Izok Corridor Project. Other locations shown.

5. SLAVE GEOLOGICAL PROVINCE CORRIDOR STUDY

The project involves four phases: determine methodology, compile the needed and available data, interpret the data, report and present conclusions and recommendations.

6. Methodology

The project is a Geographic Information Systems (GIS) based analysis of data pertaining to mineral potential in the NWT and NU. The data lends itself to spatial analysis; particularly the two most important datasets in the desktop study of mineral potential: bedrock geology and the location and character of known mineral occurrences. Both of these digital datasets are available from the GNWT through the Northwest Territories Geological Survey (NTGS). Figure 4 shows a simplified version of the analytical hierarchic process (AHP).

Ranking schemes were developed for these datasets and other geological variables to create individual thematic criteria maps. The geological variables were then considered together, and through an analytical hierarchic process (AHP) the relative importance of each in indicating mineral potential was determined. From the ranking schemes of the individual variables, and their relative weighting determined by AHP, a map of interpreted mineral potential was created by a GIS analysis. Using the map of interpreted mineral potential, otherwise known as a suitability grid, a “cost-surface” raster was produced by taking the inverse of the input mineral potential map. The “cost-surface” raster was used as input in conjunction with the current NWT all-weather highway system, used as a source raster, to create a “cost-distance” raster. The “cost-distance” raster identifies, for each cell, the least accumulative cost distance over the input “cost-surface” raster to the NWT all-weather highway system. Since the “cost-surface” was created from the mineral potential raster the “cost-distance” values represent the interpreted accumulative “cost” with respect to the distance from the source, where higher values are of lower mineral potential and lower values are of higher mineral potential, and the values accumulate with distance away from the NWT all-weather highway system. As such, by selecting a destination it is possible to determine the “least-cost pathway” from the NWT all-weather highway system; meaning the pathway which travels through the areas of highest interpreted mineral potential.

Additional data such as surficial geology (including eskers), hydrography and wetlands, and wildlife areas do not have a direct bearing on the interpreted mineral potential, but they do have an influence on mineral exploration, and certainly on road routing decisions.

The negative factors affecting road routes including hydrography (major lakes and wetlands), were employed as exclusion zones in the GIS-generated road routing process.

Analytical Hierarchic Process (AHP)

Bedrock geology, mineral tenure, mineral occurrences, and faults were considered to be of primary importance in determining mineral potential in SGP. The datasets were evaluated through analytical hierarchic process (AHP). This is a common method to enable decisions where a wide variety of input factors, ranging from objective numbers to subjective judgements, are deemed to have some impact on the outcome. The basic method involves defining an objective (in this case, evaluate mineral potential), structure the elements (the four variables to be considered), perform a pairwise comparison, calculate weighting ratios, evaluate (through GIS analysis), and obtain rankings (high versus low mineral potential). The strength of AHP is that variables that are fundamentally different, and differently characterized (objectively known values versus subjective opinions) can still be evaluated relative to one another. The method relies on subjective decisions to make pairwise comparison, and these are converted to numerical values to enable computation.

A nine-level comparison scale was used to subjectively judge the relative merits (preference or importance for mineral potential) of one variable over another. Table 1 lists the comparator terms and numerical equivalents (after Nouri et al., 2013).

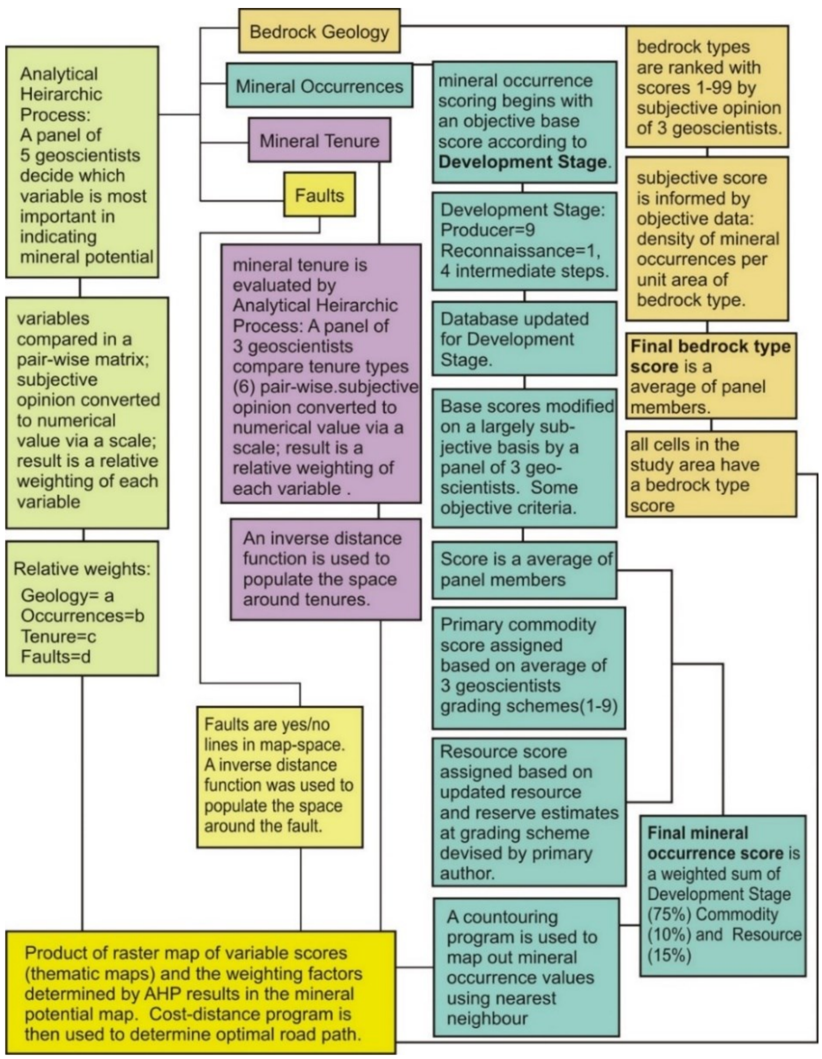

Figure 4. Map Process Flow-Chart

Simplified flow-chart of the process used to create thematic maps, starting with four datasets (variables) at top centre, and the product mineral potential maps at lower left.

General Comparator	Score
Equal	1
Slightly Better	2
Little Better	3
Moderately Better	4
Better	5
Quite a Bit Better	6
Much Better	7
Critically Better	8
Utterly Better	9

Table 1. Comparator Scale
Comparison scale used in Analytical Hierarchic Process (AHP) to evaluate variables in a pair-wise manner (after Nouri et al., 2013).

For example, if A is considered much better (or much more important) than B in determining mineral potential, A was given a score of 7 versus B. B would be score 1/7 versus A, and A would score 1 against itself, as per the example 2x2 matrix below:

Variable	A	B
A	1	7
B	1/7	1

Table 2. Example 2x2 Matrix
Example of a 2x2 pair-wise comparison matrix.

A panel of five geoscientists made pair-wise comparisons for bedrock geology, mineral tenure, mineral occurrences, and faults. Each pair was evaluated using a nine-level comparator scale (Table 1) that corresponded to a numerical score for the favoured variable, and its inverse for the less favourable variable. These paired values were used to populate a matrix, from which weighting ratios were calculated.

The study area was divided into cells, which held some score for each of the four variables based on the previously determined ranking schemes and GIS functions applied for each. The product of the cell score (for each variable according to the scoring schemes developed) and the weighting factors from AHP gave a resultant aggregate cell score. These aggregate scores were displayed using a “blue to red” colour scale based on the cell value, creating a heat map.

7. GIS ANALYSIS

The main deliverable of the study is a series of heat maps showing mineral potential based on the compiled data selected and analysed. The heat maps are raster figures with standardized values in a range from 0 – 255. The lower values, or scores, representing less mineral potential than higher values, or scores. These maps were based on a 100m by 100m cell size, to balance out required resolution with the limitations of the input data with respect to physical location uncertainties.

The four main variables used to evaluate mineral potential have different spatial attributes. The faults dataset consists of polyline features. Since the GIS analysis requires all of the cells in the study area to consist of a value, in order to create a suitability grid, the Euclidean Distance function was used to create a raster with cells consisting of values based on the relative distance from a fault zone. This distance function converted the vector polyline data into a raster format.

The mineral tenure consists of polygon features. A pair-wise comparison was used to rank the tenure types and create a weighting value for each. Since they do not fill the entire study area, a Euclidean Distance function was used to create a raster map illustrating distance from a tenure, weighted according to its type.

Bedrock geology data also consists of polygon features, but they fill the entire study area. That is, there is no cell within the study area that is not described by a bedrock type. In this case, the scored bedrock polygons (vector data) were converted directly to a raster format.

The mineral occurrences are point data which were given scores according to the methodology described under Section 10. An inverse distance weighting function was used to interpolate values between the mineral occurrences. Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance.

Pair-wise comparison of the four variables resulted in relative weightings, which were applied in the matrix summation to create the resultant suitability raster, or mineral potential heat-map (Figure 1). To create the optimized road path maps, the mineral potential data was inverted, and a cost-distance/cost-path function was used to create the path, taking into account the limited exclusion zones of hydrography and wetlands, through areas of highest mineral potential (Figure 2). The GIS workflow, showing input by the geoscientists and the resulting maps, is shown in simplified fashion in Figure 5 and in more detail in Appendix II.

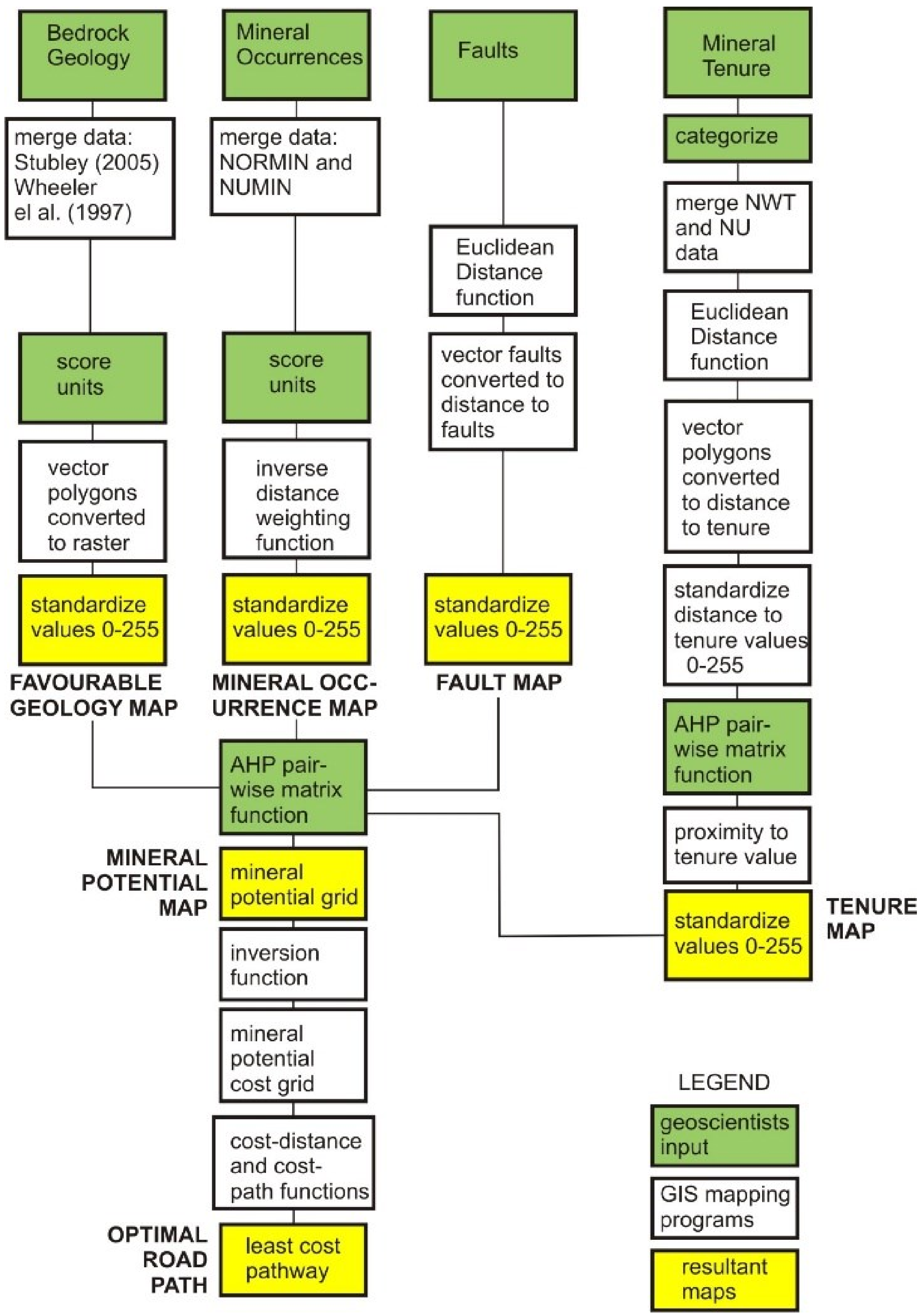

Figure 5. Simplified Workflow

Simplified workflow for GIS mapping project. The largely subjective input points from geoscientists are shown in green, including selection of the four variables. Output map products are indicated in yellow, and computerized GIS mapping processes in white. A more detailed version is in Appendix II.

In summary, for each variable dataset a scoring system and a mapping method was devised to give a numerical value in each cell of the study area for that variable. Numerical values were standardized to fall within a range of 0 – 255. Pair-wise comparison of the variables resulted in a relative weighting of variables for an aggregated mineral potential map. Exclusionary zones (wetlands, certain hydrological thresholds, etc.) were added after determination of mineral potential. The inverse of the mineral potential map was used to calculate the cost-distance raster and finally a least-cost-path raster. While the graphic results are based on numerical scores; these are built on a foundation of the subjective, knowledge-based judgements of a panel of geologists.

8. MAIN DATA SETS (VARIABLES)

Thematic maps were created through the evaluation of each variable according to some determined scoring scheme. Evaluations of the individual datasets were completed by a panel of knowledgeable geoscientists. Three to five panel members gave input into each scoring system, and ranked the dataset members.

The criteria considered for each variable dataset are outlined below:

Variable	Criteria	Number of Sub-Criteria
Bedrock Geology	Lithological Unit	64
Mineral Tenure	Tenure Type	6
Faults	Presence or Absence	2
Mineral Occurrences	Development Stage Resource-Reserve Commodity	7 Development Stages 6 Resource Estimate Levels 10 Commodity Classes

Table 3. Criteria Evaluation Variables
Variables considered in evaluating mineral potential, and the criteria and sub-criteria that characterize each.

For example, the bedrock geology dataset was evaluated by considering which bedrock types were generally more prospective for hosting mineral deposits. Each bedrock type was assigned a score, which was largely subjective, but was informed by some objective analysis. That is, the number of mineral occurrences per unit area of outcrop of a particular bedrock type (essentially the mineral occurrence density) as an indicator of the favourability of a particular bedrock unit. However, objective scores were not solely relied on in any evaluation, except for faults, because there are too many disparate sub-variables that affect the members of a given dataset, and these cannot be accounted for solely with objective scoring. This will be further discussed below.

9. COMPILATION, DATA EVALUATION AND INTERPRETATION

Data was collected from a number of datasets of varying vintage, scale, and quality, as summarized below. Once compiled, qualitative assessment of the values for each variable were made.

Dataset and Variable	Sources
NORMIN-NUMIN showings: Known mineral occurrences, development stage, commodity	GNWT NTGS Canada-Nunavut Geoscience Office Company websites, technical reports, news releases
Mineral deposit reserves and resources	Company websites, technical reports, news releases GNWT NTGS Canada-Nunavut Geoscience Office
Bedrock Geology, faults	Stubley (2005) – SGP compilation Wheeler et al. (1997) – Geology of Canada
Mineral Tenure: mining leases, claims, prospecting permits (current and lapsed), protected areas or reserves	GNWT Centre for Geomatics GNWT Environment and Natural Resources
Surficial Geology: surface geology units, eskers, wetlands	Fulton (1995) – Surficial Materials of Canada Government of Canada, NRCAN

Table 4. Sources of Data

Mineral Occurrences

As noted in the table above, the mineral occurrence data within the study area were obtained from the similarly constructed NORMIN database of the NWT (http://www.nwtgeoscience.ca/normin/), and the NUMIN database maintained by the Canada-Nunavut Geoscience Office (http://nunavutgeoscience.ca/pages/en/numin.html).

The mineral occurrence variable was the most complex data set to deal with, principally because it includes many sub-variables which can affect the perceived exploration favourability. In general, most geoscientists would consider a favourable indicator of mineral potential in a region to be in vicinity to a major deposit rather than minor occurrences, which in turn would be better than no known mineral occurrences.

In standard AHP, the sub-criteria of Mineral Occurrences could also be ranked by pair-wise comparison. However, with 2813 unique mineral occurrences in the study area, that would be unrealistic. However, the occurrences are ranked in the existing databases by an attribute called “Development Stage”, which is a grade based on amount and intensity of exploration and development. This attribute, as well as “Commodity”, and “Resources” lend themselves both to subjective and objective evaluation that could characterize a given mineral occurrence with a numerical score. It should be stated that the aim was not to characterize and grade an occurrence to reflect its own merit, but as an indicator of regional mineral potential.

Development Stage

Both NORMIN and NUMIN databases use the same terms and criteria for evaluating mineral occurrences based on the level of exploration, or Development Stage associated with each. The terms used range from “Reconnaissance” for the most poorly known and/or minor showings, through to “Producer” for active mines. The criteria for each term are listed below (source NORMIN, nwtgeoscience.ca). Table 5 lists the number of mineral occurrences in the study area at each Development Stage.

Development Stage	Number of occurrences	Percentage of total
Producer	5	0.1
Past Producer	53	1.9
Advanced Exploration	108	3.8
Drilled	730	26.0
Local Examination	862	30.7
Reconnaissance	1054	37.5
Total	2812	100

Table 5. Mineral Occurrences in Study Area
Number of each type of mineral occurrence in the study area.

- **Reconnaissance:** preliminary examination of an area has revealed a site of interest.
- **Local Examination:** sampling and ground investigations such as grid-based surveys have been carried out to further knowledge of the site. These may include trenching but not drilling.
- **Drilled:** the showing has been tested by at least one drill hole, not including small portable drill with small diameter core or holes less than three metres deep. Generally surface work has been done as well.
- **Advanced Exploration:** a deposit which is well understood in three dimensions. Generally this means enough work has been done on which to base resource calculations.
- **Producer:** a deposit which is currently being mined and producing a commodity.
- **Minor Producer:** a deposit which is currently being mined and producing a commodity, at rates of mining less than about 10,000 tonnes of ore per day.
- **Past Producer Abandoned, Past Producer Care and Maintenance, Past Producer Renewed Exploration**: a deposit which at one or more times was producing a commodity but is no longer. A Past Producer may be an abandoned mine, it may be on care and maintenance, or there may be renewed exploration for the same or different commodities in the vicinity. If a deposit cycles in and out of production over the years, its Development Stage in the database will be updated as its status changes.
- **Minor Past Producer Abandoned, Minor Past Producer Care and Maintenance, Minor Past Producer Renewed Exploration:** a past producer which produced <100,000 tonnes of ore.

While it would have been possible to evaluate each of the six Development Stages by pair-wise comparison, and thereby arrive at a relative weighting for each occurrence, we felt this level of differentiation did not have sufficient resolution. Therefore, a scoring system was devised to rank the mineral occurrences, to account for the variation between occurrences with the same Development Stage. Development Stage was used as the criteria to assign a base score, on a scale from 1 to 9, as shown in Table 6.

Development Stage	Base Score
Producer	9
Past Producer	8
Advanced Exploration	7
Drilled	5
Local Examination	3
Reconnaissance	1

Table 6. NORMIN/NUMIN Base Scores

Base score applied to each mineral occurrence in the study area by Development Stage

The higher scores indicate a generally more favourable indicator for mineral potential. Note that there is a gap in the base scores between “Drilled” and “Advanced Exploration” because the criteria indicate a significant advance in the development of a deposit. While the main criteria for “Drilled” is that there be at least one core test of the occurrence at depth; for “Advanced Exploration”, the deposit must be “well understood in three dimensions”. This generally requires considerable drilling and advanced geophysical surveys. Similarly there is a gap between “Reconnaissance”, which may be used for a single anomalous rock sample; and “Local Examination”, which generally involves some local grid-based surveys, and may include surface trenching.

While this method follows a common–sense gradation of increased score with increased advancement of the understanding and development of a deposit, there is an obvious shortcoming. Specifically, the “Advanced Exploration” stage includes a number of deposits that are currently moving toward a production decision, and are very large with some long planned mine lives. From the perspective of a road building project, it is these occurrences that should have arguably the greatest influence on road routing. However, there is a considerable range in the character of “Advanced Exploration” occurrences in the databases. Thus, rather than increase the base score of all “Advanced Exploration” members, they were considered on a case-by-case basis.

The upper categories of mineral occurrences, from “Producer” to “Drilled”, were reviewed in some detail. The summary description of each in the NORMIN-NUMIN databases was reviewed, and in some cases, supporting documents such as Assessment Reports were checked. With the more advanced, and currently active exploration or production sites, the operating company websites were reviewed for more up-to-date information than contained in NORMIN-NUMIN. The base scores were adjusted, if necessary, based on objective criteria as well as subjective judgment. These considerations are summarized in Figure 6 and further discussed below, for each Development Stage.

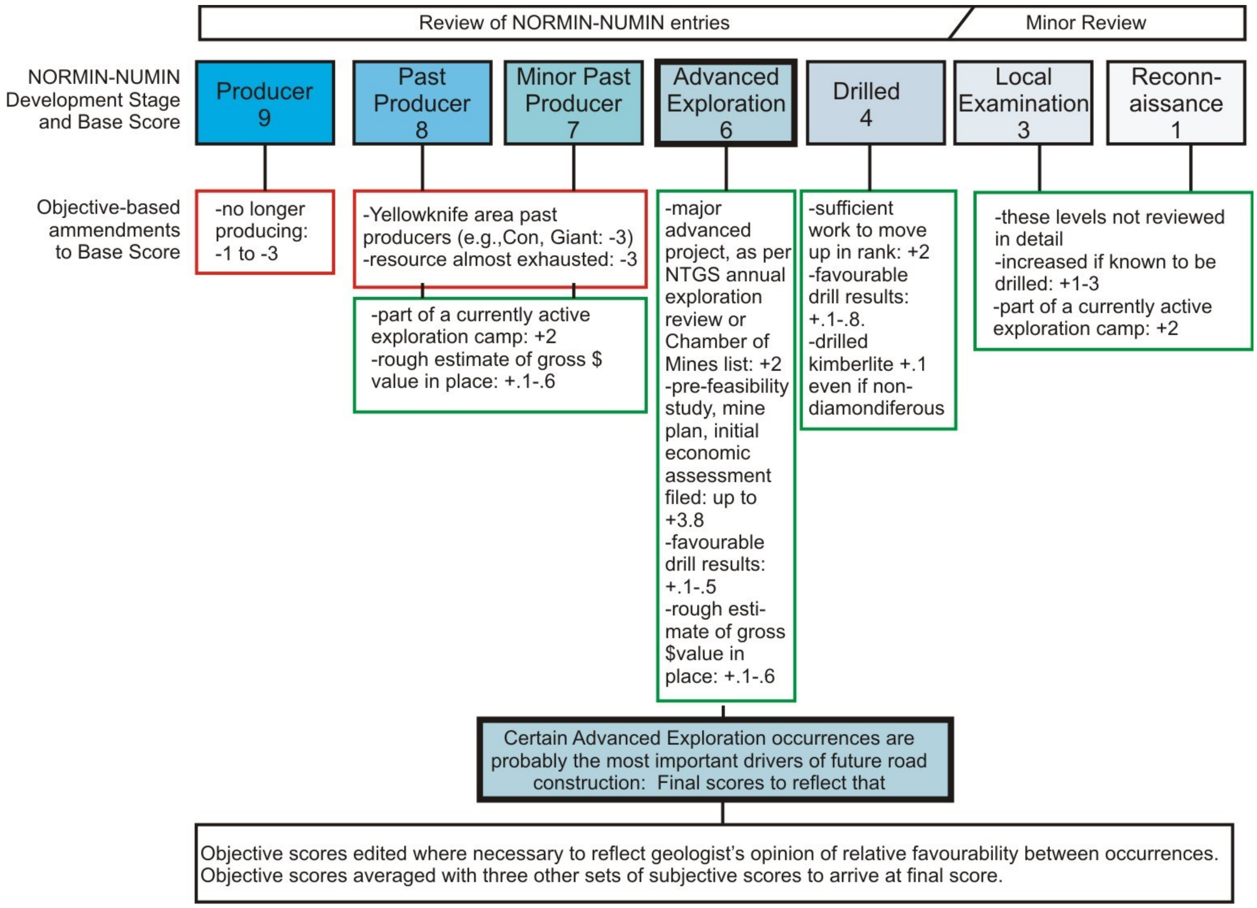

Figure 6. Factors Affecting Scoring of NORMIN-NUMIN Database members

Graphical representation of the factors affecting objective and subjective scoring of Development Stage of NORMIN-NUMIN mineral occurrences.

Producer

- Some producers (designated at the time of their entry into NORMIN/NUMIN) are no longer producing, these were marked down to the level of Past-Producer. An example is the Beartooth pit of the Ekati Mine (NORMIN # 076DNE0051) which was exhausted of ore and has of late been used to store waste rock (Carlson et al., 2015).
- Some producers have a planned or estimated finite life, with production scheduled to conclude in the next 7-10 years. That is, the value of a Producing Mine falls off as it nears the end of its life span. An example is the Diavik Mine (NORMIN # 076DNE0036, 40, 44), where production is scheduled to continue until 2022 (Yip, 2008). This should be considered in the context of road construction.
- The value of estimated resources of some producing mines are far less than other projects which may be at an Advanced Exploration Stage. Depending on how advanced these latter projects are, and the expectation that they will become a mine, their scores should reasonably be higher than the Producing Mine. This is a case where the base score might be revised due to

subjective opinion. An example is the Courageous Lake project of Seabridge Gold Inc. (NORMIN # 076DSW0003) with an estimated gold resource worth roughly 10 billion dollars at $1200 per ounce gold (Seabridge Gold website; www.seabridgegold.net).

Past Producer

- Some past producers are essentially mined out, with no resources remaining (e.g., a couple of the Ekati Mine open pits). However, other past producers have considerable delineated resources remaining, but mining was stopped for economic or other reasons. This is a fundamental difference in the overall mineral potential, and the raw score was adjusted, by subjective judgement, to reflect this. That said, the value of a past producer to *the mineral potential of a region* remains relatively constant, whether or not that resource has been mined out.
- Past-Producers vary widely in the amount and value of ore produced. In the NWT there are several small gold mines that produced only a few tonnes of high-grade ore in the 1950-70s, these should not be considered higher value than currently active projects that have outlined large tonnages of ore, but have not yet moved into production (see "Advanced Exploration" below).
- Several past-producers, particularly in NWT, became part of the Northern Contaminants Program (NCP) of the Federal Government (http://www.science.gc.ca). The sites came under control of the Crown and were/are essentially alienated from exploration/exploitation during the evaluation and remediation stages. However, while the site itself is alienated, its presence, and contribution to the mineral potential of the region remains.
- In some cases NCP sites have been remediated, and the mining leases transferred back to an exploration company. Such is the case for the Colomac Mine, an open-pit past producer (NORMIN # 086BSW0004). Remediation and reclamation occurred at the site, and subsequently the ground was transferred to Nitehawk Gold Corp., which is examining a substantial gold resource with underground mining potential (Trinder, 2013).
- Past mines in the immediate Yellowknife area (Giant, Con, and associated occurrences) were reduced in raw score (by 3 points) because they were judged to be unlikely to begin renewed production (particularly the former Giant mine given its ongoing remediation and maintenance). In any case, these occurrences are already generally road accessible and would not affect the current study.

Advanced Exploration

- As noted above, this category includes several projects that are undergoing current exploration, have had feasibility studies or preliminary economic assessments, and have mine plans that feature large resources and long planned mine lives (e.g., Glencore's Hackett River project, NUMIN # 076FNE0001). Such projects should be considered more important than most Past Producers, and in fact it is these projects that should be considered paramount in determining a road route. As such their score was increased, subjectively (up to +3.8 points).
- Others in this category may have had considerable exploration effort, and significant monies spent, that did not outline any significant resource and were then just abandoned, found to be

unfeasible from an economic standpoint, or the operating company simply changed their exploration focus.

Drilled

- This category can indicate a wide range of mineral potential, in part because the results of diamond drilling can either enhance a project (by discovering more subsurface ore) or condemn it (by failing to find subsurface continuation of mineralization found at the surface). In addition, the amount of exploration by drilling varies considerably within this category (from a minimum of a single drill hole). Database entries where the existence of drilling was merely confirmed, or the drilled intercepts were unknown or judged to be weak, were left at the base score.
- Although it can be argued that a location with a single negative drill hole is actually a poorer exploration target that an area with some of positive surface work (i.e., Local Examination level) and the base score may thus be overly high; the reality is that there are too many other factors to consider beyond the scope of this study (e.g., was the drill hole hampered by technical difficulties, simply oriented the wrong way, mis-sampled, etc.). This prevented us from making too fine a judgement at this level, and it must then suffice for our purpose to consider that the prospect is drilled for some reason of explorative attraction, and can be rated higher than a location with just surface work done.
- An exception to the base 4.0 score outlined above was for kimberlite targets: If kimberlite was intersected, a score of 4.1 was assigned, even if sampling showed the kimberlite to be barren or insufficiently diamondiferous. This is because the kimberlites tend to occur in clusters, so merely the presence of kimberlite is positive in a given area to outline a kimberlite field. Questions regarding sample size, and methods employed to judge whether a kimberlite was sufficiently diamondiferous, are beyond the scope of this report. Kimberlites with positive sampling values, i.e., a high number of diamonds in the sample, strong estimates of carat per tonne grades or valuations per carat, were given higher scores (+.2-+.5 points). This scoring was subjective.
- Drilled locations with marginal or strong ore intercepts listed in the NORMIN-NUMIN summary were judged subjectively, based on whether they occurred in advanced exploration or production areas, whether there were multiple good drill intersections, how much drilling was done overall, whether the corresponding surface sampling was encouraging, etc. The addition to the base score of +.2 - +.5 was subjective. An exhaustive review of all drill results was not carried out.
- Some locations were moved up to Advanced Exploration (+2 points) due to increased drilling and other exploration work in recent years. An example is Mountain Lake deposit (NORMIN # 086NSE0122).

Local Examination and Reconnaissance

- These levels were mostly left at their base scores. A thorough review of these lower level database entries was not performed, chiefly due to the time constraints in the scope of the project. However, some entries were subjectively scored higher by the judgement of the panel, who had knowledge of that particular occurrence. For instance, where it was known that drilling had occurred at a particular location, that NORMIN-NUMIN entry was bumped up to Drilled Stage.

The adjusted score was further refined in some cases, generally for projects at Advanced Exploration projects and above. These results were averaged with three other reviewing geoscientists, who made their own, subjective amendments to the base score. The average of the four scores was then used to characterize Development Stage (after discussions to eliminate some outlier values).

Commodity

The commodity was obtained from the NORMIN and NUMIN databases. For this study, only the primary commodity was considered, although for many NORMIN-NUMIN entries, several commodities may be listed together. In reality, many mineral deposits feature a suite of metals or minerals that are typical of the type of deposit in which they occur. For example; volcanic-hosted massive sulphide deposits commonly contain a copper-zinc-gold-silver assemblage, or a zinc-lead-silver assemblage. Lithium-bearing pegmatite may also have tantalum, niobium, and beryllium.

Only primary commodities listed in NORMIN-NUMIN were considered, although there is a possibility of other commodities being present. Gold (41.3%) and copper (22.8%) made up the majority of primary commodities listed for the study area. Diamond or kimberlite accounted for about 6% of occurrences.

Commodities were scored as shown in the table below. This score was meant to reflect the higher value of certain commodities like precious metals or diamonds, and lower values of certain bulk commodities or those minerals now considered deleterious (e.g., asbestos). The commodity scores were an average of three reviewing geoscientists. Several hundred entries in NORMIN-NUMIN did not list a primary commodity, these were determined by review of the supporting documentation for those entries.

It should be noted that the commodity will have a great bearing on road use during the production stage of a mine. Certain commodities, such as diamonds, are produced on site in largely mechanical separation plants, and the production can be flown out on a regular basis. This is the same for precious metal mines that produce dorė bars at the mine, rather than a gold concentrate. Base metal mines generally have a mill on site that produces concentrate to be shipped to a smelter. Industrial minerals and building stone are also shipped with minimal processing that does little to reduce weight and volume of the commodity. Therefore base metal mines, industrial minerals, and some precious metal mines shipping a concentrate, will exert the heaviest demand on roads in the production stage. Actual projected shipping tonnages are beyond the scope of this report, but can be grossly estimated from resource and grade estimates from base metal deposits (Appendices 8 and 9), after making further estimates of metal recoveries and the composition of concentrates.

Primary Commodity (first listed in NORMIN-NUMIN)	Score
Diamond, kimberlite	8.7
Gold, silver, platinum, palladium	8.3
Base metals (zinc, copper, lead, molybdenum	7.3
Base metals (cobalt, nickel, tungsten, tin)	7.3
Strategic metals (Nb, Ta, REE, U, Th, Li, Be)	6
Base metals (titanium, iron, vanadium, chromium, manganese, sulphide, sulfur)	5.7
Gems, semi-precious stones (amethyst, beryl, cordierite)	4
Building stone	3.3
Industrial minerals (barium, fluorite)	3.3
Carving stone, Exotic stone	3
Industrial minerals (asbestos)	2

Table 7. Scoring of Primary mineral commodities

Primary commodities from NORMIN-NUMIN database, with assigned score.

Reserves-Resources

As established by NORMIN-NUMIN guidelines, only occurrences that are rated Advanced Exploration or higher have resource estimates. In this study, we considered National Instrument 43-101-compliant resource or reserve estimates (http://web.cim.org/standards/) as well as non-compliant, outdated or rough estimates of resources. The former were obtained from searching the websites of the operating companies for technical reports or news releases with current estimates, while the latter were taken from the NORMIN-NUMIN databases. A score was assigned based on the level of confidence of the estimate, as this generally reflects a greater amount of exploration work (particularly drilling). The score was not given on the base of the size of the resource (see below). A single score was given per mineral occurrence where an estimate was recorded, based on the highest confidence level attained in the resource estimate (as resource estimates typically include several levels of confidence).

Resource or reserve	Score
Proven Reserve	9
Probable Reserve	8
Measured Resource	6
Indicated Resource	5
Inferred Resource	5
Non 43-101 compliant estimates	2
No estimates	0

Table 8. Scoring of Mineral Resources

Resources or reserves from company websites, or NORMIN-NUMIN database, with assigned score.

Value of Resource

A rough estimate of the value of metals (or minerals) in-place, was made for occurrences which had an associated resource estimate (including non-43-101 compliant); by combining estimated resources tonnages, estimated grades and rough but conservative commodity prices. These rough valuations were awarded points, as per the table below, and added to the objective Development Stage score (before averaging all three geoscientist's scores). These figures are in no way meant to represent actual valuations of any projects, but to broadly illustrate their relative attractiveness, from an exploration, rather than a development standpoint. Several of the Advanced Exploration sites increased in their score, to better reflect the intuitively obvious advantage of these over some of the lesser Past Producers.

A map graphically illustrating the coarse value of resource-in-place is shown in Figure 7. A digital file, in Excel spreadsheet format (.xls), included as Appendix III tabulates the resource estimates and grades.

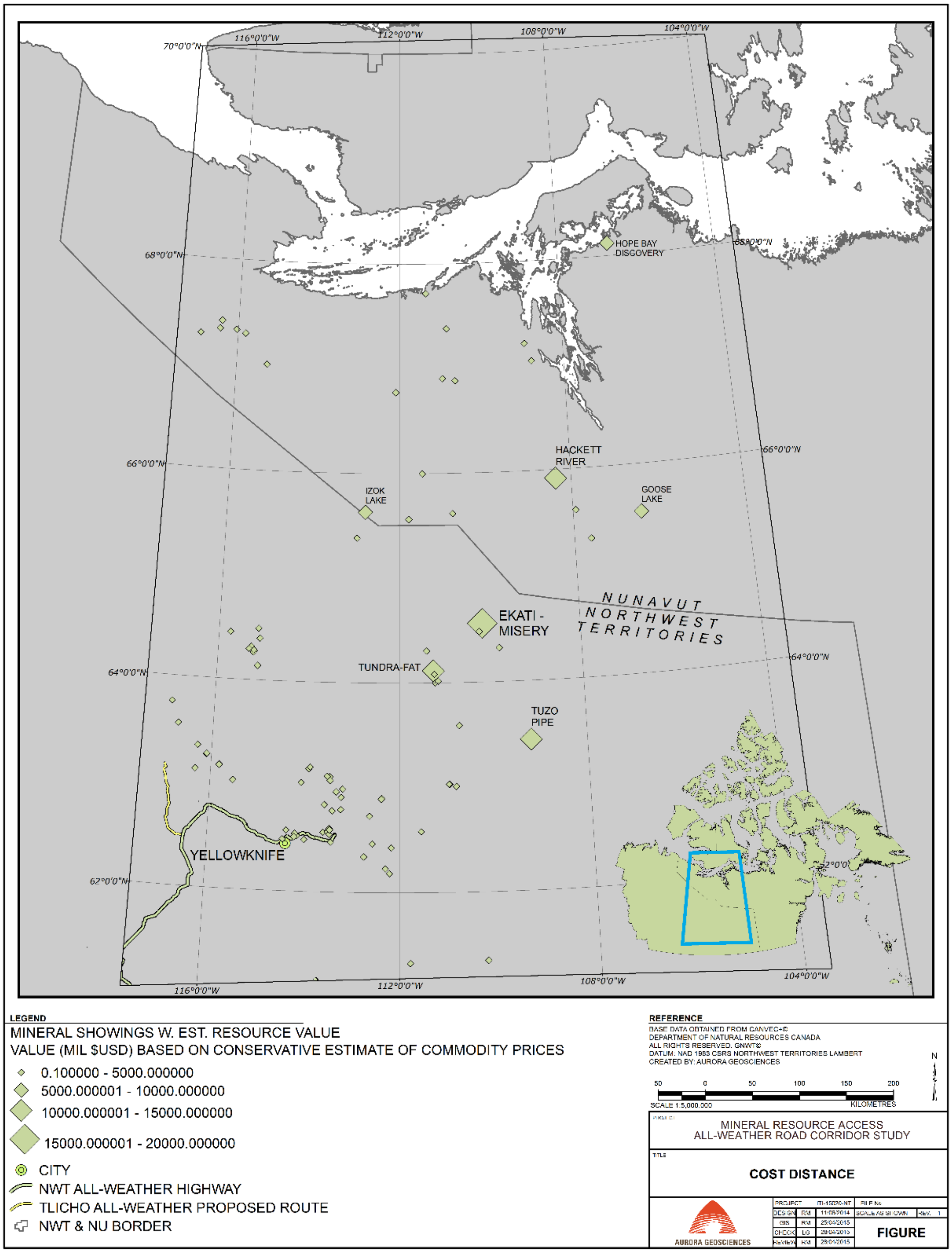

Figure 7. Mineral Occurrences with Resource Value Estimates

Map of the study area with mineral occurrences that have NI 43-101 compliant or historical resource estimates associated. Some of the major occurrences are labelled. The symbols are proportional to the calculated value of gross metal (or mineral) resource in place. See also Appendix III and Table 9.

Value of resource: gross metals/minerals in place ($US)	Extra score added to Development Stage	Number of mineral occurrences represented
>10 billion	.6	4
5-9.99 billion	.5	3
1-4.99 billion	.3	7
500-999 million	.2	6
100-499 million	.1	16
10-99.99 million	0	29
<9.99 million	0	16

Table 9. Scoring of Mineral Occurrences with Resource Estimates

For those mineral occurrences with resource estimates (including non 43-101 compliant), extra points were awarded to the objectively scored Development Stage. Points awarded by resource values based on gross metals/minerals in place; a product of tonnage, grade, and commodity price. Commodity prices used were: gold $1200/ounce; silver $15/ounce, copper $2.50/pound, zinc $0.90/pound, lead $0.80 per pound. Diamonds were valued as per published, per carat valuations (conservatively when ranges were quoted). Additional commodity prices noted in Appendix III.

Mineral Occurrence Scoring

The Development Stage, Commodity, and Resource-Reserve components are inter-related, in that every entry in the NORMIN-NUMIN databases is at some Development Stage, for which there is a corresponding Commodity; and every Resource-Reserve entry has a corresponding Development Stage.

Because of this inter-relation, the three components are more logically summed than compared against each other in a pair-wise matrix. However, some weighting scheme is desirable, because the Development Stage is considered most important in evaluating an <u>area's mineral potential</u> (rather than an individual deposit's value). Secondary considerations (assuming an unbiased explorer) are Reserve-Resource (because it indicates something is there in measureable quantities), then finally Commodity. The table below gives a weighting factor used to arrive at an aggregate NORMIN-NUMIN score for each mineral occurrence:

NORMIN-NUMIN Sub-variable	Weighting Factor
Development Stage	.75
Commodity	.10
Reserves/Resources	.15
Total	1.0

Table 10. Weighting Factors for NORMIN-NUMIN Criteria

Weighting factors used to arrive at a NORMIN-NUMIN aggregate score to characterize each mineral occurrence in the study area.

Mineral occurrences in the study area with scores are included in a digital (.xls) file accompanying this report (Appendix IV).

Mineral occurrence locations are point data, so an inverse-distance function was used around each location to interpolate the data throughout the study area. It resulted in a zone of influence around each point. This zone of influence has a basis in geological reality because: a) each mineral occurrence has some associated area of exploration and development; b) there is some error attached to most of the locations (in many cases +/- 500 m, particularly for the Reconnaissance and Local Examination level occurrences); and c) it is reasonable to assume some physical attribute of the occurrence, such as alteration, that can be described as a surrounding zone of influence around an occurrence. The mineral occurrence thematic map is presented as Figure 8.

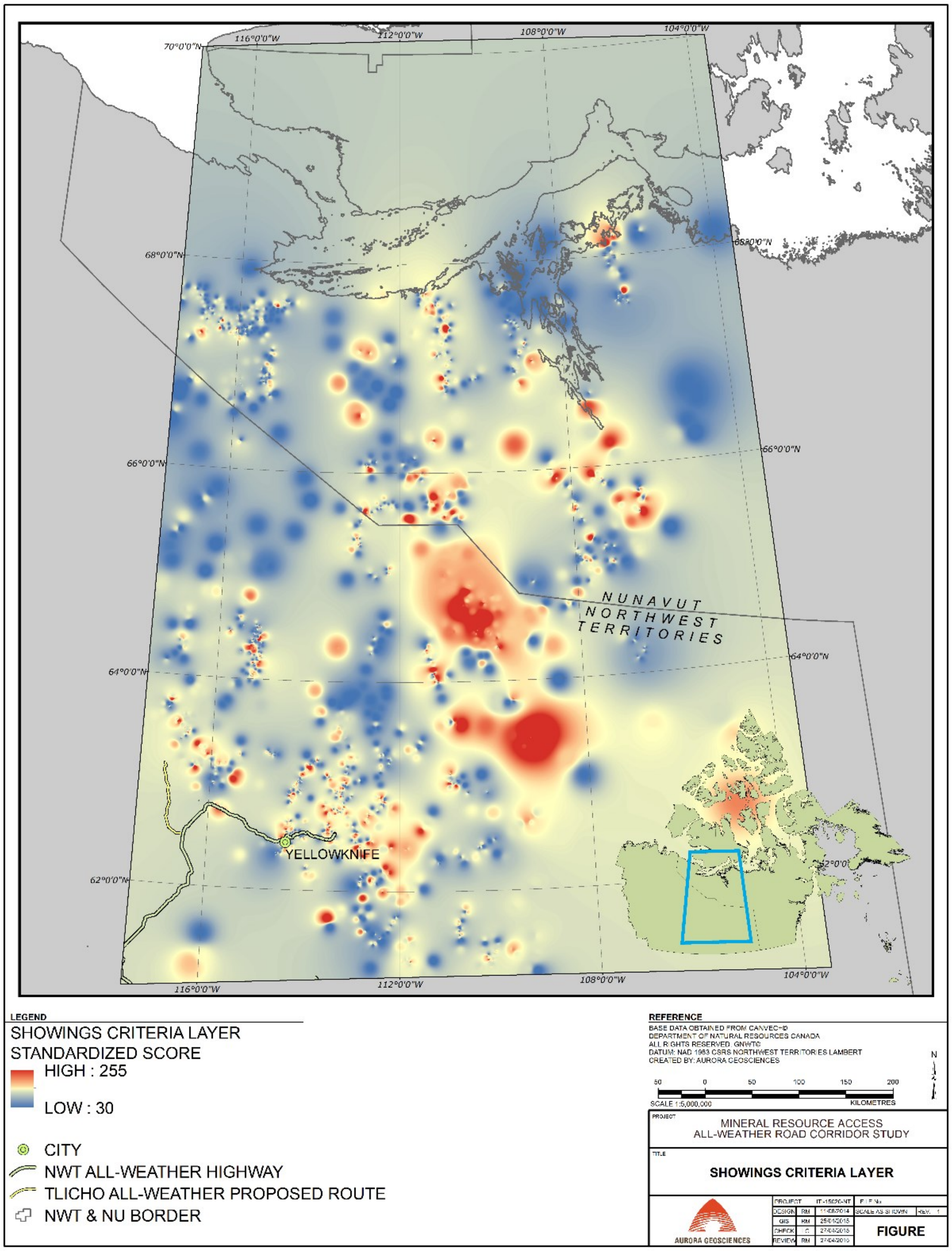

Figure 8. Mineral Occurrence Criteria Layer Heat Map

Inverse-distance function raster heat map of scored mineral occurrences. Scores were standardized to a maximum of 255. The large "hot areas" around Lac de Gras, and to the south around the Gacho Kue deposits are partly a function of those occurrences being surrounded by so few other occurrences. In contrast, many of the occurrences north of Yellowknife and in the Lupin area show as small "hot areas" because they are constrained by several neighbouring, but lesser scoring, occurrences.

Bedrock Geology

The second variable to be considered in the mineral potential map was bedrock geology. The geology map data are polygons, in contrast to the point data of mineral occurrences; therefore, every cell location had some associated value for geology. The geology polygons were obtained from the Slave Province digital geology compilation (Stubley, 2005). For the parts of the study area not covered by the Slave Province digital map, the coarse scale (1:2 000 000) digital geology of Canada (Wheeler et al., 1997) was used.

Each bedrock unit that occurred in the study area was assigned a score on a scale from 1-99; 99 being the most favourable, or relatively prospective for mineral occurrences. Three geoscientists ranked the bedrock units, Table 11 lists the bedrock units and averaged score. Because the two different source maps had different legends to describe the rock units, there are some apparent discrepancies in bedrock unit scores across the source map boundaries.

Bedrock Geology Unit	**Score**
Volcanic rocks - felsic to intermediate lavas, volcaniclastics, & related intrusions; local carbonate interbeds	94.3
Volcanic rocks - mafic to intermediate lavas, volcaniclastics, & related intrusions	92.7
Paleoproterozoic volcanic rocks	*92.0*
Archean volcanic rocks	*90.0*
Volcanic rocks - heterogeneous interlayered felsic to mafic lavas, volcaniclastics, & related intrusions	82.7
Mesoproterozoic volcanic rocks	80.0
Volcaniclastic rocks - unsubdivided	74.3
Basement - cover sequence (quartzite, BIF, ultramafic intrusions, felsic-intermediate volcanic rocks, conglomerate)	68.3
Turbiditic wacke to mudstone - medium grade; knotted schists (andalusite +/or cordierite porphyroblasts); includes areas of Unit Aam	65.7
Mafic and ultramafic intrusions (gabbro, pyroxenite, peridotite etc.); commonly enhanced magnetic signature	61.0
Carbonatite-bearing syenite-dominated alkaline complexes (ca. 2606 - 2592 Ma)	58.3
Postvolcanic (or uncertain aged) mafic / ultramafic intrusions (gabbro, peridotite, pyroxenite, diorite)	57.7
Archean-Paleoproterozoic sedimentary rocks	57.0
Archean-Paleoproterozoic sedimentary and volcanic rocks	57.0
Argillite - metasedimentary rocks dominated by thinly bedded siltstone and mudstone; biotite or sub-biotite metamorphic grade	56.7
Turbiditic wacke to mudstone - low grade (biotite- or sub-biotite - grade); includes areas of Unit Aal	56.7
Mafic intrusions (gabbro, anorthosite, diorite) associated with volcanic rocks; various ages represented but most assumed to be 'synvolcanic'	56.7

Archean-Proterozoic sedimentary rocks	55.0
Paleoproterozoic sedimentary rocks	55.0
Paleoproterozoic metamorphic rocks	55.0
Paleoproterozoic-Mesoproterozoic sedimentary rocks	55.0
Argillite - metasedimentary rocks dominated by thinly bedded siltstone and mudstone; medium grade with andalusite +/or cordierite	52.3
Unsubdivided Meso- and Neoproterozoic cover rocks	50.7
Archean sedimentary rocks	50.0
Paleoproterozoic volcanic rocks - unsubdivided	49.0
Conglomerate + arenite + siltstone clastic sequence (mostly <2605 Ma)	48.3
Turbiditic wacke to mudstone - high grade to migmatitic (sillimanite-grade +/or anatectic melt phases)	48.3
Mesoproterozoic sedimentary rocks	48.0
Mesoproterozoic-Neoproterozoic sedimentary rocks	48.0
Miscellaneous metasedimentary rocks; includes quartz-biotite schist, migmatite/paragneiss, argillite/slate, BIF, carbonate, conglomerate, chert	44.0
Turbiditic wacke to mudstone - upper-amphib to granulite grade (locally opx-bearing; common garnet-cordierite-Kspar assemblages)	43.3
Felsic to intermediate composite intrusions (granite, granodiorite, tonalite, +/- diorite) with an "early" or synvolcanic (ca. 2700 - 2650 Ma) component	40.7
Alkaline complex (syenite, gabbro, granitoids, etc.); mostly ca. 2190 - 2023 Ma	40.0
Unsubdivided Paleozoic carbonate & siliciclastic cover rocks	40.0
Granitoids - 2-mica or K-feldspar megacrystic, pegmatite; mostly syn- to post-kinematic (ca. 2605 - 2580 Ma); enhanced magnetic signature	40.0
Granitoids - 2-mica or K-feldspar megacrystic, pegmatite; mostly syn- to post-kinematic (ca. 2605 - 2580 Ma); includes Unit Agkm	40.0
Paragneiss/migmatite (primarily non-turbiditic) or "straight gneiss"; in part Ca- and Fe-rich, with BIF	36.7
Biotite +/- hornblende rich granitoids, mostly pre- to syn-kinematic (ca. 2625 - 2590 Ma); includes Unit Agbm	35.7
Alkaline-mafic intrusions - mostly unfoliated hornblende-bearing syenogranite, syenite, gabbro, quartz monzonite	35.0
Diorite, quartz diorite, tonalite, granodiorite, gabbro (mostly 2630 - 2605 Ma)	35.0
Granitoids of uncertain age; variably foliated; local breccia	34.3
Paleoproterozoic shelf (+/- rift) facies dominated by carbonate rocks (dolomite, dololutite, stromatolites)	34.0
Paleoproterozoic granitoid intrusions - unsubdivided	32.3
Paleoproterozoic foredeep facies; primarily greywacke and pelite (turbidites)	31.3
Diabase/gabbro sills and dykes; various ages	31.0
Mesoproterozoic intrusive rocks	30.0
Archean intrusive rocks	30.0
Archean-Paleoproterozoic intrusive rocks	30.0
Granitoids - unsubdivided; includes intrusions with minimal published descriptions or which are not characteristic of other subdivisions	29.3

Unsubdivided supracrustal rocks - primarily mixed amphibolites and metasedimentary migmatites	29.0
Biotite +/- hornblende rich granitoids, mostly pre- to syn-kinematic (ca. 2625 - 2590 Ma); enhanced magnetic signature	29.0
Granitoids with abundant supracrustal/gabbro/gneiss xenoliths	27.7
K-feldspar porphyritic granite to granodiorite; local rapakivi texture; strongly deformed to augen gneiss (in part, ca. 2617 & 2641 Ma)	26.7
Neoproterozoic intrusive rocks	25.0
Paleoproterozoic intrusive rocks	25.0
Archean-Paleoproterozoic metamorphic rocks	25.0
Paleoproterozoic shelf/alluvial (+/- rift) facies dominated by argillite, quartzite & conglomerate with lesser carbonate rocks	24.7
Tectonite/mylonite derived from various Proterozoic and/or Archean protoliths	24.0
Unsubdivided Proterozoic (+/- Archean) gabbro, granitoids, sedimentary and volcanic rocks; mixed-aged rocks in principal tectonic zones	23.7
Gneiss & granitoid complex - heterogeneous; in part, with demonstrated or assumed "basement" (>2.8 Ga) components	21.7
Gneiss & granitoid complex - heterogeneous and unsubdivided; massive to migmatitic and gneissic granitoids; various ages represented	21.7
Archean metamorphic rocks	20.0
Biotite- or hornblende-bearing quartzofeldspathic gneisses, amphibolite; heterogeneous; uncertain ages	19.0
Paleozoic sedimentary rocks	18.0

Table 11. Bedrock Geology Unit Scores

Bedrock units and scores within the study area. The units are from Stubley (2005; his map attribute "Legend"), and those in italics from Wheeler et al. (1997; their map attribute "AGERXTP"). Note that the Wheeler et al. (1997) map is more general in nature. Stubley (2005) was more detailed and specific in his delineation of units, so that there are fewer broad categories.

This ranking was subjective, based on the geologist's knowledge of mineral deposits and opinion of which rock types were most likely to host economic deposits. Generally, the volcanic (greenstone) belts of the Slave Province are deemed most favourable, as they are known to host both gold and volcanic-hosted massive sulphide (VHMS) deposits. The (meta-) sedimentary turbidite units host a number of gold deposits, both in quartz veins and banded iron formation (BIF). The basement gneiss complexes, certain plutonic suites and some Paleozoic sedimentary rocks (outside of the SGP) were considered the poorest potential hosts for mineral deposits.

Ranking of the bedrock geology units is probably the most subjective of the four main variables, and is most dependent on the panel member's experiences, perceptions, and biases. For example, anecdotal comments from one geoscientist (not a panel member) indicate that the relatively low rating of the granitoid rocks is perhaps unfair, and more a function of the relatively low amount of exploration these rocks have received to date. An increased number of geoscientists to grade the bedrock units would probably be helpful in arriving at the better scores, but we feel these are reasonable.

There is a large amount of recent research concerning the tectonics and geological evolution of the SGP. A review of the literature, and especially of metallogenic studies of SGP is beyond the scope of this project, but it would certainly help with the bedrock unit scoring. Comprehensive metallogenic reviews of the entire SGP are not known to the authors, but Padgham and Fyson (1992) provide an overview and Bleeker and Hall (2007) discuss some of the more favourable Slave Province lithologies. The Neoarchean (2800-2600 Ma) is recognized as a strong period of metallogenesis, while the Mesoproterozoic (1600-800 Ma) is noted to be poorly endowed with mineralization. (R. Hrkac, pers. comm.)

Padgham and Fyson (1992) note that the SGP comprises about 33% supracrustals (the favourable volcanic belts and (meta-) sediments). Of this total, 73% are greywacke-mudstone assemblages (the meta-sediments) and 27% are volcanic rocks (the greenstone belts). Therefore the most favoured greenstone belts underlie about 9% of the study area.

As a way to increase confidence in the subjective scores, the number of mineral occurrences per unit area of a bedrock type were calculated. This is essentially a calculation of mineral occurrence density. However, it must be cautioned that a major factor in density values is the overall level of exploration an area has seen to date, a large part of which is due to relative accessibility.

A tabulation of some of some major bedrock types, with over 100 known occurrences each, are presented below:

Bedrock lithology (with score from Table 11)	General Rock Type	Number of NORMIN-NUMIN occurrences*	Number of occurrences Per 10x10 km area*
Volcanic rocks-mafic to intermediate (score 92.7)	Supracrustal volcanic	468 (466)	0.77 (0.77)
Turbiditic wacke to mudstone-medium grade (score 65.7)	Supracrustal sedimentary	447 (433)	0.04 (0.04)
Turbiditic wacke to mudstone-low grade (score 56.7)	Supracrustal sedimentary	406 (402)	0.06 (0.06)
Volcanic rocks-felsic to intermediate (score 94.3)	Supracrustal volcanic	178 (178)	2.88 (2.88)
Mesoproterozoic volcanic rocks (score 80.0)	Supracrustal volcanic	174 (174)	0.03 (0.03)
Paleoproterozoic sedimentary rocks (score 55.0)	Supracrustal sedimentary	144 (144)	0.05 (0.05)
Granitoids- mostly pre- to syn-kinematic (ca. 2625-2590 Ma) (score 35.7)	Granitoid intrusion	116 (90)	0.06 (0.04)
Granitoids- mostly syn- to post-kinematic (ca. 2605-2580 Ma) (score 40.0)	Granitoid intrusion	110 (73)	0.04 (0.03)
Paleoproterozoic intrusive rocks (score 25.0)	Granitoid intrusion	110 (110)	0.01 (0.01)

Table 12. Bedrock Types hosting 100 or more Mineral Occurrences

*Bedrock units with over 100 known mineral occurrences within the study area, with their assigned score. Bedrock units in italics are those from the Wheeler et al. (1997) map. * The number of occurrence values in brackets are for mineral occurrences and densities not including kimberlites and diamond occurrences. The volcanic units generally have a higher density of mineral occurrences, and the granitoid rocks the lowest, particularly when discounting the diamond/kimberlite occurrences. See text for discussion.*

From Table 12, it is apparent that while there are many occurrences in the supracrustal sedimentary rocks, their density (0.05 occurrences per 10x10 km area, weighted average of the three entries in Table 12) is far less than the supracrustal volcanics (1.07 weighted average). The granitoid intrusions weighted average of occurrences per area unit is almost as high as for the supracrustal sediments (0.04 vs. 0.05). However, if one disregards the diamond/kimberlite occurrences within the granitoid rock polygons, the density falls to 0.025, which may be a better reflection of the general prospectivity of the granitoid rocks.

There were some rock types that had much higher occurrences-per-area values, but these were generally the rarer bedrock types with limited areal extent. The top seven (and 9 of the top 15) bedrock types for mineral occurrence density all had areal extents of less than 50km^2. Six of the bedrock types in the top 15 contained three or fewer mineral occurrences. Examples of these rarer bedrock types are alkali intrusions and carbonatites, mafic-ultramafic intrusions, and undifferentiated or unsubdivided supracrustal rocks and basement-cover assemblages.

The top 15 bedrock types with the highest mineral occurrences per 10x10km area (all > 2.0) can be grouped into the following categories:

- Five supracrustal sedimentary rocks: including unsubdivided and mixed assemblages, and basement-cover sequences;
- Four mafic and ultramafic intrusions: including diabase dykes and sills;
- Three granitoid and dioritic intrusions: including unsubdivided rocks;
- Two alkaline complexes: syenites and carbonatites; and
- One volcanic rocks: felsic to intermediate lavas, volcaniclastics, and related intrusion.

Listing the mineral occurrence densities in this fashion would seem to diminish the importance of volcanic rocks. However, the raw number of non-kimberlite occurrences in the felsic to intermediate volcanic category listed above is 178, versus 92 for all the 14 other bedrock types combined, and the areal extent in the study area is 6181 km^2 for felsic to intermediate volcanics versus 1453 km^2 for the other 14.

Therefore, the objective analysis does support the subjectively determined strong favourability of the volcanic belts, while perhaps reducing the importance of the widespread turbidites, particularly those of higher metamorphic grade. The granitoids, particularly the syn- to post kinematic group, are mostly important for their associated rare metal pegmatites. This was noted by Padgham and Fyson (1992), but, as mentioned previously, may also be a function of the lower amount of exploration granitic terranes have seen.

The scores from bedrock geology units (including kimberlites, see below) were normalized and the polygons converted to raster data, to produce a favourable geology theme map (Figure 9).

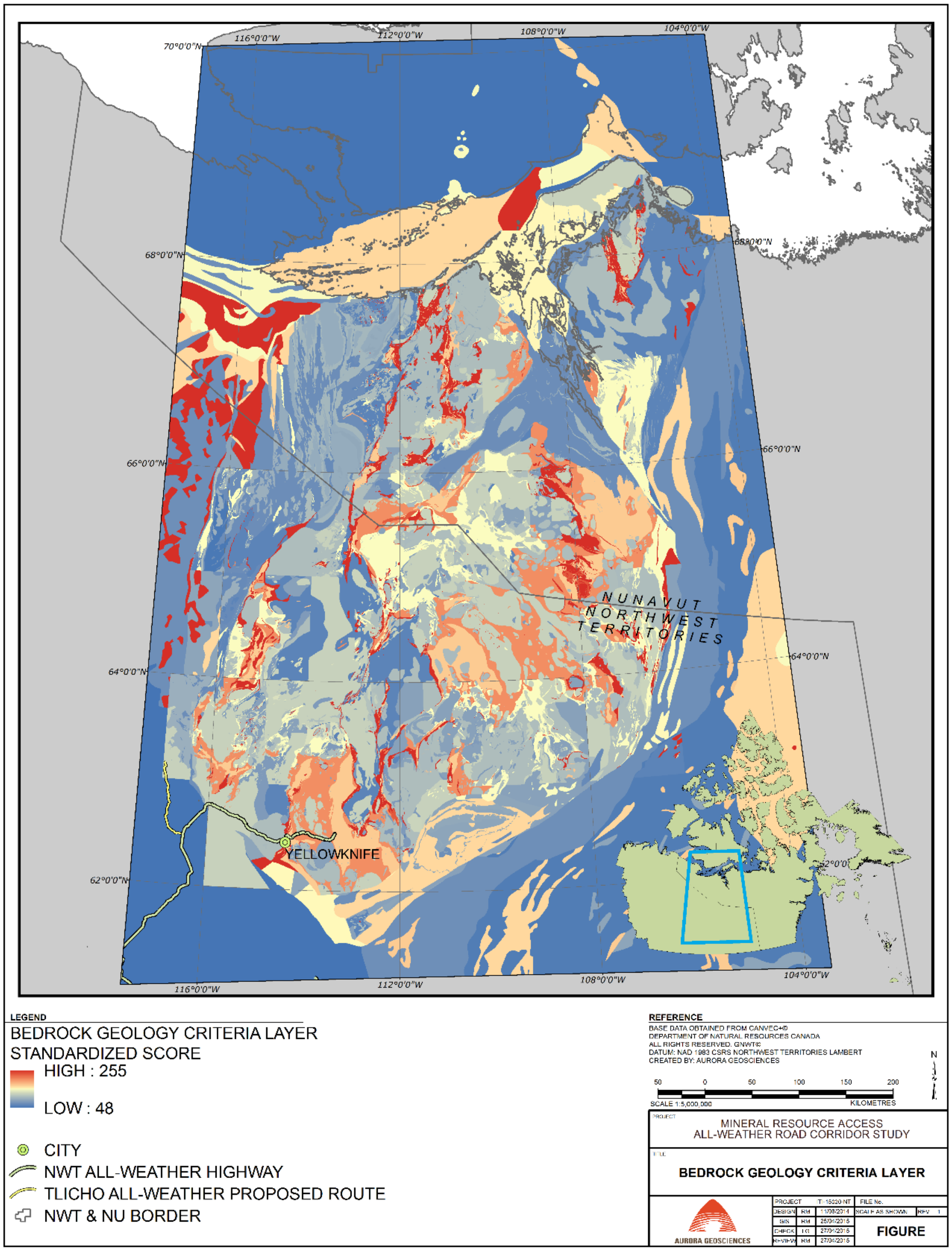

Figure 9. Bedrock Geology Criteria Layer Scores

Geology polygons scored for favourability and converted to raster data. Note that the high scoring units at the northwest margin of the Slave Geological Province are at least partly a function of the poorer resolution digital geology (Wheeler et al., 1997) outside of the Slave Province.

Kimberlites

Kimberlite locations were obtained from the NORMIN/NUMIN database. As noted above, in considering overall favourability of bedrock units, the diamond and kimberlite occurrences were removed from the host bedrock units, and scored on their own as distinct rock units. The point kimberlite locations were ascribed to a circular polygon feature using a reasonable but arbitrary diameter of 300 m (Figure 9).

The kimberlite occurrences were judged to be a highly prospective geological unit (score 95), even though some have been demonstrated to be non-diamondiferous. This is because kimberlites do tend to occur in clusters, which may include bodies with widely variable diamond grades and valuations. Thus, the existence of an individual kimberlite body will help define a cluster or field, where new discoveries (or re-evaluations) might occur.

Dykes

Dyke swarms occur throughout the Slave Province, and Stubley (2005) lists 17 unique dyke swarms, along with nine other undifferentiated groups. These groups of parallel dykes are a good indicator of crustal stress regimes, and can be related to fault zones. However, as a rock type they are not generally favourable mineral deposit hosts, except ultramafic dykes and sills. The high occurrence density value of 2.53 occurrences per 10x10 km square is likely the result of the vast majority of dykes being mapped as lines rather than polygons in the digital maps, not being included in area summations, and thus greatly underestimating the overall area covered by dykes. Because of their equivocal nature with respect to mineral prospectivity, the dykes were ranked low. It should be mentioned that the diabase rock comprising most dykes can furnish good road building material. The dykes represented by lines in the geological map, unlike those mapped as polygons, were not incorporated in the study.

Faults

Faults were obtained from the digital maps of Stubley (2005) and Wheeler et al. (1997). While these are geological phenomena, they are considered separately in this study because they occur as line locations, rather than polygons, and they can be considered in many cases to be vectors for prospectivity.

Faults were considered favourable, because while not necessarily host themselves to mineral deposits (although they can be both for brittle displacement veins and ductile shear zones), they may be the conduits for mineralizing fluids that formed deposits (and as such they are proximal features).

Also they are often associated with minor related structures that occur within an enveloping zone, and there can be a demonstrable relationship between distance from a fault and intensity of alteration, veining, etc. Therefore a Euclidean Distance function was used adjacent to faults to indicate this (Figure 10).

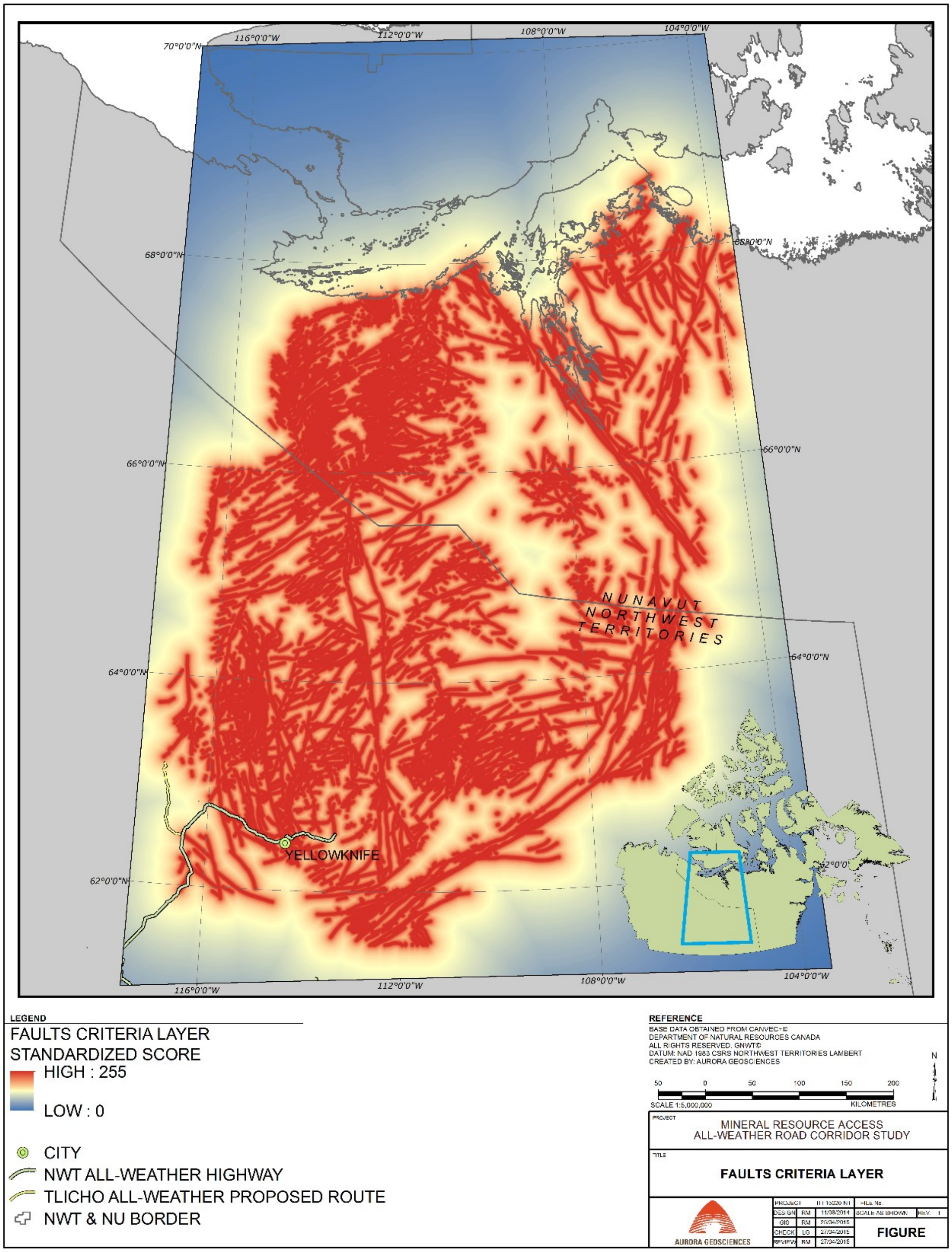

Figure 10. Fault Criteria Layer Map

Fault polylines were analysed with Euclidean Distance function and converted to raster format to illustrate density and proximity.

Mineral Tenure

Mineral tenure data was gathered from the GNWT (Centre for Geomatics, http://www.geomatics.gov.nt.ca/).

Existing mineral tenure is generally a positive indicator of mineral potential, as it indicates that other explorers have found the area to be of interest. Leases are an advanced stage of mineral tenure, indicative of a deposit that has been found, and that plans have been made to exploit it. A lease would of course be accompanied by a mineral occurrence with an advanced Development Stage. Claims are an earlier stage of mineral tenure, and generally indicate ground of interest. Prospecting permits awarded as an incentive to explore less popular areas (where there are no pre-existing claims), and because they are so large, they are less indicative of geological favourability.

Lapsed, or expired mineral tenures, are generally less favourable for mineral prospectivity, although there are many possible reasons why tenure would expire apart from failure in exploration. Expired leases are a special case, because in order for a lease to have been originally awarded, there had to be the expectation of production, and therefore they represent a strong exploration target. Most lapsed leases are associated with past producers. Lapsed claims cover almost all of the SGP, and are thus of limited help in discriminating the mineral potential of the study area. However, mineral tenures that lie within subsequently withdrawn lands, if allowed to lapsed, cannot be reclaimed as they become absorbed by the withdrawal, and therefore become alienated from further exploration.

Six types of mineral tenure were evaluated through an AHP with pair-wise comparison. Evaluation by three geoscientists resulted in the following matrix.

	Active Mineral Leases	**Active Mineral Claims**	**Active Prospecting Permits**	**Past Mineral Leases**	**Past Mineral Claims**	**Past Prospecting Permits**
Active Mineral Leases	1	4	8	4	6	8
Active Mineral Claims	1/4	1	7	4	4	8
Active Prospecting Permits	1/8	1/7	1	1/7	1	5
Past Mineral Leases	1/4	1/4	6	1	4	8
Past Mineral Claims	1/6	1/4	1/4	1/4	1	5
Past Prospecting Permits	1/8	1/8	1/6	1/8	1/5	1

Table 13. Mineral Tenure Pair-wise Comparison
Pair-wise comparison of mineral tenure types.

From the matrix, it is apparent that leases, claims, and expired leases are considered the most important tenure types, while prospecting permits of any kind are regarded low. The matrix row values, after normalization, yielded a weighting value which was used in mapping the tenures. A Euclidean distance function was used to populate study area cells where no tenures existed.

10. OTHER DATA SETS

Several data sets that were deemed to lack direct bearing on mineral potential analysis, but did have a bearing on road routing, are included on the report maps. These include hydrology and wetlands, and general infrastructure.

Surficial Geology

Although not a critical part of the mineral potential mapping exercise, surficial materials were evaluated because of their importance in both mineral exploration and road construction and planning. Coarse-scale surficial geology digital data was obtained from Fulton (1995). This mapping was at a scale of 1:5 million and so the results are very broad. However, polygons covered the entire study area. Surficial units from the map legend (Fulton, 1995) were scored by three panel members, for general favourability, and the average score is tabulated below:

Surficial Unit	Score
Glaciofluvial Complex	8.0
Glaciofluvial Plain	8.0
Till Veneer	5.0
Coarse-grained (Glacio-) Lacustrine	6.0
Coarse-grained (Glacio-) Marine	5.3
Lag (Glacio-) Marine	5.3
Till Blanket	5.7
Alluvial Deposits	3.3
Undivided	4.5
Fine-grained (Glacio-) Lacustrine	2.0
Fine-grained (Glacio-) Marine	2.3
Marine Mud	1.3

Table 14. Surficial Geology Units and Scores

As noted above, this variable will have a greater effect on road building decisions than mineral potential. The type of surficial deposits present will influence exploration decisions, but these cannot be well characterized except in specific cases, and thus surficial deposits are of limited value in evaluating mineral potential. For example, the surficial material will affect the types of geochemical and geophysical surveys that can (or should) be undertaken. Certain surficial materials are more desirable for a diamond exploration program, incorporating till sampling for kimberlite indicator minerals. Likewise, thick and/or conductive overburden may negatively impact geophysical surveys, and drill programs. In the case where a project moves to the development stage, the overburden must be removed to exploit bulk commodities at which point it becomes an engineering concern.

We considered surficial deposits here because they lie within the realm of geology, and there was an easily incorporated (if very coarse scale) database available. However, the units were scored largely from the standpoint of roadbuilding: coarser materials scored higher (glaciofluvial, till) while finer materials (glaciomarine, muds) scored lower. There are bound to be exceptions; for example, a thick till blanket might be most preferred if there are abundant surface gravel deposits associated to aid in road construction.

It should be noted that an updated, detailed digital compilation of surficial geology for NWT and Nunavut is underway (Kerr et al., 2013) and this will provide much more useful information in the study area.

Eskers

Esker data was obtained from the NRCAN CANVEC+ dataset. Eskers are a component of surficial geology, being a glaciofluvial deposit. They are considered separately here because they are linear data, rather than polygons as for the rest of the surficial data. From a mineral potential perspective, they may have some bearing on exploration for diamond (or other) deposits. As glaciofluvial channel deposits, they may have concentrated heavy minerals in lags.

Eskers were scored highly against other surficial deposits because they are desirable for road development, as a source of aggregate and sometimes as the roadbed itself. That said, they are often important wildlife habitats.

The surficial geology map with scored polygon values, and including eskers as polylines, is included in Figure 11 for information purposes.

Hydrology and Wetlands

Hydrology and Wetlands (saturated soils) data was obtained from the NRCAN CANVEC+ dataset. Lake data were filtered to remove any water body less than 1 km^2. These elements were used as exclusion zones in the cost-path/cost-distance road route selection program, in order to have the computer choose possible routes that avoided lakes and wetland areas.

Infrastructure

An infrastructure map, showing existing highways, communities, parks and protected areas, power lines, and telecommunications systems was created as an accompanying informational map (Figure 11).

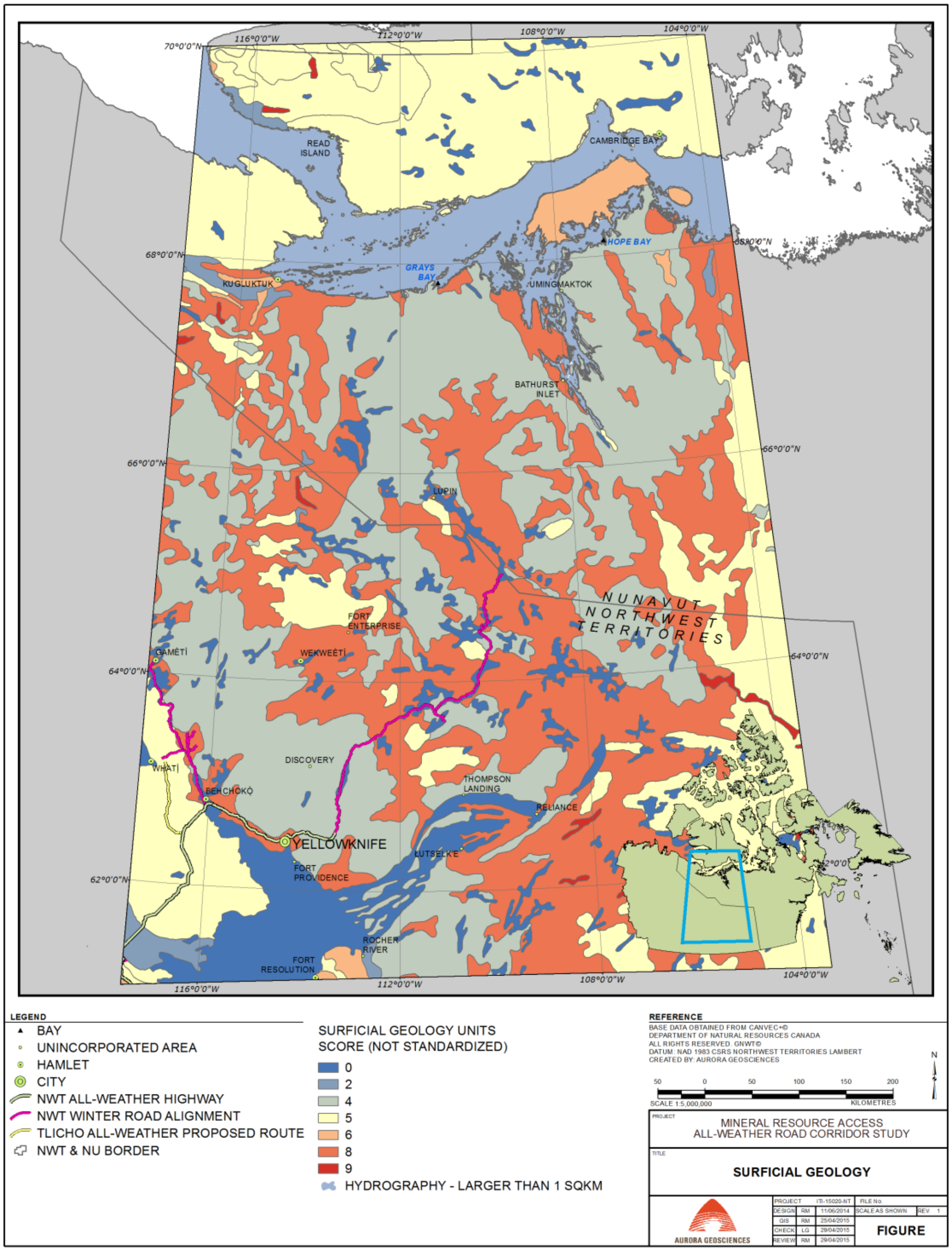

Figure 11. Surficial Geology Units and Scores

Surficial geology polygons scored for favourability and converted to raster data. The coarser surficial materials rank higher (red shades).

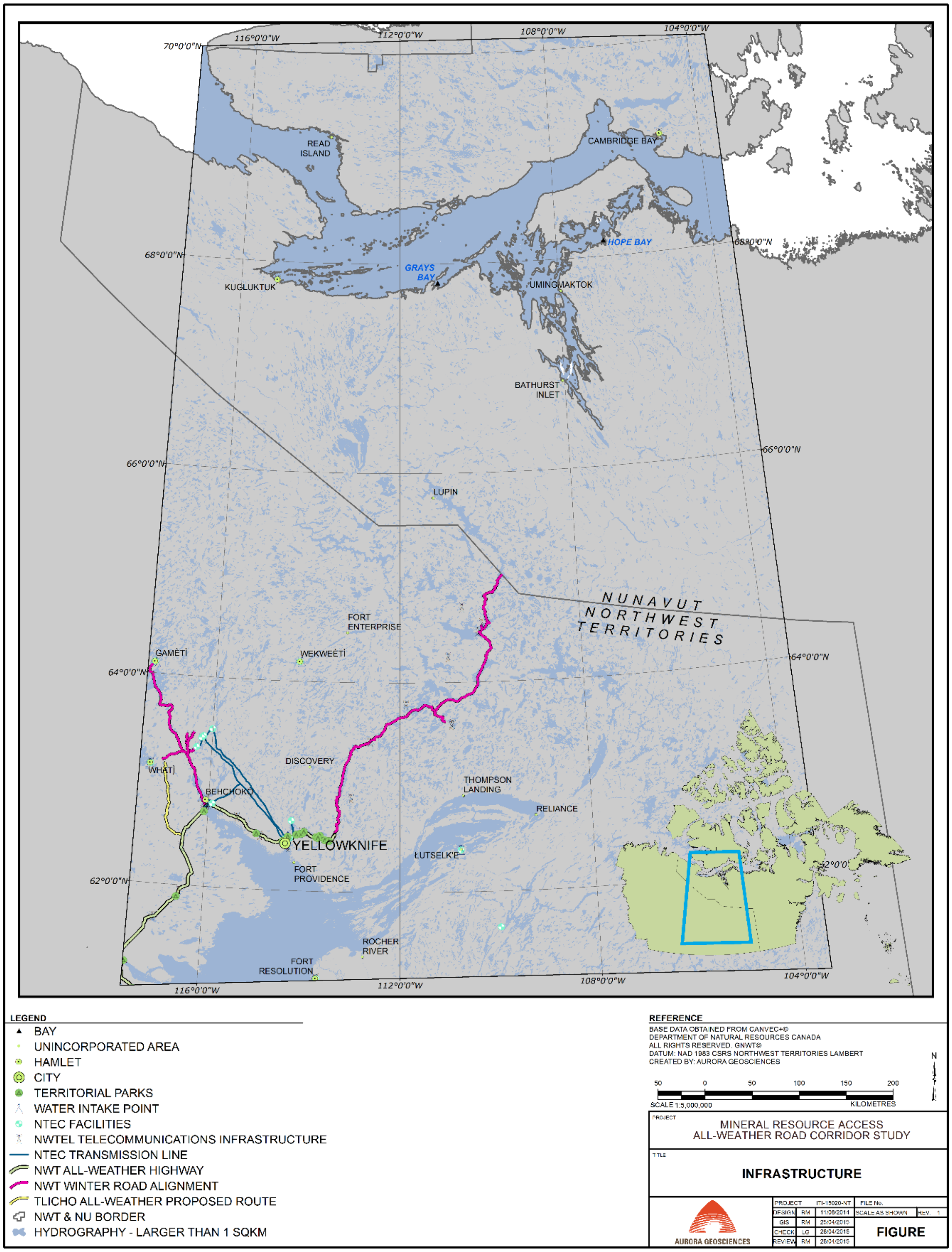

Figure 12. Infrastructure Elements in the Study Area

11. PAIRWISE COMPARISON OF MINERAL POTENTIAL VARIABLES

A panel of five geologists evaluated the four variables, from the standpoint of a reasonable, unbiased mineral explorer, to consider which of each pair was better or more important. The numerical average of their responses was used in constructing the matrix below. While bedrock Geology and Mineral Occurrence were considered the most important by a significant margin, it is interesting to note that the two variables were judged (on average) to be virtually equivalent. Two evaluators considered mineral occurrences more important, while the remaining three chose Bedrock Geology to be of higher importance.

	Mineral Occurrence	Bedrock Geology	Mineral Tenure	Faults
Mineral Occurrence	1	1	5	6
Bedrock Geology	1	1	7	6
Mineral Tenure	1/5	1/7	1	3
Faults	1/6	1/6	1/3	1

Table 15. Multi-Criteria Evaluation Matrix
Matrix developed through Analytical Hierarchic Process.

The weighting factors obtained through the matrix were as follows: Bedrock Geology 44%, Mineral Occurrence 40%, Mineral tenure 10%, Faults 6%. These weighting factors were then applied against the rasterized maps for Bedrock Geology, Mineral Occurrences, Land Tenure, and Faults, and the total summed to obtain the overall interpreted mineral potential map (Figure 1).

12. RESULTS

Mineral Potential Map

Mineral potential map (Figure 1) shows that bedrock geology, and particularly the high-scoring volcanic greenstone belts, exert a strong influence on the interpreted mineral potential. Generally north-trending zones in western, central, and eastern SGP are apparent, largely influenced by the greenstone belts. The easternmost, and north part of the central zone, seem particularly strongly favourable. The Lac de Gras area, and to the south around the Gacho Kue deposits, also reflect high mineral potential. There remains a relatively high potential area on the northwest margin of the SGP, but, as noted previously, this is largely due to the poor resolution of the digital geology in that area.

Cost-Path Road Route Map

From the mineral potential map, a GIS analysis function was employed to determine optimal road routes to maximize exposure to high mineral potential areas and minimize cost (distance). First a cost-distance function map was created using the inverse of the mineral potential map (to make the highest mineral potential the lowest “cost”) and constraining the distance cost from any point along the existing NWT Highway system. This map, an interim step in the process, is shown in Appendix V.

The maps were constrained by having a starting point from somewhere along the existing highway system (i.e., NWT Highways 3 or 4) and to avoid the exclusion zones of all wetlands, and waterbodies of greater than 1 km^2 in area. River crossings were not considered. Six destination points were set, and the mapping program determined the optimal paths. Result is shown in Figure 2 and summarized in Table 16.

Path	Path Destination	Path Start	Distance (km)
P1	Grays Bay	Hwy. 4 near Tibbit Lake	742
P2	Izok Lake	Hwy. 4 near Tibbit Lake	495
P3	Lupin	Hwy. 4 near Tibbit Lake	450
P4	Hackett River	Hwy. 4 near Tibbit Lake	680
P5	Ekati	Hwy. 4 near Tibbit Lake	357
P6	Any point on the Arctic Coast	Hwy. 3 near Behchoko	654

Table 16. Summary of Road Paths
Summary of modeled road paths for six destinations using cost-path GIS analysis.

Route P1 to P5 all depart the existing highway system from near the east end of the Ingraham Trail (Highway 4). The P1 route trends essentially northward, passing just west of both Ekati and Lupin. The Izok (P2) route branches off to the northwest near Ekati, while the Hackett (P4) route branches off to the east near Diavik, before turning north. It is interesting that the least constrained destination (route P6) takes a markedly different path, from near Behchoko almost straight north to Kugluktuk. The P6 route does pass near the prospective Indin Belt (including the old Colomac Mine) but it may be influenced by possibly optimistic high potential areas on the northwest margin of SGP, as discussed earlier. None of the modeled routes depart directly northward from Yellowknife.

13. CONCLUSIONS

The GIS analysis was successful in using weighted scored and rasterized maps of four key variables (bedrock geology, mineral occurrences, mineral tenure, and faults) to map interpreted high mineral potential in the SGP; and choose, through cost-distance and cost-path analysis, a number of constrained possible road paths. The methodology is flexible enough to accommodate many different scenarios, route constraints, and weighting factors of the main variables.

Because the foundation of the data analysis was subjective and knowledge-based, there was a degree of expectation that the modelled routes would follow the volcanic greenstone belts, as they were scored the highest of the bedrock geology units, and also pass close to many advanced exploration projects and operating mines. These expectations were broadly met, and the advantage of the GIS mapping is that it limits personal biases. That said, as the mapping program relied on mainly subjective judgements, some biases may have occurred.

Increased resolution in the data sets (particularly bedrock geology) and more robust judgement of mineral occurrences, and an increased number of subjective judgements (through wider participation of informed experts) would likely improve the results.

While there are limitations in the subjective analyses, the results are plausible; and this study should be of value when used in concert with others in choosing a final route, and bearing in mind its limitations.

14. LIMITATIONS AND RECOMMENDATIONS

As mentioned in the Disclaimer at the beginning of this report, the interpretations presented here cannot be considered stand-alone, nor can the report be considered static and final. Ongoing developments, chiefly in mineral exploration, will impact the mineral occurrence scores within a very short time-frame, perhaps within months. Therefore this report presents more of a snapshot in time.

Bedrock Geology is relatively static, but new digital compilations of NWT Geology recently completed and ongoing (Okulitch and Irwin, 2014; Irwin, 2014) will increase the resolution of geology outside of the core SGP area (Stubley, 2005). This will result in changes to bedrock geology polygons and fault location. More importantly, the uniformly compiled geology will have a new standardized legend which will require a new scoring of units. However, unless Nunavut geology is also included in the new standardized compilation, this reappraisal of geology units for this study will have limited benefit.

Mineral tenures are almost always in flux, and changes to mineral tenure score can be expected on almost a weekly basis.

This analysis can be improved in several ways. Firstly, as with most subjective analyses, the participation of greater numbers of knowledgeable analysts will improve the scoring results, by moving toward (ideally) a normal distribution.

More variables could be considered, such as a geochemistry and /or geophysical anomaly component, an estimate of mineral exploration expenditure per unit area. The KIMC and KANDD databases maintained by NTGS may be useful in this regard. Government (Geological Survey of Canada and NTGS) regional geochemical surveys, quite extensive in western NWT, are greatly lacking in SGP.

Faults could be considered in more detail, perhaps grading fault segments based on mapped length, which could be considered as a proxy for the scale of the fault zone (width). However, the wider, major fault zones do not necessarily correlate with the best mineral potential, as mineral occurrences are often associated with smaller cross structures to the larger fault zones.

A comprehensive, SGP-wide metallogenic compilation would be helpful in outlining the most prospective geological units. Such a study could focus on the major commodities and deposit models.

Many studies of SGP tectonics have been done that would inform such a compilation (e.g., Goodwin et al., 2011; Helmstaedt and Pehrsson, 2012). Smaller-scale, focussed metallogenic studies could be compiled in a synthesis (e.g., Ootes et al., 2006; Jackson and Ootes, 2014).

The ongoing digital compilation of surficial geology of the territories, led by Natural Resources Canada, will be very helpful when completed (Kerr et al., 2013). This tri-territorial surficial geology database will feature a new uniform legend (Deblonde et al., 2014) for units across the entire region, which will allow more accurate and meaningful scores to be assigned for various units.

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16. APPENDICES

I. Project Document (RFP)
II. GIS Workflow Chart (.html digital file)
III. Gross Mineral Resource-in-Place spreadsheet (.xls digital file)
IV. Mineral Occurrences in Study Area spreadsheet (.xls digital file)
V. Cost-Distance function map