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**Mineral potential map of the Yukon
Phase 1-Northern Yukon
Dawson Fault to Kaltag Fault.**

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Introduction

This map, covering the southern part of Northern Yukon, is the first of a planned series which will ultimately be integrated into a complete Mineral Potential Map of the Yukon. It is intended as a tool to assist in the implementation of various land-use initiatives, most notably the Yukon Protected Areas Strategy, by contributing information on mineral values in early planning stages. Areas of high mineral potential can be avoided by including mineral potential values in the range of values influencing candidate site selection, thus facilitating adequate ecological representation without compromising access to mineral wealth.

This mineral potential map is designed as a regional planning tool to help the selection of areas of interest for protection. It is based on data that are insufficient for use as a detailed planning tool. It is not a mineral assessment of a study area. A detailed mineral assessment of a study area would require the analysis of more detailed information and possibly field studies where existing data may prove to be inadequate.

Description

This mineral potential map provides a comparative ranking of the land base that reflects current thinking on geological potential. It is based on the known resources of the area and on the ability of experts to predict the potential of specific rock sequences to host undiscovered mineral deposits. These estimates are in turn based on, and limited by, publicly available geoscientific information such as exploration history, known mineral occurrences, regional geochemistry, comparisons with similar host rocks and deposits elsewhere in the Cordillera and general expert knowledge.

The result is a map that provides a regional view of areas of varying importance to the mineral industry, based on geological factors. The ranking does not take into account socio-economic factors such as access, proximity to power supply, feasibility of production, etc. Such factors may be incorporated in further, multiple accounts analyses.

The process is reproducible, and is based on scientific knowledge and principles. It is politically impartial. The results of this first regional assessment will be incorporated to further ones in order to create a mineral potential map of the Yukon.

The outline of the study area was chosen in order to provide input into the parks planning process underway in Northern Yukon. The area north of the assessed (*study area sounds like proposed park to me*) area was not evaluated due to time limitations, and may be assessed in a later phase.

Methodology

The methodology used was developed by the United States Geological Survey and adapted by the BC Geological Survey for use within their regional land-use CORE process. The BCGS, through Ward Kilby, provided the data, programs and expertise necessary to run the probabilistic estimates through the Monte-Carlo simulator, as outlined below.

The methodology is outlined in detail in Kilby, 1995. The application of this methodology to this project is summarized here.

The analysis of an area is conducted in five main steps: data compilation, tract definition, assessment, data processing, and production of a mineral potential map.

Data compilation

The digital compilation of all available geoscientific information at a 1:250 000 scale facilitates the integration of this information. The Yukon Digital Geology compilation by Gordey and Makepeace (1999) at 1:250 000 scale was used as the base layer, and the legend accompanying the map was used for lithological descriptions. A GIS map compilation was the only geological map available at the time.

The MINFILE (DIAND, XXXX) database was overlain on the geology layer, with labels for number and name. Deposits with known reserves were highlighted with a larger symbol and reserve figures were reported. Topography and drainages were also added to the geology layer.

Regional stream geochemical data were treated statistically and also displayed at a 1:250 000 scale, one map for each element. The data set was very large and was not normalized to bedrock lithology. Instead of the classic grouping by percentile, a different way to portray variations in the data set was followed, after a suggestion by Peter Friske from the Geological Survey of Canada. It was decided to choose the different anomaly thresholds based on their spread from the median. We believe this approach provides a better representation of the data set and refines our ability to define anomalies. The different ranges of values portrayed on the geochemical maps are outlined in Table 1.

Geophysical coverage was mostly inadequate. Aeromagnetic surveys for the study area have line spacings that are too wide for mineral assessment purposes. A very small portion of the southwesternmost part of the study area was covered by a useful aeromagnetic survey.

All the MINFILE information (WordPerfect version) was printed out in text format. In addition, a summary of all the occurrences and their host lithologies was tabulated (Table 2). This table was also sorted according to formation name, which then showed all the occurrences in each stratigraphic unit and in each tract. An outline of known reserves, also derived from MINFILE, is found in Table 3.

A summary of significant mineralization occurring in similar stratigraphy outside of the study area was also provided.

Two versions of mineral deposit models were used, one descriptive, the other one numerical. The descriptive mineral deposit models were taken mostly from the BC Mineral Deposit Profiles, vols. 1 and 2, as well as some unpublished ones (D. Lefebure, pers. comm.). This important work has been very useful in defining and summarizing the characteristics of individual mineral deposit types. Additional descriptive models were taken from GSC Economic Geology Report 36 (1984). The pertinent profiles are listed in table 4 along with the median tonnage for each deposit type. shall we put them in the report or just refer to them? If no descriptive models existed, the assessors would agree on the a tonnage for the model they were assessing prior to their estimations.

The numerical deposit models are used in the computer modeling. Each deposit model used in the assessment consists of a table containing tonnage data from pertinent examples. Most models were taken or adapted from those provided by the BCGS.

Where no numerical models existed, CalData was contracted to create new files for these models.

Tract definition

A 1:250 000 scale map, outlining the tracts to be assessed, was drawn based on the geological compilation. Each tract includes rocks of similar geology and/or age, and averages approximately 1000 sq. km. Tract definition is based on geology, not on the potential of a certain rock type for a certain model.

Because the size of the tracts determines the coarseness of the assessment, it is important to define tracts in a way that will be useful for land use planning. Each tract is assessed as a whole. It is important to keep this in mind, because a deposit model may occur in restricted parts of tracts. Later refining of the results is possible by re-examining the criteria for each estimate. For example, the outline of tract 92 is less than ideal. Most of the rocks consist of Cambrian clastic rocks, which are generally considered of low potential. But the inclusion of small islands and slivers of rock types of significantly higher potential strongly influences the ranking of that tract. A more detailed look, using a finer geological filter than the original tract outline, is necessary for any detailed analysis.

Tracts 1 to 20 are not displayed on the map. They occur north of the study area and time allotted for the expert estimations did not permit their assessment.

Due to an editing lapse, there is no tract 29 and no tract 86 on this map.

Assessment

An assessment workshop was held from March 30 to April 1, 1999. Four panelists were chosen for their expertise in the geology and mineral deposit models pertinent to the study area. After an analysis of the compiled geoscientific information for each tract, each estimator was asked to estimate the probability, on a scale of 0 to 100%, of finding one or more undiscovered mineral deposits of a specific type, keeping in mind the median size and grade of that type of deposit (table 4) to guide their estimation. Each estimator filled out one sheet per deposit model per tract. This was done for every tract and for a total of 22 mineral deposit types that were thought of having a probability of occurring in those tracts. Table 5 lists the models assessed for in each tract. Also for each tract and each model, each estimator evaluated the other estimators' expertise by distributing a fixed number of points between them. The resulting overall weighting is factored in the computer modeling.

The estimators also noted their own confidence in their assessment, based on the quality of information. Figure 1 shows the average confidence for each tract. What do you think, shall we put this in?

Tracts were assessed for their potential to host gold, silver, lead, zinc, copper, uranium, nickel, cobalt, molybdenum, chromium, platinum-group elements (PGE's), mercury, barite, jade; iron; and Nick-type (shale-hosted nickel sulphide) deposits. The potential for coal was determined from the existing literature. The potential for oil and gas, placer deposits and for most industrial minerals was not addressed.

Data processing

Simulation

Each estimate is coded into a digital format. The resulting file is run through the Raw2Mark program. The output file summarizes the probability estimates of all the estimators into one estimate per model per tract. The resulting file is then input? into the Mark 3b Monte Carlo simulator, which converts the estimations into probability graphs and combines these with known grade and tonnage data. For each combination of deposit model and tract, the simulator samples the curve (or graph) of the averaged probability estimates at the 90, 50, 10, 5 and 1% *(from what I understand, it samples the curve according to the unit vectors in the digital deposit models, i.e., anywhere, and reports the estimates at the 90, 50, 10, 5, and 1% c.i.)* probability level. Using a tonnage curve based on real and pertinent examples, it lists the predicted amount of each commodity, for each probability level, in each tract. It does this 4999 times before going to the next model or the next tract. This results in a file that lists the predicted number of tonnes of each commodity for every combination of deposit type and tract (simtot.csv) (table 6).

The simvalu.exe program then combines the latest file with a price list (Table 7) of all commodities that is based on a ten year average (1980-1989), listed in 1986 dollars. The final output file (GIPV.csv) combines the value of all the commodities for each tract and lists the dollar value of that tract at each probability level.

Note: The output of the Monte-Carlo simulator includes iron and Nick-type deposits. Because the potential for these deposits is ranked and displayed separately (see below), the values for these deposits have been separated from the rest of the data and treated separately for the steps following the simulation.

Ranking

The GIPV.csv file is edited to achieve final scoring and subsequent ranking of all tracts (table 8). First, a column for 100% confidence or probability level is added by inputting the dollar value of known reserves in the appropriate tracts. Then, for each tract, the dollar value of each confidence level is divided by the area covered by that tract. This value is entered in a new "index" column. Then, starting with the 100% confidence index category, the whole data set is sorted according to increasing index values and each tract ranked accordingly. This operation (index, sort and rank) is repeated for each of the other confidence or probability levels before going on to the next. A score for each tract is obtained by adding up the different rankings that have been multiplied by a factor proportional to their probability level. The associated weightings are 1, .9, .5, .1, .05, .01 for the 100%, 90%, 50%, etc confidence level. The final rank for each tract is obtained by sorting the score column. Table 9 displays a summary of the final ranking for metallic minerals.

It is important to note that the dollar figures are meant only for the purpose of comparing tracts to one another.

Ranking for iron and Nick-type deposits were determined separately from the other metallic minerals as they are displayed separately (see below). The edited GIPV file for iron is in table 10, the one for Nick-type is in table 11. Table 12 shows a summary ranking for Nick-type deposits.

The ranking for coal that is outlined on the map is taken from Norris (1997), and from Sinclair et al (1981). The breakdown for the ranking is based on the significance of the occurrences and is outlined in table 13, along with the ranking for iron.

Production of a mineral potential map

It was decided to separate the estimated models/commodities into four categories and display each one separately on the map. All metallic (and some industrial and ornamental minerals) were assessed using probabilistic estimates and the computer simulation. The potential to host iron, coal and Nick-type deposits is ranked and displayed separately due to the extremely high contained value of these deposits compared to the other deposits grouped under "metallic minerals".

The potential for Nick-type deposits, a significant exploration target, is also ranked separately due to uncertainty surrounding its status as an economically viable target. Known occurrences of this type of mineralization could be extremely valuable, but none are yet mined in the western world. As more information is becoming available on this type of target, finalisation of this model should be possible in the near future.

Four different categories of mineral deposits are displayed as they cannot be ranked with respect to one another. For example, there is no ranking of the importance of an iron deposit over that of a coal or a copper deposit. The four categories are: all likely deposit types containing metallic minerals (including: gold, silver, lead, zinc, copper, uranium, nickel, cobalt, molybdenum, chromium, platinum-group elements (PGE's), mercury, barite and jade); iron; coal; and Nick-type (shale-hosted nickel sulphide) deposits.

Interpretation

This map compares the relative mineral potential of 80 tracts of roughly equal size to host twenty-three mineral deposit models containing 16 commodities. The potential to host metallic deposits is shown by the range of colours, with red representing the highest potential and blue the lowest. In general, each colour range represents approximately equal amounts of surface area, with the warmest colours representing the highest potential for metallic minerals and the coolest colours representing the lowest potential. *(You just wrote the same in the previous sentence)* The tracts that rank the lowest do not follow that equal area guideline. The dark blue tracts, representing about one third of the total surface area, represent rocks that were evaluated by the estimators to have such low probability of hosting metallic mineral deposits that they decided not to assess for them. As these tracts all have the same ranking, they must all be of the same colour.

The potential for iron, coal and Nick-type deposits, derived from the probabilistic estimates, and the potential coal, derived from the existing literature, are displayed using different grid patterns. Rank categories for iron, and Nick-type deposit follow the same tracts as the metallic mineral deposits, they are based on natural breaks within the data population (see tables 12 and 13) and do not follow any equal area guideline. Rank categories for coal do not follow tract outlines but rather are restricted to the specific rock formations which host documented coal reserves and occurrences. The different categories are based on whether the formation contains known reserve, significant occurrences, or minor occurrences.

Significant parts of the study area lack regional geochemical surveys (see inset on map), have inadequate geophysical coverage, and are considered to be under-explored. The lack of information affected the confidence level of the assessors, and resulted in the

ranking of these areas as lowest in mineral potential. For the areas for which there was no information, the estimators had to extrapolate from their assessments of the same types of rocks where information was available. Figure 1 shows the confidence in the data noted by the estimators. Confidence increases with amount and quality of data. The map also shows, however, that if the potential is deemed either high or low, even if by extrapolation, the estimators don't rely as much on the quality of the data. An adequate database seems to affect mostly those tracts of intermediate potential, where uncertainties could be clarified by more work. I don't know, what do you guys think? *I think this last sentence is very confusing. I don't know what you mean.*

Simplified Cumulative Ranking map

The Simplified Cumulative Ranking map (large inset box) offers a generalized guide to the mineral values of the area. The four categories are not ranked with respect to one another, but the simplified map shows the location of significant mineral values. The colour groupings are simplified (four categories instead of six). Tracts portrayed in the main map as red and orange are grouped together, the same with the blue-green and green tracts. This compilation map displays the highest rank achieved in any of the four deposit categories. For example, if a tract is coloured red, at least one of the four categories is ranked as high, the same with the other colours.

Assumptions

The estimators made certain assumptions and observations that are listed here.

- Estimation for Mississippi-Valley Type deposits includes types of mineralization that don't rigorously fit that model. These mineralization types are included nonetheless since the overall grades, metal content and contained value are equivalent to MVT's.
- It was assumed that the iron deposit of the Alto-Fe model is hosted in the Cretaceous part of the strata.
- The absence of regional geochemistry and/or of exploration history affects the confidence the estimator had in those assessments.
- Some areas are mismapped (tract 76), again resulting in reduced confidence in the assessment

Limitations

The methodology used to produce this map is the widely accepted for assessing mineral potential over very large areas. The evaluation is the most systematic, consistent, reproducible, and uses expert advice. It minimizes the possibility of selecting areas containing undiscovered resources, but only represents a "best guess at the time" and cannot be quantified with absolute certainty. Since it is an assessment of hidden, undiscovered resources, it is important to recognize that our knowledge base is in a constant state of growth. Mineral deposits may one day be found in rocks that were once thought to be of low potential. Rocks hosting the diamond deposits in NWT as well as those hosting the nickel deposits of Voisey's Bay in Labrador were once considered to be of low potential. They are now known to host extremely valuable mineral deposits.

Conclusions derived from such a study are only as good as the data that is available for the evaluation. Where information is lacking, our confidence in the assessment is diminished. This assessment was made with only partial geochemical coverage (see inset map) and inadequate geophysical coverage. Assessments such as these need to be reviewed as the geoscientific database evolves.

The greatest challenge, is to ensure that end-users understand the use and limitations of this product. Planning initiatives should involve the participation of knowledgeable geological staff who can help with the interpretation of such a complex map.

Conclusions

The mineral potential map for northern Yukon was derived from probabilistic estimates from four expert estimators. Their estimates were processed through the Monte-Carlo simulator program that combines the estimates with known grade and tonnage data to predict the amount of each commodity in each tract. The resulting map portrays four different categories of mineral deposits. The southernmost part of the study area ranks the highest for most minerals. The high ranking tracts for metallic minerals correspond generally to rocks of Proterozoic inliers, Selwyn Basin and Mackenzie Platform. Tracts hosting the Rapitan Formation rank highest for iron while the highest values for coal are located (*in tracts hosting*) the Bonnet Plume Formation.

Nick-type deposits are an important and valuable exploration target that cannot be ignored. However, they should not have the same status as the other metallic mineral deposits. Tracts hosting a particular lower Devonian horizon rank the highest for this type of mineralization.

The process was limited by unevenness in the amount and quality of the data and in the amount of exploration history. Nevertheless, this map represents an accurate picture of the current thinking on the geological potential of the area. It is a complex picture. It is hoped that it will be well used and will contribute to balanced decision-making for future land-use planning exercises.

Acknowledgments

Ward Kilby from the BC Geological Survey provided invaluable guidance, help and support; Dave Lefebure, also from the BCGS, provided updated mineral deposit profiles, CalData completed the mineral deposit models database; Aurum Geological was contracted to digitize the assessment information and run the Monte Carlo simulation. This project would not have been possible were it not for the digital geological compilation of Yukon Geology, by Steve Gordey and Andrew Makepeace from the GSC, we thank them for providing us with timely information. Jo-Anne van Randen, Gord Nevin and Tammy Allen from YTG Mineral Resources Branch kindly contributed long hours towards the completion of this project.

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Appendices

Mineral deposit profiles from BCGS and GSC if we're putting them in.