THE B.C. MINERAL POTENTIAL PROJECT - NEW LEVEL 2 MINERAL RESOURCE ASSESSMENT METHODOLOGY AND RESULTS

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INTRODUCTION

In August 2002, the Geological Survey Branch (GSB) of the Ministry of Energy and Mines was asked by the Ministry of Sustainable Resource Management to undertake a Level 2 Mineral Resource Assessment (MRA) of the Coast Information Team's (CIT) project area which encompasses approximately 11 million hectares. This was followed by a similar request in February 2003 to do the Lillooet Land Resource Management Plan (LRMP) area. The primary purpose of these assessments was to provide more detailed information on metallic and industrial mineral resource potential in support of concluding detailed land use plans. The Coastal resource assessment was carried out in early October, 2002 and final results delivered to the Ministry of Sustainable Resource Management and the CIT at the end of December 2002. The Lillooet assessment was completed in April 2003. This report summarizes the methodology used in these projects and briefly reviews the results which are now posted on the MapPlace website (http://www.mapplace.ca). A review of the original Level 1 MRA methodology is also included here because the Level 2 MRA used the results from the original assessment.

All users of mineral resource assessments should be aware that they are based on historic information and current knowledge. They are, therefore, a snapshot in time which can change with more information and knowledge. One only has to think of the discovery of diamond mines in Canada in the 1990s to recognize the difficulty of assessing hidden resources. For this reason areas of low mineral potential may reflect our lack of understanding of the geology of the region, not an absence of future mines. As well, mineral potential assessments can only be used effectively at the scale at which they were completed. Just as one wouldn't use a map of the province to locate a house in your community, provincial scale mineral potential maps cannot be used for detailed resource assessments in small areas.

HISTORY OF THE MINERAL POTENTIAL PROJECT

Early in 1992, the British Columbia Geological Survey Branch of the Ministry of Energy, Mines and Petroleum Resources (later Employment and Investment and now Energy and Mines) launched the Mineral Potential Project to develop the information required by the Commission on Resources and the Environment (CORE) over a 5-year period. The Geological Survey Branch dedicated in excess of 30 geologist-years to meet this information requirement. Completion of the assessments in step with the land use planning processes was critical. This earlier assessment is referred to here as a Level 1 MRA. Results of this MRA are presented in Figure 1.

The first major task of the Mineral Potential Project group was to determine the type of information that would be useful in land use negotiations and develop a methodology which would best produce this information. A two-day workshop involving participants with recent experience in producing and using Mineral Resource Assessments in Canada and around the world determined that the MRA products must be quantitative rather than qualitative, provide a ranking of the land base, have major input from experts from the mining and exploration industries, produce digital GIS-compatible products and be readily available.

Quantitative, easily understood results were desired because the LRMP process involved people with a wide range of technical and non-technical backgrounds who had to consider the MRA results in the decision-making process. In addition, quantitative information can be used in subsequent socio-economic analysis. Ranking of the land base was necessary because the Protected Areas Strategy dictated that a target of 12% of the land area in each region would be protected, double the amount protected at that time. A major objective of the Mineral Potential Project was therefore to rank the relative mineral potential of the land base so that planners could easily identify areas with the lowest relative mineral potential during their land use planning.

The mining and exploration industries of BC have built an enormous knowledge base that is not in the public domain. Their involvement and cooperation gave us access to some of this knowledge and also enabled us to familiarize public sector stakeholders with the strengths and limitations of the MRAs. Government dictated production of all information for the land use planning processes in Geographic Information System compatible digital format. Adherence to this policy assured the information was easily incorporated into the analysis systems used by the planners. In addition, storage of the information in digital format provides an opportunity to more easily upgrade the information in the future. Virtually all the data and map products discussed in the article are now available over the Internet at **www.em.gov.bc.ca/Mining/Geolsurv**.

LEVEL 1 MINERAL RESOURCE ASSESSMENTS

Based on the results of the workshop, a plan for the production of MRAs in BC was developed that was based on the United States Geological Survey's "Three Part Mineral Assessment Methodology" (Singer, 1993). Modifications were made to their procedure to meet the specific requirements of this project. Early in the life of the project, a number of minor adjustments were made to

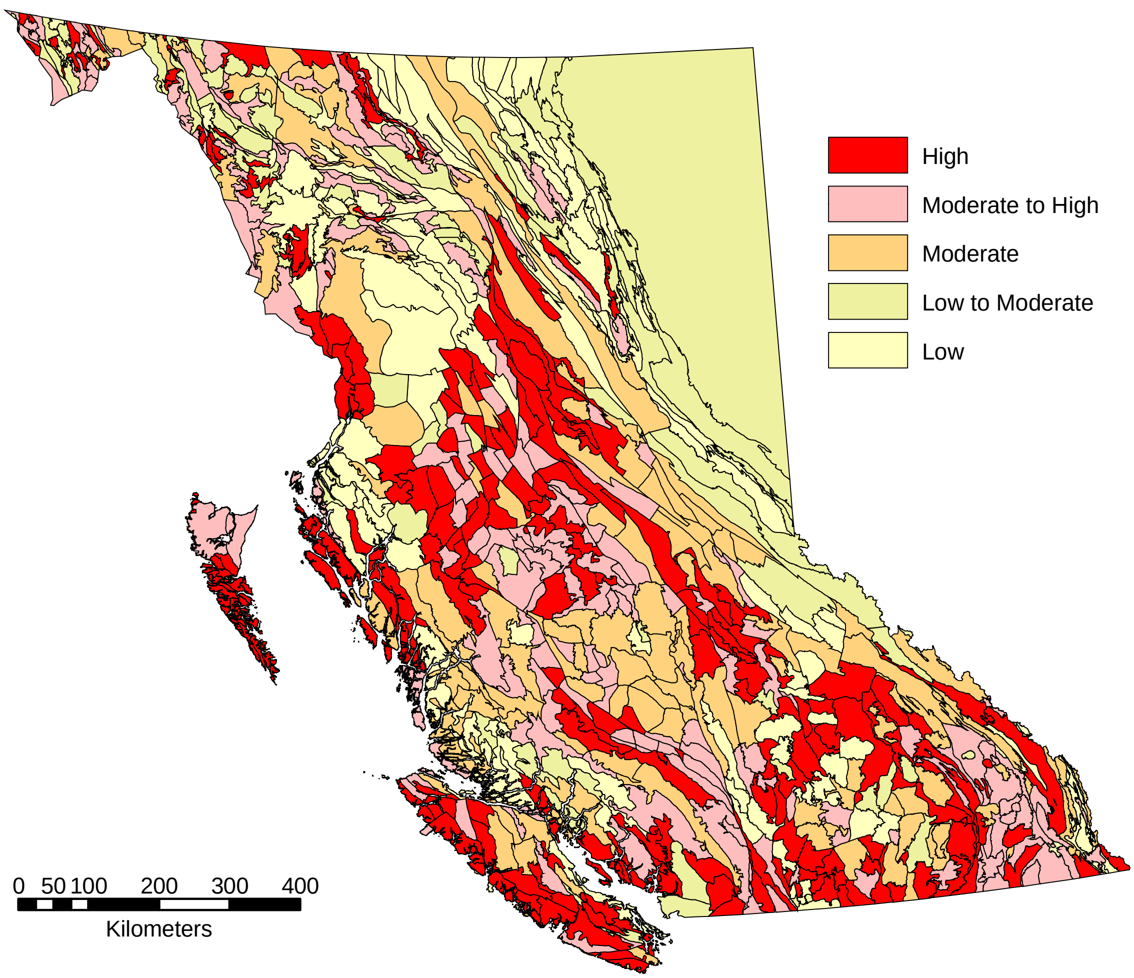

Figure 1. Metallic mineral potential map for B.C. based on the Level 1 MRA completed in 1997. Total number of tracts is 794.
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the initial methodology. This methodology has been applied consistently to all assessment regions, so the results from one region may be compared to the results from a neighboring region. Two different techniques are used to assess metallic and industrial mineral commodities due to their very different dependence on infrastructure and markets. A six-step process is used for the **metallic resource assessments**:

1. compile geology
2. select mineral assessment tracts

3. tabulate discovered resources and construct deposit models
4. employ a team of industry and government experts to estimate the number of undiscovered deposits by deposit type and tract
5. determine quantities of metallic commodities remaining to be discovered using the Mark3B Mineral Resource Assessment Monte Carlo simulator
6. calculate the gross in place value (GIPV) of each tract based on the undiscovered and known commodities it contains.

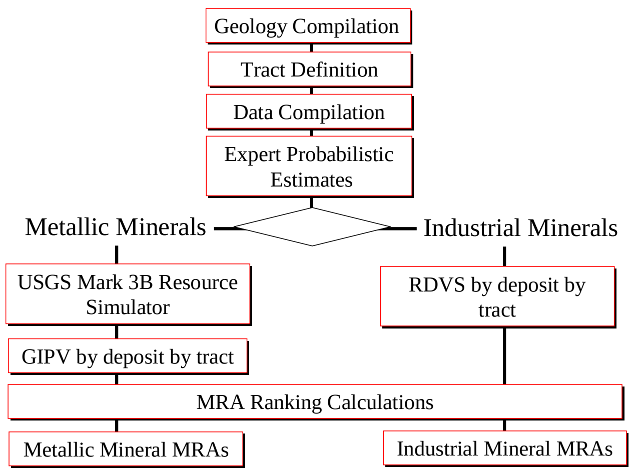

Figure 2. Flow chart for the Level 1 MRA process.

For **industrial mineral assessments** the first 4 steps are the same. However, instead of using the Mark3B simulator and associated GIPV, a relative ranking of industrial mineral deposit types was employed (Kilby *et al.*, 1999). All industrial mineral deposit types were given a relative ranking score from 1 to 100 based on their perceived value and viability. This relative deposit value score (RDVS) was used to determine the importance of each tract with respect to undiscovered deposits. The estimates are then blended with the value of discovered industrial mineral deposits to produce the overall industrial mineral tract assessment ranking.

Industrial Minerals Relative Deposit Value Scores (RDVS)

Metallic and industrial mineral deposit evaluations require different valuing methods. A methodology was developed for the Level 1 MRA project to provide a meaningful comparison between resource assessment tracts based on their industrial mineral potential. This methodology is described in Kilby *et al.* (1999).

Generally, metals are sold on the world market, they are relatively highly priced, and transportation costs are relatively minor compared to mining and refining costs. Providing that a company can produce the metal at or below market price it can generally sell the product relatively easily. Therefore, metal mines can be developed at considerable distances from population centres or processing plants. With industrial minerals the situation is more complex. Many industrial mineral commodities have low unit values. Thus transportation costs are a major consideration and deposits have to be close to market, or have access to inexpensive transportation, to become producers. This situation exists because the geological resources far exceed the anticipated demand for the commodity in the foreseeable future. For example, in some parts of British Columbia there is excellent potential to locate large limestone deposits in areas where it is impossible to transport the rock or possible products (e.g. cement, lime) economically to the market. In other words, there are significant potential geological resources, but the demand for the commodity limits the value of the resource for the foreseeable future (a relatively uncommon situation for metallic deposits). If the value of in-place resources for deposits like this were used in mineral potential assessments, it would overshadow the value of smaller deposits with readily available markets or high unit values. Since there is a limited market for most of the industrial minerals, estimates of the relative value of industrial mineral resources must often be “capped” to provide a meaningful value for planning processes.

Given the difficulties associated with determining a realistic “gross in place value” (GIPV) for industrial mineral assessments, the GSB developed a new approach. In this process two different assessments are made, one for metallic commodities, and one for industrial mineral commodities. The results are presented separately and no attempt is made to equate or combine the results of the two assessments.

The Level 1 ranking of the land base for metallic deposits is based on the GIPV of commodities in each tract contained in both known and a predicted number of undiscovered deposits. The GIPV of the commodities in each deposit are used to generate a total dollar score per hectare for each tract (Kilby, 1995, 1996). These total dollar scores per hectare are then used to rank all of the tracts under consideration. The GIPV of many industrial mineral deposits is not an acceptable way to compare their relative values because of market constraints. The industrial mineral assessment used a deposit score system where each deposit type was given a “relative deposit value score” (RDVS) from 1 to 100. The RDVS provides a relative ranking for the industrial mineral deposit types and may vary from one geographic area of the province to another. So while the relative deposit rank of metallic deposits is based solely on the value of contained metals or the “gross in place value” (GIPV) industrial mineral deposit relative rankings consider the following six characteristics:

1. commodity unit-value,
2. size and location of potential market,

3. deposit grade and size,
4. transportation costs,
5. existing infrastructure, and
6. extraction costs.

In the industrial mineral resource assessment process, the RDVS is used in the same manner as the total GIPV of all the commodities in a metallic mineral deposit to describe the relative value of each undiscovered deposit type.

Deposit Models

Descriptive deposit models were developed as part of the Level 1 MRA for mineral deposits that were known and believed to exist in British Columbia. This work built on the work by the USGS and others (Cox and Singer, 1986) but updated these global models and more closely described characteristics expected in BC. Along with the descriptive models, a classification framework was established in which deposit types were ordered according to their genetic characteristics (Lefebure and Ray, 1995, Lefebure *et al.*, 1995 and Lefebure and Höy, 1996; Simandl *et al.*, 1999).

Descriptive deposit models are essential to the BC mineral resource assessment process. They provide the standardization required to assure that all participants and users understand exactly what is meant when discussing a given deposit type. The deposit examples given in each model help the estimators visualize the deposit type being estimated. The deposit description assists the estimators during the estimation process by identifying characteristic geological, geochemical, geophysical, alteration and weathering features.

MINFILE deposit classification

The MINFILE database of mineral occurrences in the province contains about 12,000 entries. At the start of the Level 1 MRA, this database was in good shape but did not contain uniform deposit classification information. Consequently, a series of contracts were let to industry consultants to classify the deposits that were listed in MINFILE. The contractors assigned a given deposit up to four possible classifications in order of importance. This classification information is now incorporated into MINFILE. Classification of all known occurrences provided a database that was used for several purposes during the mineral resource assessment. First, the classifications allowed associated resource tonnages to be included in the calculations if they met the qualifying criteria for inclusion in the digital models. Second, knowing the locations of all deposits of a given deposit type in MINFILE was very helpful to the experts during the estimation process.

Geology Compilation

Mineral Resource Assessments rely on accurate, up-to-date geologic information since geology is the primary control for the distribution of mineral resources in the Earth's crust. A major task during the original Level 1 MRA was to compile the geology of the province at a scale of 1:250 000. All available information was examined and reinterpreted using the latest information on the geology of the region. Typically, all available provincial, federal, academic and industry work was compiled and digitized to form the final map product. More than 30 geologist-years were dedicated to this effort. All compilations were produced in GIS compatible digital format and were made available for download and viewing over the Internet (http://www.mapplace.ca). This geological compilation formed the basic framework on which all subsequent MRA analysis was performed.

MRA Tracts

Upon completion of the geological compilation, the province was divided into mineral assessment tracts. These tracts are based on common geologic features and their boundaries correspond to existing geologic boundaries such as faults or significant changes in the age and types of rocks present. Once defined, these tracts become the base unit areas in which the assessments are performed. The original Level 1 MRA resulted in the definition of 794 tracts in the province. The size of tracts can vary significantly but in general were intended for use on a broad regional scale (e.g. 1:250 000). The average size of tracts in the Level 1 assessment is about 100 000 hectares. For each tract, permissive deposit types were determined and an estimate for their existence within the tract in question was made by a panel of experts.

Deposit Model Data Preparation

The two types of input required for the Monte Carlo Mineral Resource Simulator are the experts' estimates of the potential for new discoveries and the digital deposit models describing the grade and tonnage distribution of each deposit type for which the simulator will be used. The digital deposit model contains a list of realistic deposit grades and tonnages for the model types that might be found in the area being assessed. The USGS has constructed many of these models using deposits from around the world. In some cases the parameters of these models were modified to better describe probable grade and tonnage distributions for deposits likely to be found in British Columbia. New models were required where an adequate model did not exist. In some cases existing USGS models were combined or subdivided to better accommodate the British Columbia situation (Grunsky, 1995).

Known Resources

The final resource assessment value for each tract incorporates both the known and yet to be discovered resources. The known resource values were compiled as part of the Level 1 MRA project. Each mineral occurrence in the provincial database was researched to see if any resource values had ever been published. All deposits with resource values were tabulated and their deposit types evaluated. These values were incorporated into the digital deposit models that are used as part of the input to the Mark3B simulator. The results of this resource compilation work were subsequently incorporated into the MINFILE database and have been published as Open File 1995-19 (MINFILE Team, 1995). This publication is the source of resource values used in the final calculation of the Level 1 tract assessment score. The resource values were converted to a dollar value based on a commodity price list developed for the Level 1 assessment.

Commodity Values

A dollar value was established for each commodity to allow the calculation of gross in-place values (GIPV) for each tract. In the Level 1 MRA, the dollar value used for each commodity was the average market value of that commodity for the ten-year period from 1981 to 1990. The dollar values used for the Level 2 MRA described in this report are based on either December, 2002 commodity prices or averages for the last ten years as of the end of 2002.

Resource Estimation

Mineral resource assessments have a long history and an associated large number of assessment methodologies. At the beginning of the Level 1 MRA project a workshop was organized to obtain input from government, university and industry sources on the type of methodology that would be best suited to our required products, our existing databases, our resources and our time constraints. The workshop was held in Victoria, BC on April 22 and 23, 1992. The content and results of the workshop are described in detail in Kilby, 1992.

The estimation procedure that was developed for the Level 1 MRA project incorporated several significant modifications to the USGS three part methodology. In the USGS methodology a single set of estimation values is sent to the simulator. If a group of estimators were involved, this single estimation would have been obtained by consensus. A great deal of work in the field of psychometrics has shown that a true consensus may be unachievable, and certainly would not be achievable within the time constraints most resource assessment projects are faced with. The interaction of people's personalities and agendas would override the information being solicited in a group setting (Acquired Intelligence Inc., 1993). In order to reduce stress and undo influence, each estimator was allowed to make estimates in confidence. The weighted scores provided by the estimators were then used to produce a weighted average of the estimates and obtain a single group estimate for input to the simulator.

The Mark3B simulator requires estimation input at discrete confidence intervals. However, making estimates at specific confidence intervals is believed to restrict the accurate expression of the estimators' true feelings. This is believed to be due to the fact that a great deal of concentration is diverted to thinking about the confidence intervals rather than the estimate being made. An alternative way to record the estimates, and the one used in both the Level 1 and Level 2 MRA projects, is based on fuzzy logic theory. In this method the estimator records the value as a position between two end points. The two end points being, "no chance of a deposit" (0% confidence) and "certainty of a deposit" (100% confidence) (Acquired Intelligence Inc., 1993). The simple linear scale is believed to capture a more realistic sample of the estimator's feelings than the discrete probability level entry style of the USGS three-part methodology. Once the estimates are recorded in this manner discrete probability level values are derived numerically.

Estimation Workshops

The Level 1 MRA involved convening estimation workshops for different regions in the province in order to solicit the required expert estimations for the assessment. Industry and government personnel familiar with a given region and mineral deposit types being assessed were invited to the workshops. These experts were divided into groups of 3 to 4 individuals and each group was assigned a series of deposit types to assess. A large amount of background information, such as the geological compilation, MINFILE occurrence maps and geochemical maps were prepared prior to the workshop to assist the estimators. Today most of this information is provided on-line through the MapPlace web site (www.MapPlace.ca).

Estimators

Estimators were invited to the workshops based on their expertise in the area being assessed and their familiarity with specific deposit types. Naturally, for any given area, one or more individuals might have a better level of knowledge to bring to the table. In order to capture this variability and allow for some weighting of the estimates, each estimator was asked to give a numerical score for their fellow estimators that reflected how they perceived each persons knowledge level.

Estimators were not asked to rate their own knowledge level and were automatically given a score of 50.

Workshop Data

Geological information forms the basis of all discussions during both the Level 1 and Level 2 MRA workshops. At the workshops, this basic information was provided as both paper maps at 1:250 000 scale and as online access to the MapPlace web site. Other spatial data sets such as geochemistry, mineral occurrences and tract outlines were usually superimposed on the geology in the form of overlays or plotted directly on the printed maps. In general, as much as possible of the spatial information was made available in the same projection and at the same scale to facilitate efficient use of time by the estimators.

For some data sets it proved to be more important to have the supporting information available in its original format rather than in a totally integrated format because that was how the estimators were familiar with it. Geophysical information, for example, was always made available but was usually in its published format. Though the format was not digital, it was used for some deposit types and proved to be easily integrated by the estimators.

In addition to the information presented in map format, a large amount of material was made available in text format. A compendium of the following information was provided to each estimation table:

- descriptive deposit models
- graphs of the digital deposit models
- a list of all deposit types with their median tonnages and grades
- a small map displaying all tracts in the study area
- a list of all tracts and their areas
- a list of all resource bearing deposits by tract
- a list of all MINFILE occurrences by tract with deposit type information
- a tracking sheet for the table facilitator to log estimates made.

The PC based MINFILE/pc database system was also made available at all workshops.

In addition to information that the project made available at the workshops, estimators brought company information, usually in the form of private reports or works in progress that proved extremely useful. This private information was freely shared at the estimation tables and was essential to the success of the process. More important still was the personal experience and knowledge of the estimators; it was key to the success of the assessments.

Estimation Process

Each Level 1 estimation workshop began with a presentation that described the estimation process, its rules, the information available, the estimator’s responsibilities and how the estimation results would be processed. A second presentation by a geologist involved in the area's geological compilation and tract selection described the geology and metallogeny.

The invited estimators were divided into groups of 3 to 4 people. Each group was assigned a series of mineral deposit types and their task was to provide estimates for each tract in the entire study area. For example, they might be asked to estimate the number of copper and iron skarns and multi-element veins deposits for the whole of Vancouver Island. Each group or table consisted of these estimators and one facilitator. The facilitator’s purpose was to keep the process on track, manage the coding sheets and make sure the rules of estimation were followed. The facilitator did not make any estimates but was free to participate in any discussions or assist in any way possible. Each group was assigned a table to work at and all tables were relatively close to each other to promote consultation with other tables should the need arise.

Four basic guidelines were followed by the estimators:

1. The estimators made their own estimate in confidence. No table consensus was sought.
2. Each person made a confidential evaluation of the other estimators with respect to each tract/deposit model combination.
3. If all estimators agreed that a particular deposit type would not be found in a tract, then no estimate was made, but if at least one estimator felt there was a chance for the deposit type to occur in the tract then everyone made an estimate.
4. The deposit size, for this process, was the median tonnage of the digital deposit model for the deposit type.

A typical sequence of actions for the estimate of a single tract/deposit type combination would be:

1. A general table discussion of the tract geology and the characteristics of the deposit type would often result in the group identifying characteristics of the tract that were favourable for the deposit type. All available information sources would be used during this step, such as MINFILE, geochemistry, geology, geophysics and personal knowledge.
2. The group would identify any known occurrences of the deposit type being estimated from MINFILE. Care was taken to properly include these known occurrences. So long as an occurrence did not have defined resources, it

influenced the estimates of undiscovered deposits. If it had significant known resources but was not expected to be enlarged through additional exploration by at least the amount of the digital deposit model median tonnage, it was excluded because the resources would be counted as inventory. If there was an opportunity for a deposit to be increased in size by at least the amount of the median tonnage for the deposit model type, an estimate for this additional amount could be considered in estimators' evaluation. In this case, the already known resources would be considered as inventory and the potential new resources possible through additional exploration would be considered as potential resources.

3. When each estimator recorded estimates for a single deposit type they would do the following:
    - Ask themselves "How confident am I that at least one more deposit of the median tonnage size can be found in this tract?" They would then place a tick mark on the estimation scale and the number one above it to record the number of deposits associated with the estimation tick mark (Figure 3).
    - Then they would proceed by asking themselves how confident they were that at least two deposits of the median tonnage could be found. In this instance the probability estimate tick mark is labeled 2. Estimators were not restricted to increments of one deposit but could choose any number that was appropriate. They were, however, limited to a total of six tick marks on the scale.
    - Then if they wished, they could add a single tick mark to the scale, which recorded the confidence level, at which they were confident no deposits could be found. This option was often confusing and required care in use. If this option was not provided, then the simulator assumed a default value for zero deposits because the program always assumes that there is some chance of the deposit type existing. Although this feature is used to help constrain the simulator, it was seldom used by the estimators.
    - Following completion of their estimates, they were required to evaluate each of the other estimators for that tract/deposit type combination. To do this they recorded the estimators' initials and record a ranking score. They were required to distribute 50 ranking points between the other estimators at the table. In this way they could adjust the weight placed on the others' estimates in accordance to their feeling of each person's knowledge of the tract and deposit type.
    - Finally the estimators would place one tick on the estimation confidence scale recording their overall feeling of the quality of that estimate. This was not a measure of their confidence in their own estimation but was a measure of their confidence in the quality of the estimation made by the group as a whole that included the general group knowledge of the tract and deposit type, the quality of the information available and the quality of the estimators. This value is not used in calculating the potential of the tracts but has value for gauging the quality of the estimate should the issue arise in the future.
4. Once all the estimates for the tract/deposit type combination were completed, the facilitator would check to make sure all required information had been recorded and then staple all the work sheets together.
5. The table would then move on to the next tract/deposit type combination.

Pre-Simulation Estimate Preparation

Upon completion of the estimation of the potential for undiscovered mineral deposits in a tract, the information captured on the coding sheets was converted into digital files. These files were then processed to provide input into either the Mark3B simulator or the industrial mineral evaluation process.

The estimation coding sheets were processed once a workshop was completed. The initial step was to digitize the linear Estimate Scale on each sheet. This digitization involves measurement of the distance along the estimation bar, from 0 to 100 for each tick mark made by the estimator.

Once all the estimation-coding forms were digitized the information was recorded into computer files. Upon completion of the data entry phase, the multiple estimates for each group/tract/deposit combination must be reduced to a single weighted estimate based on the weights assigned by each estimator at the table. The QuickBasic program RAW2MARK.exe written by Ward Kilby produces a single weighted estimate for each tract/deposit type. Two output files are created by the program, one containing a script of input values for the Mark3B simulator and the other containing the weighted estimates of the number of deposits that the group thought could be found in the tract at the 90, 50, 10, 5 and 1 percent confidence levels. The program uses linear interpolation between the values noted on the coding sheet to calculate the number of deposits expected at the five discrete confidence points needed for input to the Mark3B simulator. Simple weighted averaging is used to combine all the estimates for a single tract/deposit type combination.

As described earlier, each estimator was required to rate each of the other estimators at the table by distributing 50 ranking points between the other estimators based on the estimator's feeling of their relative knowledge of the deposit type and tract being estimated. Each estimator was also assigned 50 ranking points to assure that each estimator's estimations provided at least some input to the group estimate as the estimators could not apply any ranking points to their own estimations. Thus the total number of points for any estimate would be 100 times the number of estimators. The weighting of each estimator's values in the combined result would then be their total number of points divided by the total number of points for the whole table.

Industrial Mineral Resource Calculation

As described earlier, the industrial mineral (IM) resource assessment calculations differ from those performed for metallic minerals. The processing of the estimate information for the two types of commodities diverges after the weighting stage. Once the weighted mean estimates for each IM deposit type in each tract have been calculated, the deposits are valued by multiplying the number of deposits by the RDVS.

At this point, the estimate portion of the industrial mineral assessment is ready to be integrated with tract area and inventory information to allow final tract ranking calculations to be performed. This integration and calculation step is performed in MS Access. Two MS Access queries are used to perform some simple calculations on this data, add some additional fields and perform the ranking of the tracts.

The calculations performed in MS Access are identical for industrial minerals and metallic minerals. The only difference is that the values in the estimation fields for metallic commodities are in dollars and the corresponding values for industrial minerals are RDVS.

MARK3B MINERAL RESOURCE ASSESSMENT MONTE CARLO SIMULATOR

The original Mark3 simulator was developed by the USGS and has been used in many mineral resource assessment projects (Brew, 1992, Brew *et al.*, 1991, Cox and Singer, 1986, Cox, 1993, Root *et al.*, 1992 and Spanski, 1992). An excellent example of one of these projects, and a description of the operation of the simulator, can be found in Root *et al.*, 1992. The simulator itself was released in 1998 (Root *et al.*, 1998). Originally the simulator was available in the Fortran computer language and required significant computer resources to operate. During the Level 1 MRA project the Mark3 simulator was rewritten in QuickBasic by the USGS so that it could be operated on the more common PC platforms. This new simulator was called Mark3B to designate its QuickBASIC source code. This QuickBASIC version was provided to the GSB along with considerable advice and recommendations (Root, Pers. Commun. 1993). The Mark3B was modified slightly to provide a custom output file that simplified the data processing involved in producing tract rankings. The functions of the simulator have been described elsewhere (Brew, 1991 and Root *et al.*, 1992) but the eleven basic steps that the simulator goes through during a calculation are summarized here (from Root, unpublished).

1. Choose, at random, the number of deposits for this iteration. If it is zero, go to step 10 otherwise go to step 2.
2. Choose, at random, a suite of metals. Go to step 3.
3. Evaluate, at random, m+1 independent standard normal random variables (m= the number of metals in the model). Go to step 4.
4. Calculate the linear combinations of the values of the standard normal random variables from the matrix of coefficients in the "bem" file to obtain the values of m+1 dependent standard normal random variables. Go to step 5.
5. Find dependent uniform values from the dependent standard normal random variables (by the inverse of the cumulative standard normal distribution function evaluated at the values determined in step 4). Go to step 6.
6. Find tonnage and grade values from the dependent uniform values and the inverse of their cumulative distributions. Go to step 7.
7. Add the amount of each metal to its total for the deposits in this iteration. Go to step 8.
8. Check to see whether there is another deposit to do in this iteration. If there is, go to step 2, otherwise go to step 9.
9. Check to see whether 4,999 iterations have been completed. If not, go to step 1, otherwise go to step 10.
10. For each metal, sort the 4,999 totals from each iteration (least being rank1 and greatest being 4,999).
11. Graph 1 minus the rank divided by 4,999 on the y-axis versus the quantity of metal on the x-axis to obtain the assessed distribution of the metal in the area.

In addition to the above steps, a modification to the program extracted the total amount of each commodity calculated for each tract at five probability ranks (0.9, 0.5, 0.1, 0.05, 0.01) and output this information into a file called SIMTOT.all.

Operation of the simulator can be performed either in interactive or batch mode. With the output from the RAW2MARK.exe program the batch mode of operation is very straightforward.

The results in the simulator output, SIMTOT.all, are the tract number, the deposit type number, the commodity, a mean tonnage value, and the volume of the commodity in tonnes expected to be discovered at the five confidence levels (.9, .5, .1, .05, .01). The next step in the processing of the metallic mineral estimates is to convert the commodity amounts to dollar values to allow integration of all the commodities into one value for the deposit and subsequently the tract. This can be done easily in either MS Access or MS Excel or by using the SIM-VALU program created by Ward Kilby.

Once total tract dollar values have been calculated, this number is normalized for tract area to give a GIPV per hectare value. In the Level 1 MRA this value is integrated with inventory information to allow final tract ranking calculations to be performed. This integration and calculation step is performed in MSAccess.

Post-Simulation Calculations

Final ranking of tracts for both the metallic and industrial minerals assessment are performed in exactly the same way once the valued estimation information has been merged with the resource inventory and tract area information. MS Access is used to perform the manipulations required to produce the final rankings. The calculations are all based on a per hectare basis. In the calculations, each tract is ranked using each of the six confidence interval values individually, and then the six rankings are weighted by their probability and combined to produce the final rank value. This is done to isolate the estimates at the various confidence levels so they do not bias the final ranking score. This approach prevents an extremely high ranking at a low confidence level from overshadowing a lower ranking at a high confidence level.

For each of the variables (confidence interval levels), the tract is assigned a rank based on that variable normalized for the size of the tract (area). The rank numbers run from one, for the lowest ranking, to the total number of tracts for the highest ranked tract for that variable. The rank numbers for each variable are then weighted by their confidence value and summed to give a total score for each tract. For the final ranking, the scores for each of the tract are sorted from lowest to highest and assigned ordinal numbers from 1 to the total number of tracts (794) to give the final ranking.

The weightings assigned to the variables are, 1.0 for the inventory values, .9 for the 90% confidence values, .5 for the 50% confidence values, .1 for the 10% confidence values and .01 for the 1% confidence values.

Tract Ranking Maps

Two provincial scale maps were generated to display the relative ranking of the mineral potential across the province for the Level 1 MRA. One map illustrated the mineral potential ranking based on the metallic mineral commodities and the second map illustrated the mineral potential based on the industrial mineral commodities. These maps are useful to illustrate very broad trends in the potential but are not valid for detailed analysis of tract rankings. The maps do not include any measure of important variables that have affected resource development in the province such as regional exploration histories and infrastructure development. The mineral assessment evaluation was carried out on a regional basis.

Limitations of Mineral Resource Assessments

Mineral Resource Assessment maps and products are a very valuable component in any land use planning process. In jurisdictions containing substantial mineral resources such as British Columbia they are essential. Although considered essential to the process they are only a component of the information needed to make an informed decision on land use. There are a number of limitations to any Mineral Resource Assessment product.

COMPARISON OF TRACTS

Comparison of tract rankings from widely separated regions may result in flawed analysis due to their very different histories. Two tracts may have exactly the same mineral potential but due to the remote location of one relative to the other it will not have received the exploration attention over time and will likely have a lower mineral potential ranking than the tract that received the most exploration. Detailed comparison of tract rankings within a region or closely separated tracts in two adjacent regions is valid, as they will in most cases have shared a common exploration and developmental history.

TIME RELATED ISSUES

The principle limitation is the timeliness of the assessment. All assessments are made based on historic information and current knowledge. They are therefore, a snapshot in time. They cannot be expected to accurately portray the mineral potential of a portion of land far into the future. Our knowledge of mineral deposits will advance with time changing our ability to discover and

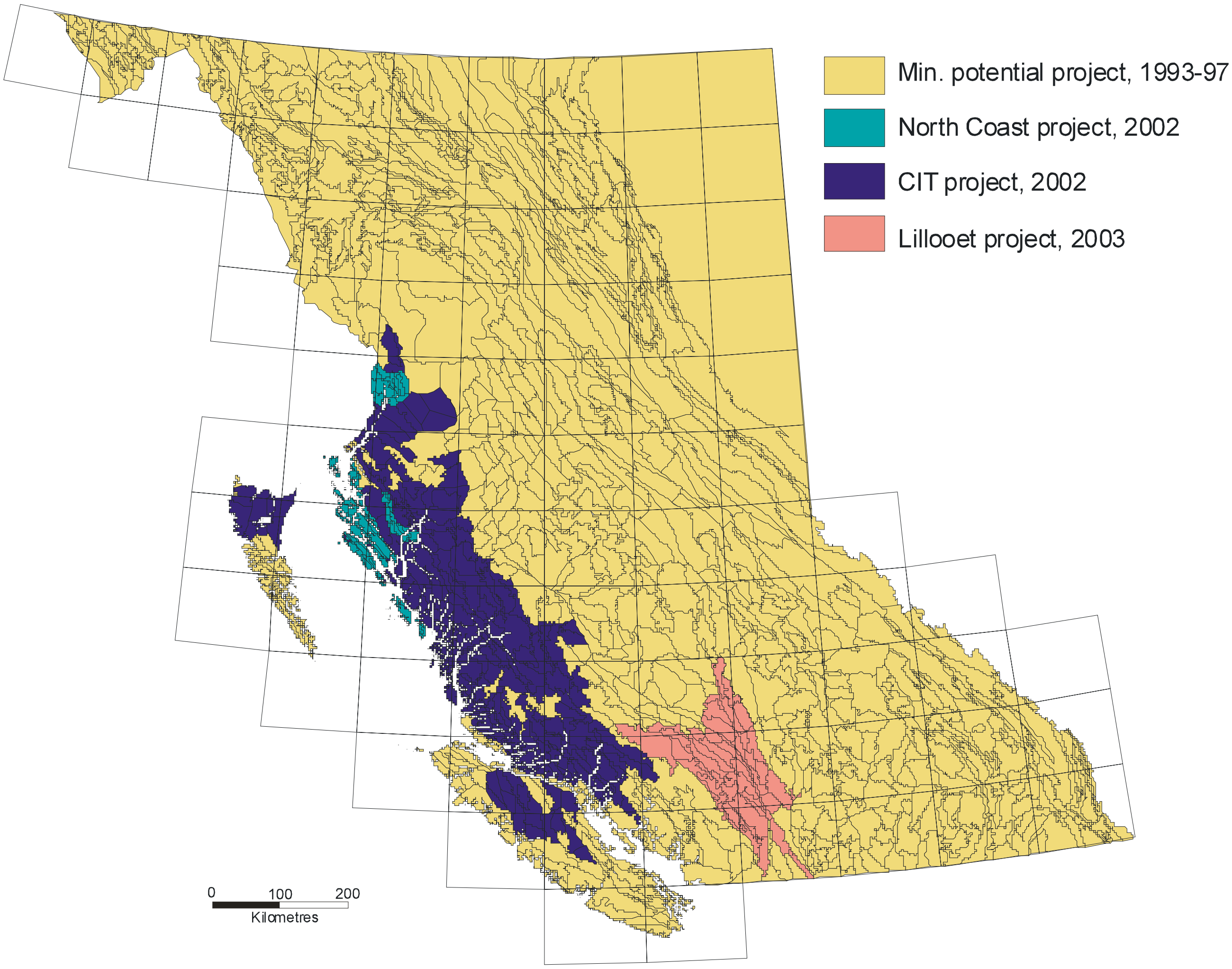

Figure 3. Mineral potential tract map for B.C. Tracts that were subdivided during the North Coast, CIT and Lillooet Level 2 Mineral Resource Assessment projects are shown in cyan, blue and pink respectively.

develop deposits in unimagined environments, at greater depths and with lower grades. New technologies will allow certain deposit types to be discovered with greater ease and will allow the profitable exploitation of deposits that are currently uneconomic. In addition deposit types that were not believed to exist in the study area during the analysis may subsequently be found within the area. Societal demands for certain commodities will change causing the relative values of deposits to change and thus the relative ranking of mineral assessment tracts.

SCALE RELATED ISSUES

The Level 1 MRA was conducted at a scale of 1:250 000. This scale was dictated by the client of the information and was used to present all resource evaluation information from all sectors to the various planning processes. The scale of analysis dictates the required resolution of the analysis units (tracts). Tract size limits the size of planning areas in which the tract can provide any information of value in differentiating the planning area. For example, if a planning area contains a single mineral assessment tract the mineral assessment information adds nothing to the planners' abilities to subdivide the planning area on the basis of mineral potential. In British Columbia as the planning process progressed, smaller and smaller study areas were proposed and land use planning initiated. In some LRMP areas only a few 1:250 000 scale mineral assessment tracts covered the whole LRMP. In these small areas an analysis of greater detail than the initial 1:250 000 study was required to be able to make any reasonable contribution with respect to mineral potential.

In some cases, the information in the provincial scale MRA can be used to generate a more detailed product without conducting a new estimation of undiscovered resources. Usually, the mineral resource assessment tracts contain a variety of geological units. The units, though grouped at a scale of 1:250 000, may in fact be permissive for different types of mineral deposits. If deposit types contributing significantly to the total value of a tract prove to be controlled by geological or topographical features that can be delineated within the tract then the associated values of known and estimated resources can be placed in these sub-tracts. By this means it may be

Estimator: ____________________ Date: ________ Time: ________

LRMP	Tract ID	Hectares	Minfile Occs.	Metallic Inventory $86	Exploration Expenditures $86	Past Production $86	Ind. Min Inventory $86	Metallic Rank (794 highest)	Ind. Min. Rank (794 highest)	Region			
ncoast	CP8___SKEE	127464	2	0	2827	0	0	80	135	SKEE			

Sub-tract	Primary Feature	Deposit Models								
		C1	H4/H6	H5	J4	K5	O2	O8		
		%	%	%	%	%	%	%	%	%
		100%	100%	100%	100%	100%	100%	100%	100%	100%

Associate Estimators

	Initials	Weight (%)
1		
2		
3		
4		
		must = 50%

Remarks:

Figure 4. Typical Level 2 MRA coding form used to redistribute exisiting estimates to sub-tracts.

possible to extract greater spatial resolution from the original study without performing a new assessment but simply redistributing the previously calculated values. These more detailed assessments are referred to as Level 2 MRAs.

LEVEL 2 MINERAL RESOURCE ASSESSMENTS

In order to provide a more detailed MRA for the CIT and Lillooet project areas, Level 2 assessments were conducted in October, 2002 and February 2003 respectively. The areas covered by these assessments are shown in Figure 3. These assessments incorporate elements from the Level 1 assessment (Bellefontaine and Alldrick, 1994, 1995; MacIntyre *et al.*, 1994, 1995; Massey, 1994, 1995) for undivided tracts and a preliminary Level 2 MRA applied to selected tracts within the North Coast LRMP that was done in February 2002

A major philosophical change was incorporated into presentation of Level 2 MRA results. The tracts were ranked only on the estimate of the undiscovered resources to emphasisze the potential for new discoveries. The known resources are shown by plotting the mineral occurrences and deposits as point data showing their gross-in-place-value (GIPV). In Level 2 maps this data is often superimposed on the MRA tract plots. This change means that Level 1 and Level 2 tract values cannot be directly compared.

The following tasks were completed in chronological order to produce the final Level 2 MRAs for the CIT and Lillooet LRMP areas.

Selection of MRA tracts for subdivision

Existing Level 1 MRA tracts that intersected or were within the CIT and Lillooet LRMP areas were examined and candidate tracts for subdivision were selected. All tracts with significant area within the LRMP boundaries and in excess of 100,000 hectares were targeted for subdivision. A final list of tracts was compiled together with pertinent information from the Level 1 MRA. A preliminary map in ESRI shape file format showing the tracts targeted for subdivision was prepared and posted to a MapGuide website prepared especially for each project.

Invitation to Quote for Metallic and Industrial Mineral Experts

Upon approval to proceed with the Level 2 assessments, an Invitation to Quote (ITQ) was prepared and posted to the BC-Bids website inviting metallic and industrial mineral experts with knowledge of the project areas to participate in an "experts workshop". Selection of participants was based on a review of pertinent credentials and their daily contract rate.

Expert Workshops

The first task assigned to the metallic mineral tables was to examine the geology of the existing Level 1 tracts targeted for subdivision and decide how they should be subdivided. Depending on the complexity of the geology

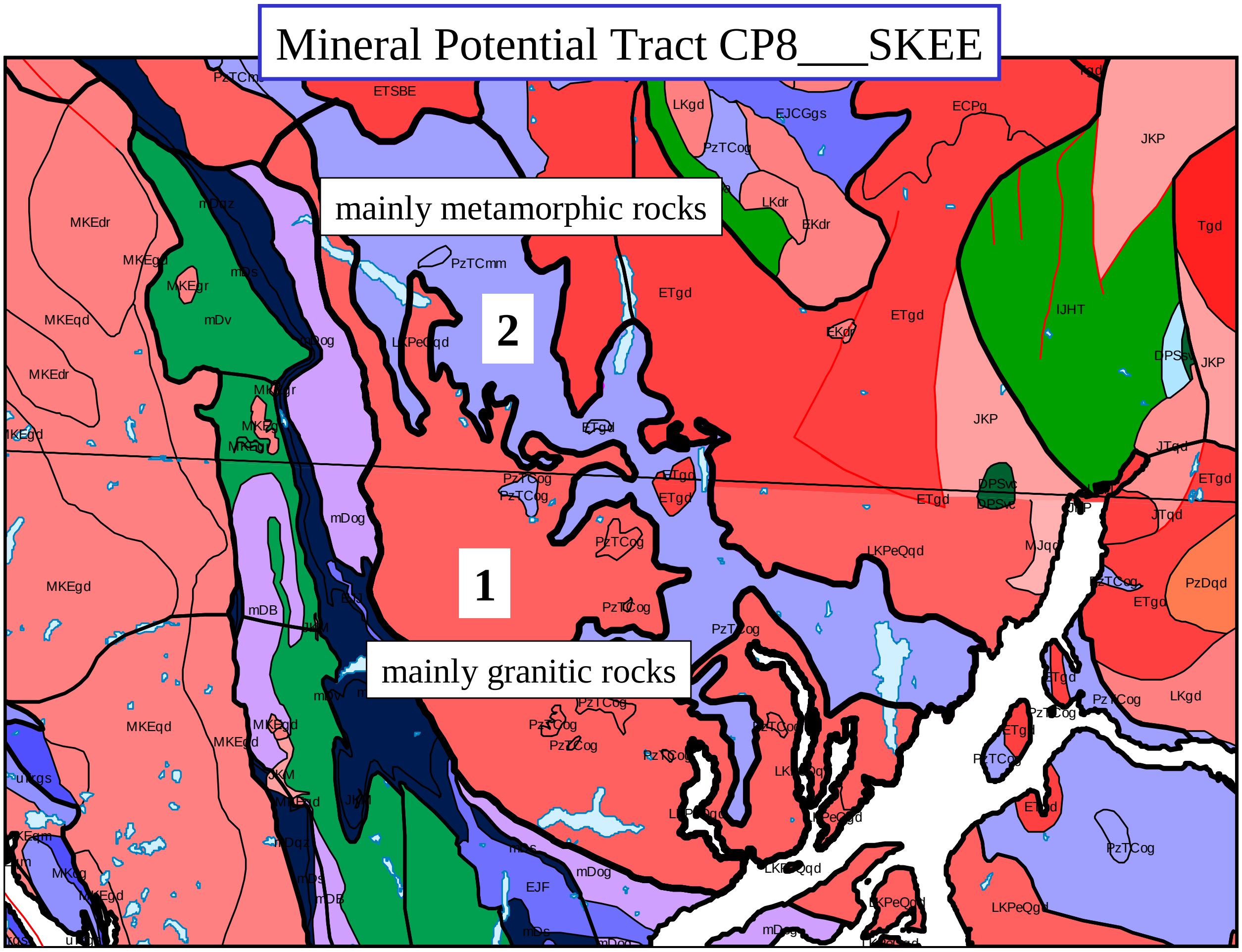

Figure 5. Map of tract CP8_SKEE showing a simple subdivision into two sub-tracts, one dominated by granitic rocks, the other by metamorphic rocks.

within the tract, anywhere from 1 to 5 sub-tracts were defined. Sub-tract boundaries were drawn directly onto coloured geology maps that were plotted specifically for each project. Sub-tracts were given a numeric label i.e. 1, 2 etc. The industrial minerals table that was convened the following week used the same sub-tract boundaries established by the metallic mineral experts.

Once the sub-tract boundaries were established, coding sheets were handed out for each tract being subdivided. As shown in Figure 4, these sheets contained information from the Level 1 MRA such as dollar values for inventory, exploration expenditures, number of MINFILE occurrence, tract hectares, etc., plus columns for each of the deposit models considered in the Level 1 MRA. Blank columns were also provided for any new deposit model estimates. These columns were labeled with the deposit code used in the original MRA. A lookup sheet was provided so that these codes could be cross-referenced to existing deposit profiles. For each sub-tract, a row was added to the table grid and a brief description of the primary geologic features of the sub-tract entered in the cell next to the sub-tract number.

For each deposit model, the experts were given time to discuss the likelihood of that type of deposit occurring in each of the sub-tracts. To assist this discussion, the facilitator used a notebook computer connected to the Internet and a digital projector to display information on the geology, mineral occurrences, geochemistry and geophysics in the vicinity of the tract under consideration. Most of this information was derived on-line from the MEM MapPlace website (www.mapplace.ca). Also included in the discussion was an evaluation of the models considered in the Level 1 MRA and whether new models should be estimated for. If the table decided that new models should be considered, estimation forms for that model were distributed and the experts were asked to fill these out using the same methodology used in the Level 1 MRA. Once this task was completed the experts were then asked to indicate the percentage of each deposit model estimate that should be assigned to each sub-tract. These redistribution percentages were based on the geologic characteristics of the sub-tracts and the relatively likelihood that a particular deposit model would occur in that sub-tract. In some cases, because the deposit model

Similar sub-tract areas

metamorphic assoc.

granitic assoc.

Tract ID					Estimated no. undiscovered deposits				
					Confidence Level				
CP8__SKEE			28220 Ha		99%	90%	50%	10%	1%
C1	Placer Au		Tract estimates		0.000	0.000	0.81	2.580	3.000
	1	57.41 % of tract area	Redist. to sub-tract	48.96 %	0.000	0.000	0.397	1.263	1.469
	2	42.59 % of tract area	Redist. to sub-tract	51.04 %	0.000	0.000	0.413	1.317	1.531
H4/H6	Besshi/Cyprus Massive Sulphide (Merged)		Tract estimates		0.000	0.000	0	0.670	1.000
	1	57.41 % of tract area	Redist. to sub-tract	29.62 %	0.000	0.000	0.000	0.198	0.296
	2	42.59 % of tract area	Redist. to sub-tract	70.38 %	0.000	[illegible]	[illegible]	[illegible]	[illegible]
H5	Noranda/Kuroko Massive Sulfide		Tract estimates		0.000	[illegible]	[illegible]	[illegible]	[illegible]
	1	57.41 % of tract area	Redist. to sub-tract	29.62 %	0.000	0.000	0.000	0.418	0.592
	2	42.59 % of tract area	Redist. to sub-tract	70.38 %	0.000	0.000	0.000	0.992	1.408
J4	Au-Quartz Vein		Tract estimates		0.000	0.120	0.79	1.600	2.000
	1	57.41 % of tract area	Redist. to sub-tract	41.46 %	0.000	0.050	0.328	0.663	0.829
	2	42.59 % of tract area	Redist. to sub-tract	58.54 %	0.000	0.070	0.462	0.937	1.171
K5	Polymetallic Ag-Pb-Zn Vein		Tract estimates		0.000	0.130	0.83	1.670	2.000
	1	57.41 % of tract area	Redist. to sub-tract	46.91 %	0.000	0.061	0.389	0.783	0.938
	2	42.59 % of tract area	Redist. to sub-tract	53.09 %	0.000	0.069	0.441	0.887	1.062
O2	Porphyry Cu-Mo-Au		Tract estimates		0.000	0.000	0	0.500	0.000
	1	57.41 % of tract area	Redist. to sub-tract	66.55 %	0.000	[illegible]	[illegible]	[illegible]	[illegible]
	2	42.59 % of tract area	Redist. to sub-tract	33.45 %	0.000	[illegible]	[illegible]	[illegible]	[illegible]
O8	Porphyry Mo (Low F-type)		Tract estimates		0.000	0.000	0	0.700	1.000
	1	57.41 % of tract area	Redist. to sub-tract	68.56 %	0.000	0.000	0.000	0.480	0.686
	2	42.59 % of tract area	Redist. to sub-tract	31.44 %	0.000	0.000	0.000	0.220	0.314

Figure 6. Summary of redistribution results for tract CP8__SKEE.

was not strongly controlled by a specific geologic characteristic there would be roughly equal likelihood that a deposit might be found in each of the sub-tracts. For other deposit models, such as those associated with specific rock types such as intrusions, the occurrence or absence of these features in a sub-tract would significantly influence the percentage of the original estimate to be assigned to that sub-tract. Naturally, column totals for each deposit model must total 100%. The experts were also asked to indicate on the redistribution form a personal confidence level (PCL) as a score out of 100, which would reflect how they felt about their personal knowledge of the tract and mineral deposit models being discussed. In addition, they were also asked to rank the other experts at the table by assigning points, the total of which must add up to 50. Figure 5 shows a typical tract which has been subdivided into two subtracts. Figure 6 shows the final redistribution results based on input from each member of the expert panel.

Data Processing

Data processing was done by GSB staff and began immediately after the expert workshops were completed. The first task involved processing metallic and industrial mineral deposit estimation forms. For each estimator and each deposit model this involved measuring the location of tics on a probability bar, converting these values to a probability percentage, recording the number of deposits estimated at each probability level and recording the weights given to the other estimators at the table. This raw data was entered into separate excel spreadsheets for metallic and industrial mineral deposits. This data was then reformatted and exported as a comma delimited ASCII file for input into the RAW2MARK QuickBasic program written by Ward Kilby. This program calculates the weighted average number of deposits for each deposit

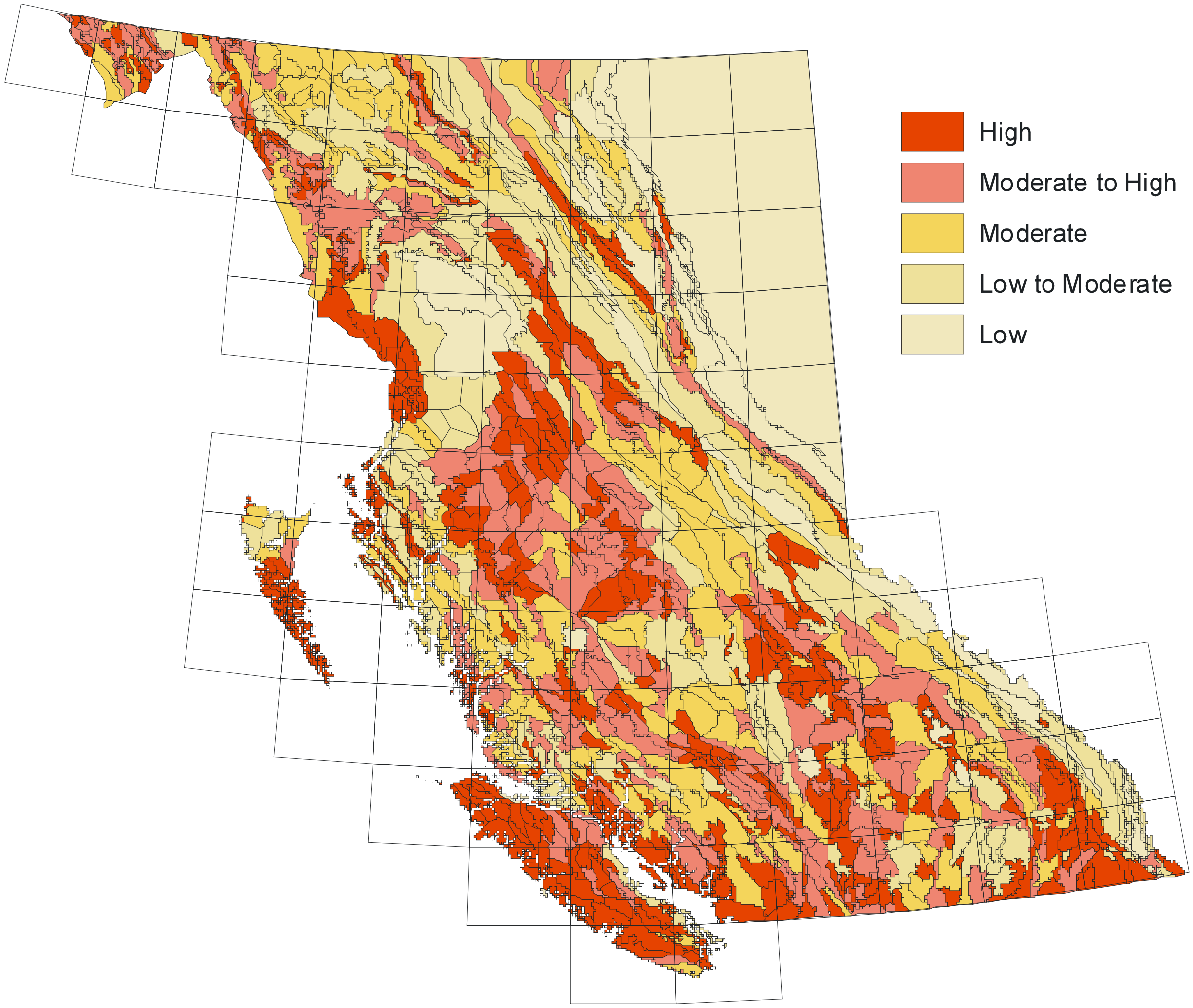

Figure 7. Revised metallic mineral potential map for B.C. incorporating Level 2 MRA assessments for the CIT and Lillooet LRMP areas as discussed in this report. Total number of tracts is 907 (794 in original mineral potential map).

model at the 99, 90, 50, 10 and 1 percent confidence levels. The results of these calculations are given in tables 3 and 4 respectively.

The second data processing task involved entering the redistribution percentages, personal confidence levels and weights assigned to the other estimators at the table from the redistribution worksheets. Redistribution percentages were recorded in an MS Excel spreadsheet with one record created for each value recorded on the worksheets. Personal confidence levels and weights given to associated estimators were entered in separate spreadsheets. All this data was imported into an MS Access Database where a series of queries were used to calculate a weighted average redistribution percentage for each deposit model in each sub-tract. These percentages were then applied to existing Level 1 estimates of the number of undiscovered deposits at the 99, 90, 50 , 10 and 1 confidences levels and new estimates completed as part of this project to give a new set of redistributed values for each sub-tract-deposit model combination.

Once the estimated number of undiscovered deposits at the 5 confidence levels had been tabulated for each of the tracts and sub-tracts in the project area, this data was reformatted for input into the Mark3B resource simulator. The input required to run the simulator includes the tract number, deposit model number, number of iterations to perform, number of confidence levels to use and the estimated number of undiscovered deposits at each of the confidence levels. Since the tract names are too long for input into the simulator a key number was created for each tract and subtract deposit numbers used by the simulator correspond to the names of a series of files containing commodity, grade and tonnage information used in the Monte Carlo simulation process.

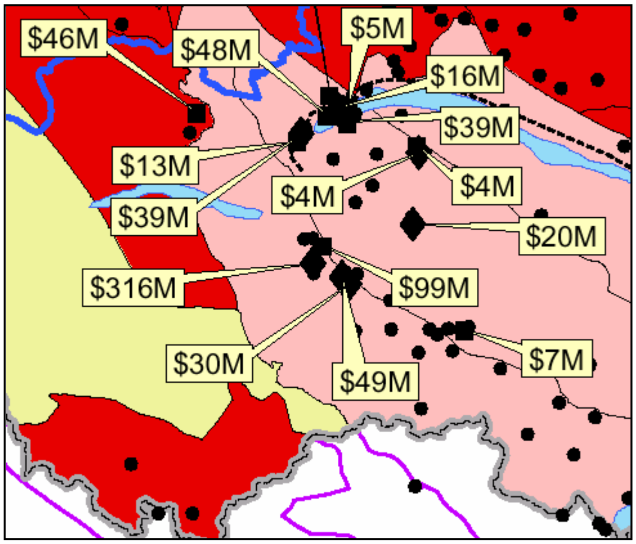

Figure 8. Level 2 MRA tract map of the area around the Bralorne Mine. Tract rankings are the same as shown in Figure 7. Superimposed on the Level 2 map are the GIPV for known resources in the Bralorne area.

For this.project the number of iterations for each tract-deposit model combination was set at 2000 and estimation data was entered for the 90, 50 and 10 percent confidence levels. The output from the simulator is written to a comma-delimited, ASCII text file (SIMTOT.ALL). Each record has the tract number, deposit, number, commodity name and predicted tonnes for the mean and 90, 50, 10, 5 and 1 percent confidence levels. In order to have a base to compare rankings across the entire province, all tracts were re-run through the simulator. This resulted in an increase in the overall number of tracts from 794 to 907, this increase being a result of the subdividing of tracts that occurred as part of the Level 2 assessments described in this report.

The final data processing task for the metallic mineral deposit models was to determine the relative tract rankings using Gross-In-Place-Values (GIPV). This procedure for ranking metallic mineral tracts is the same as that used in the Level 1 MRA with the exception that the value of known resources was not included in the calculation. The Level 2 MRA rankings are based strictly on the predicted value of undiscovered resources determined by the Mark3B resource simulator as described above. To determine the Level 2 rankings the predicted tonnes of commodity for each deposit model in a tract at the various confidence levels was multiplied by the per tonne value in current Canadian dollars. The values used for this calculation are listed in Table 7. The dollar values were then totaled for the tract and divided by the tract area to give a GIPV per hectare. These values were then discounted by factors of 0.9, 0.5, 0.1, 0.05 and 0.01 for the 90, 50, 10, 5 and 1 percent confidence levels respectively. Finally, these discounted values were given an ordinal ranking for each of the confidence levels. These ordinal ranks were then summed for each of the tracts or sub-tracts and this value was used to produce the final ordinal ranking for the tract. All of these calculations were done within an MS Access database. The rankings were then categorized into 5 divisions, each division representing 20% of the total land area of the province. A new Level 2 MRA map for B.C. was generated and is shown in Figure 7. This is map is now posted on the MapPlace website (www.mapplace.ca).

The ranking of tracts for industrial mineral potential does not use data from the Mark3 resource simulator. Instead a Relative Deposit Score Value is used as described for the Level 1 MRA. The number of predicted deposits is multiplied by the RDVS and then normalized to the tract area. These normalized values are discounted and ranked in the same way as the GIPV/HA values for metallic mineral deposits described above.

Known In-ground Resources

Unlike the Level 1 MRA, known in-ground resources (reserves) have not been included in the tract rankings. These values have been recalculated using current commodity prices and are presented as a point map for use with the Level 2 MRA ranking maps. An example of how the data is presented on such a map is shown in Figure 8. The map shows the GIPV of resources defined in the Bralorne Mine area of the Lillooet LRMP. Note that even though there are significant resources in the area, the tracts that contain most of the deposits are only given a Moderate to High ranking (pink colour) for potential for new discoveries. Adjacent tracts, on the other hand, are given a High ranking (red colour) for new discoveries. This approach clearly separates the known from the unknown and should assist land-use planners in assessing the potential for new mineral discoveries in a given MRA tract.

CONCLUSIONS

The Level 2 MRAs completed to date represent a significant improvement over the original Level 1 MRA because;

1. In general tract (sub-tract) areas are smaller and more appropriate for regional land-use planning
2. The subdivision of tracts into sub-tracts based on geology has resulted in a better definition of the potential within tracts to host specific types of deposits. This has resulted in a better definition of the areas within the CIT project area that have the highest mineral potential.
3. Values used for ranking are based on current commodity prices
4. Estimates for deposit models not included in the Level 1 MRA were added to the assessment and included in the final tract ranking.
5. The final tract rankings for the Level 2 MRA are based on the potential for new discoveries only

and are not influenced by known resources (in-ground reserves).

6. Known resources have been re-valued using current commodity prices and will be presented as a separate map layer in the future. Therefore, Level 1 and Level 2 tracts cannot be compared directly as they incorporate different datasets.

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