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Quality Assurance/Quality Control (QA/QC) for Resource Estimation at Inco Technical Services Limited

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Abstract — Resource modelling is a complex process involving different specialists with relevant experience using a multi-disciplinary approach and the best available technology and reviews by independent auditors. The reliability of the final resource estimate is highly dependent on the quality control exercised at each stage of the process. At each step in the resource modelling process it is necessary to define the specific objectives, the methodology proposed to achieve those objectives and to establish a set of checks and validation tools to assess the effectiveness of the proposed methodology. Designation of responsibility and authority for meeting these objectives must also be clearly identified. External audits must also be incorporated to review and validate the implementation of new procedures.

Resource modelling is the basis for any economic appraisal of a mining project and includes a number of steps from data acquisition and validation to resource reporting, classification, and risk analysis.

Introduction

Resource modelling is a complex process involving different specialists with relevant experience using a multidisciplinary approach. The reliability of the final resource estimate is highly dependent on the quality control exercised at each stage of the process. Data collection methods, as well as the data processing techniques, must be carefully selected in order to achieve the specific objectives outlined for each stage. Designation of responsibility and authority for meeting these objectives must also be clearly identified. A set of checks and validation tools must be established to assess the effectiveness of the proposed methodology in addressing these issues. External audits must also be incorporated to review and validate the implementation of new procedures. This validation step requires reliable documentation of the entire modelling process including a comprehensive listing of all the assumptions and limitations related to the resource model.

The purpose of this paper is to present the current quality assurance and quality control program used by Inco Technical Services Limited (ITSL) in the economic assessment of its exploration projects. The program is divided into a series of stages (Fig. 1), which include data acquisition and validation, geological interpretation, sample selection, global resource estimation, spatial and statistical characterization, grade interpolation, resource classification and reporting, and risk assessment. At each stage, the objective, the procedures to achieve the objective, the checks and verifications, and the responsible person(s) are all identified.

It is the responsibility of the resource evaluation group to compile and evaluate all of the deposit information. At each stage of the compilation and assessment of the deposit, the person responsible for the work is, or will be supervised by, a qualified person who will sign off on the completed work.

Finally, it is extremely important to understand that resource modelling is a dynamic process and the resource model changes over time as additional quantitative and qualitative data become available. Therefore, it is important that each stage in the process is fully and properly documented. This allows the assumptions underlying the model to be revisited on a regular basis to validate their relevance and reliability.

Data Acquisition and Validation

The objective at this stage is to create an accurate, reliable, and representative database for the mineral deposit. It

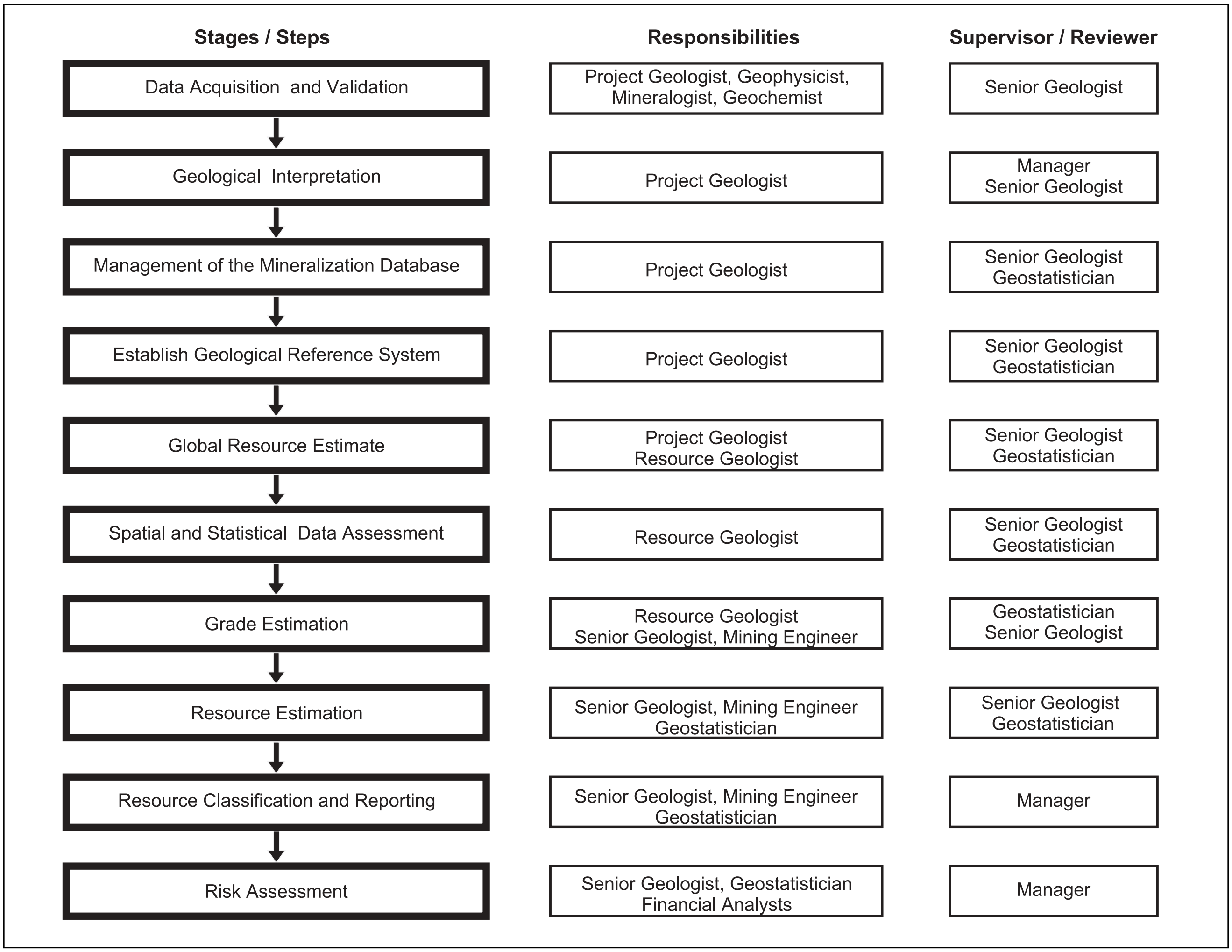

Fig. 1. Flowchart of QA/QC for resource modelling.

is the responsibility of the project geologist, geologists, technicians, geophysicists, mineralogist, and geochemists supervised by the senior geologist to ensure this objective is met. Data are obtained from mapping, diamond drilling and logging, sampling and assaying, geophysical surveys, and mineralogical and metallurgical studies.

Diamond Drilling

Ensuring that a diamond drill hole is located and oriented as planned is essential to effective and cost-efficient diamond drilling. For all ITSL projects, the drill hole collar location and collar orientation are established using a portable global positioning system (GPS) device. As drilling progresses, a single-shot gyroscopic survey test is done every 100 ft down the hole. A north-seeking gyro survey measuring absolute north is completed approximately halfway to the target. This gyro instrument is accurate to ±0.50 on azimuth readings and ±0.120 on dip readings. Periodic field calibrations and checks of the north-seeking gyro are done by the supplier/contractor with repairs completed as required. The results from the north-seeking gyro surveys will be compared to the current collar azimuths. At this point, the projected path of the hole to the target is reassessed and corrections to the path are made as the drill hole advances. When the hole has reached the target area, a final north-seeking gyro survey is completed. In areas of complex geology, oriented drill core is used to provide data on the orientation of lithological and mineral contacts as well as important structural features.

Drill Core Logging

The information collected during the core logging phase of exploration is the primary information used in the geological interpretation and assessment of the mineral deposit. It is important that all observations and measurements derived from the drill core be systematically recorded. Both geological and geomechanical information should be acquired during the core logging phase of data collection. The information collected includes a description and determination of the lithologies, style of mineralization, an estimate of the concentration of the mineralization, contact and structural feature measurements and character, and rock mass properties.

Standard logging procedures and software are used for all exploration projects. Training is provided to ensure that all geological personnel can acquire the necessary information, and follow the core logging standards.

All intersections of significant sulfide mineralization are cut in half using a core saw to maintain a permanent record of the intersection for further test work or additional observations required for geological modelling.

The geologist and technologist responsible for the drill program complete an error check of the drill log. Prior to being uploaded to a master drill hole database the logging software performs a check of each drill hole as well. These checks ensure that potential errors such as incorrect hole azimuths and dips, sample number sequences, rock codes, and hole depths are minimized. The drill log is also compared with adjacent verified and validated drill hole information.

Sampling and Assaying

Optimizing the precision and accuracy of the assay results begins with sample collection. Errors commonly associated with poor sample collection include sample contamination, sample biases, non-representative samples, and inappropriate sample lengths. Sources of contamination include the mixing of material at the limits of the prescribed sample and mixing of broken or loose core in the core box prior to sample collection. These sources of error can be minimized through careful core sample separation and drill core handling.

At the sample preparation stage the entire split core is crushed. Homogenizing the crushed material prior to riffling is critical in order to ensure a representative split for pulping. Dust losses, which can represent a concentration of sulfides higher than the original sample, are minimized by selecting an evasive form of ventilation. Homogenizing the crushed material prior to riffling is critical in order to ensure a representative split for all samples.

Errors may also occur during assaying of the pulps. Sources of error can include instrumental problems and human errors (i.e., switches between samples, incorrect weights used for the samples). The contract laboratory's internal quality control report is received every two weeks and compiled with previous values. Accuracy and precision of the certified and in-house standards are examined to ensure that acceptable levels are maintained and no long-term trends are developing. Duplicate sample assays are also examined for acceptable precision.

Switches can occur during sampling of the core, sample preparation, and assaying. The first check of the assay results is the comparison of the assays to the drill log estimate. This check minimizes the possibility that switching of samples has occurred.

The ITSL check program is carried out routinely and it consists of randomly selecting 5% of the samples, which are prepared by the contract laboratory from the crushed reject. These check pulps are assayed at Inco's laboratory to ensure that the original values meet the expected precision and accuracy. Inco's quality control samples are reported along with the check results and are compiled to ensure that the Inco results continue to meet the highest standards. The Inco laboratory automatically repeats any outliers. Check samples, which fall outside the expected precision (along with the original surrounding samples), are reviewed by the contract laboratory to determine if the error is systematic for a group of samples or merely isolated cases. Upon reconciling the differences, corrections are issued by the laboratory. The ITSL program checks both the sampling and assaying procedures of the contract laboratory and encourages the laboratory to minimize systematic and random errors. Precision and accuracy of these checks are routinely examined to ensure assays are within acceptable limits of error.

Occasional assay checks of the original pulps at the Inco laboratory ensure that accuracy at the assaying stage is acceptable. However, care must be taken to avoid selecting older samples that have oxidized, thereby introducing an additional source of error. In order to minimize oxidation of the samples, the crushed rejects are placed in containers, purged with nitrogen and stored in a walk-in freezer.

Geophysical Survey Data

Recent advancements in geophysics, in particular, borehole geophysical surveys, have improved the amount and quality of data that can be used for geological interpretations and resource modelling. The geophysical information is integrated with the drill hole database to improve the deposit model interpretation.

Geophysical methods fall into two main categories: those that measure the rock mass properties at the drill hole wall and those that measure the rock mass properties surrounding the drill hole or between two drill holes. In the second case, the properties are used to image the distribution of the mineralization between or around the holes.

Conductivity, acoustic velocity, density, and natural gamma probes are examples of methods used by ITSL to measure physical properties at the drill hole/rock interface (Cochrane et al., 1998). For these methods, quality control is concentrated on ensuring the veracity of the data collected through the regular use of calibration holes and samples.

Drill hole electromagnetic methods, radio imaging methods, and seismic tomography are used to determine the distribution of mineralization between and/or around drill holes. Imaging, modelling, and inversion methods are applied to these data to generate tomographic reconstructions of mineral distribution between holes or estimates of the location and attitude of the boundaries of mineralization. These data processing techniques produce results that are very sensitive to errors in the locations and orientations of the sources and receivers used. Therefore, for these methods, quality control focusses on issues relating to hole location and trajectory. In addition to the drill hole surveying procedures discussed previously, precision GPS surveys are also used to locate the surface electromagnetic (EM) transmitter loops. Hole trajectories are obtained using a combination of north-seeking and differential-free gyros. Downhole EM probes carry three axis magnetometers and accelerometers that provide independent, though less precise information about drill hole trajectory. These data are regularly compared to the gyro results to detect gyro malfunction as well as transcription and processing errors.

Specific Gravity Determination

Diamond drill core data used for resource estimations may have been collected from several drilling campaigns that have spanned several years. Prior to the commencement of block modelling, due diligence is conducted on the drill sample database to ensure that all data to be processed has a measured or calculated specific gravity. A review of data collected over a long period of time can indicate that the inherent variability of the specific gravity (density) of samples is reflected by the period of time that the exploration drilling was carried out. Each campaign may have utilized various analytical styles, techniques, and assaying methods that resulted in the derivation of different specific gravity figures for the same orebody.

Simple scatter plots are generated for various elements versus density and sulfur. Examination of these plots will ensure that the "most correct" database is utilized to generate the best possible block modelling results. A customized regression formula for the specific gravity is occasionally recommended for samples belonging to a specific property where no specific gravity exists in the existing drill hole database.

Mineralogical and Metallurgical Studies

The objectives of the mineralogical studies are to provide information used to assist in the definition of a deposit resource, recognize possible mineralogical domains within the deposit and provide key information for assessing the results of metallurgical tests. A series of representative samples of all styles of mineralization within all lithologies is submitted for comprehensive mineralogical studies before the mineralization model is completed. A detailed mineralogical study provides information concerning major and trace sulfide assemblages, grain size distributions, relative abundance of the sulfides, textural variations, styles of mineralization, nature of the mineral intergrowths and spatial variations in the sulfide assemblages in the deposit. The mineralogical studies are used to assist in determining mineral domains and patterns, the presence of deleterious minerals, and an understanding of the mineralizing process and mineral continuity.

The objectives of the metallurgical studies are to provide information to assist in the evaluation and assessment of the possible mineralogical domains within a deposit. Complete metal and rock analyses, microprobe determinations and metallurgical tests are completed. These studies are used to determine metal balances, overall recoveries and tailing grades, and ensure the mineralogical domains are consistent with known mineral processing techniques. The tests are completed using a representative composite sample of the mineralogical domains within the deposit. The metallurgical samples are collected using crushed drill core reject samples that have been purged with nitrogen and stored in a walk-in freezer.

Geological Interpretation

The objective of the geological interpretation is to create a representative 3D model of the deposit geology and the mineralization shape, incorporating all available information (Fig. 2). The geological interpretation, utilizing the collected and verified data, has the greatest effect on the quality of a resource estimate. The main issue in the interpretation involves establishing the spatial continuity of the mineralization domains where the grade distribution is assumed to be stationary; i.e., grade population has consistent statistical and spatial characteristics. The deposit model forms the basis of the resource estimate. It is the responsibility of the project geologist supervised by the senior geologist to create the geological and mineralization model. The exploration manager then reviews the model before additional work is completed.

Geological Model

The geological model forms the basis of the resource estimate and all subsequent geological, engineering, and

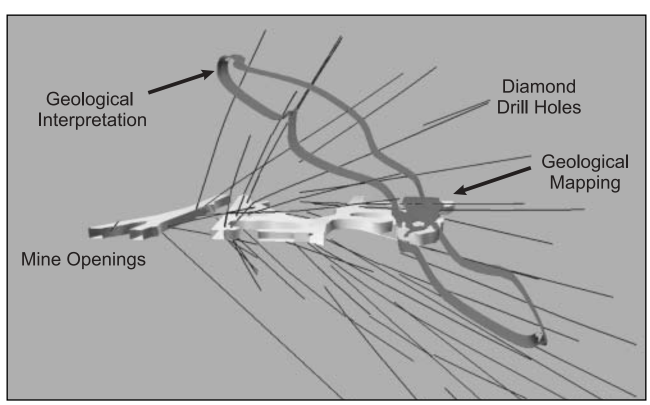

Fig. 2. Example of 3D mineral envelope.

economic estimates are ultimately based on this interpretative model (Cochrane et al., 1998). Early conceptual geological models are usually simple and idealized. As the information database increases, the model becomes increasingly refined and detailed. Geological interpretations evolve as new information is collected during the exploration and evaluation process.

Geological models contain information important to resource estimations. These include the continuity of the mineralization between drill holes, mineral zonation, the form and character of the mineralization, contact information, structural features and cross-cutting relationships, and geometry of the mineralization and associated lithological units.

The project geologists are responsible for combining all relevant data and observations into a 3D geological model. Interpretations are checked to ensure that the geological relations of the deposit are consistent with the regional geology. A review/assessment is completed to ensure consistency of the interpretation. Models of known similar deposits are commonly used as a comparison.

Mineralization Model

The modelling of the mineralization domains involves recognizing the existence of different zones created during the mineralization process. In geostatistical terms, these zones are often referred to as domains of stationarity. In practical terms, the geologist must identify the domains where the style of mineralization and mineralogical composition are similar and the grade distribution shows consistent statistical and spatial characteristics (e.g., histogram, variogram). This is the most critical step in the process of modelling a mineral resource. No sophisticated data processing or calculation will compensate for poor recognition of the mineralized domains. The outcome of this stage is a series of 3D envelopes, which are used to select mineralized samples and to model grade distribution.

The mineralization model is checked by both the geostatistician and senior geologist to ensure that the interpretation is consistent with the mineralizing process. The envelopes or wireframes are checked to ensure that the grade of the mineralization has not been overstated by assuming an irregular and complex interpretation of the mineralization between holes rather than a simpler, more realistic, broader-zone interpretation. In peripheral deposit areas, with limited geological information, a consistent criterion for extrapolating the mineral envelope is established.

Management of the Mineralization Database

The objective of database management is to ensure that mineralized samples are properly selected and separated into the different domains of stationarity. At this stage, missing values and calculated values must be carefully revisited to validate the mineral database integrity. Length compositing is also performed at this stage to ensure proper weighting of grade and density data. It is the responsibility of the project geologist supervised by the senior geologist and geostatistician to build an accurate and unbiased database to be used for the purpose of global and local grade estimation.

Calculated and Missing Values

Missing values in the grade and density database can be interpreted as true missing values or as implicit values. For example, in a sulfide deposit, the absence of visible sulfides in the rock implies the absence of a significant amount of base metal mineralization. But significant precious metals may be present which can only be determined if the same sample is assayed. In this specific example, base metal grade and density should be set to a low background value while precious metal grade should be recorded as unknown.

Another important issue to address at this stage is the potential occurrence of calculated values in the database. For example, assays done prior to any given date may include calculated values for some elements. Normally these calculated values are easily recognized on scattergrams. It is important to flag these values and check that they were calculated in a consistent manner for the entire database and under assumptions that are still considered valid.

Length Compositing

At the sampling stage, the project geologist must recognize significant changes in lithology and grade composition of the core and take separate samples for assay. Commonly, these changes occur over shorter distances in high-grade zones. As a result, higher-grade zones are usually sampled over shorter lengths. It is important for further data processing and calculations to assign an equal weight to all the samples. The original samples must be composited over a uniform length that is chosen on the basis of the median and the mode of the frequency distribution of assay length and the level of detail required in the final resource model.

Establish Geologic Reference System

The objective at this stage is to select the most appropriate reference system to assess spatial continuity and to model grade distribution within the envelope of mineralization. The distance between samples should be calculated using the frame of reference for the original mineralizing event (geological distance).

Because the spatial distribution of the mineralization is normally influenced by many controlling factors such as preexisting footwall topography, pinching and swelling of the zone, folding and faulting, the actual geological distance rarely coincides with the XYZ Cartesian distance. In order to obtain a proper reference system to measure spatial continuity between samples and interpolate grade distribution, a new reference system normally has to be established. Examples are provided in Figure 3. Many mining software packages provide specialized "unfolding" modules to achieve this coordinate transformation. The senior geologist and an experienced geostatistician must carefully review the selection of the reference system.

Global Resource Estimate

The objective of this stage is to obtain representative statistics and a global resource estimate. It is the responsibility of the project geologist and a resource geologist supervised by the senior geologist and the geostatistician to complete this step. A resource geologist is a project geologist qualified and trained in geostatistics and resource modelling techniques. This step requires careful management of clustered information and recognition of the effect of poorly oriented drill holes.

Declustered Global Estimate

Samples are commonly taken preferentially from high-grade areas of the deposit based on a drilling strategy focussed on confirming their existence and extent. Therefore, declustering of the data must be undertaken. If the relative importance (weight) of each sample is not taken into account when calculating statistics then biases may occur resulting in an overestimate of the average grade.

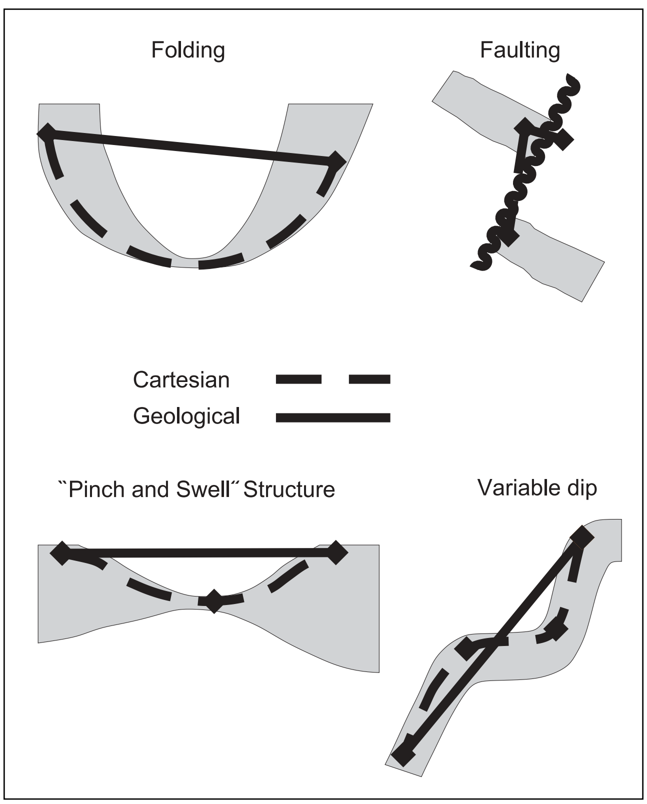

Fig. 3. Cartesian vs geological distances.

Once a representative dataset for the area under study is obtained, a preliminary estimate of the tonnage and average grade of material within the entire area can be determined. It must be emphasized that these estimates are preliminary and no mineability constraints have been applied. These estimates, which represent a global mineral inventory, do not necessarily represent a mineral resource, however, they do serve the purpose of checking for global bias at the grade estimation stage.

The procedure to decluster the data involves the assignment of grade to different polyhedral regions of space based on the proximity of the closest sample. If an area is heavily sampled, each sample will represent a smaller volume than in areas where the sampling is sparse. The relative importance of each sample is therefore directly proportional to the volume of material estimated by each sample. Declustering can be accomplished with most commercial mining software packages that are equipped to create nearest neighbor or polygonal models.

The results from the declustering stage are analyzed and validated by the geologist and the geostatistician. In addition, a manual calculation should be carried out using a 2D polygonal method to check that the declustering weights and global resource estimate match.

Impact of Poorly Oriented Drilling

In many steeply dipping tabular deposits, diamond drilling often fails to provide drilling perpendicular to the zone. This problem can result in significant biases during grade interpolation particularly when drilling is sparsely distributed. If poor drilling orientation results in significant local conditional biases, angular corrections can be used to address this problem (Terzaghi, 1965).

Spatial and Statistical Data Assessment

The objective of this stage is to revisit the assumption of stationarity of the mineralized zone, create variograms, identify future drilling targets, assess the interrelationships between metals/minerals, and determine the search strategy to use for final model grade estimations. It is the responsibility of the resource geologist supervised by the senior geologist and an experienced geostatistician to achieve this objective.

Linear geostatistics depends on the concept of stationarity. This concept requires a zone to be homogeneous in a statistical sense and behave identically in a spatial sense. Using this concept, models, such as the variogram, can be used to help in the estimation process. Therefore, great care needs to be taken to identify different populations within the entire mineralized zone. If the deposit in question is polymetallic or contains other minerals of interest, the correlation between metals/minerals should be examined statistically and spatially. Many commercial mining software packages have the required statistical tools. Specific programs and routines can also be developed in-house.

The senior geologist and/or geostatistician examine the data and zonation (if any), along with the project geologist, and suggest changes to the geologic model if required. Potential drilling targets will be examined for their potential to add value to the project in terms of identifying additional mineralization, proving up indicated and inferred areas of mineralization, and the impact of new holes to add to the variogram definition. This last step is important since the variogram indicates the geologic continuity of the mineralization. It is important that detailed data in three directions be used to define the variogram and provide increased confidence in the continuity of the mineralization or lack thereof (Figs. 4 and 5). Figure 4 shows a variogram for which there is good knowledge in the continuity of mineralization in all three directions. Figure 5 shows a variogram in which the down-dip variogram is known but the along-strike and across-strike directions are poorly characterized or unknown. Most international standard reporting procedures emphasize the importance of confidence in the geologic continuity as one of the key requirements for classifying the resource into inferred, indicated or measured categories (Haystead, 1993).

Grade Estimation

The objective at this stage is to create a model of appropriately sized blocks with locally unbiased estimates of block properties (i.e., grade, lithology, and density) through an estimation technique. These properties will be considered homogenous throughout the extent of each block. It is the responsibility of the resource geologist and the senior geologist with the assistance of a mining engineer to select a block size that is appropriate with respect to drilling density, continuity of the mineralization, and the mining methods to be tested. An experienced geostatistician must supervise the grade estimation process, ensuring that proper sample selection strategy and interpolation methods are employed. They must also provide assistance in the application of various validation tools to check for and correct potential problems such as conditional bias and over-smoothing.

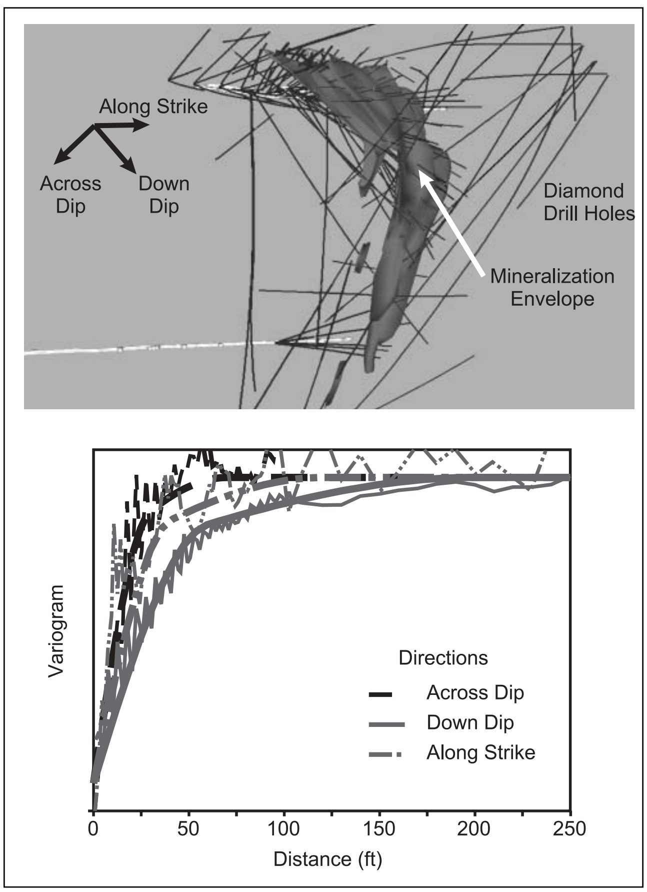

Fig. 4. Good knowledge of spatial continuity as a result of good drilling coverage.

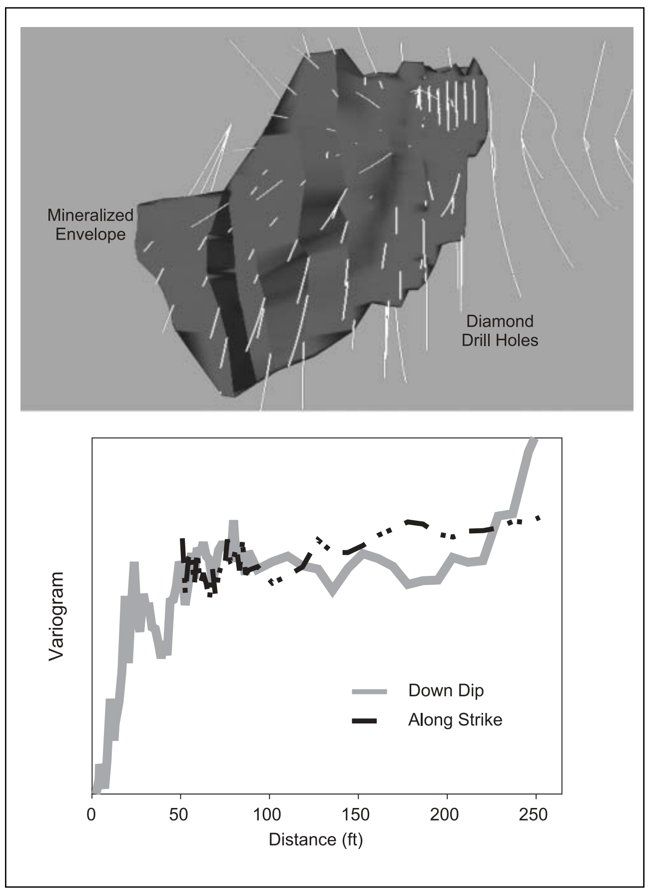

Fig. 5. Limited knowledge of spatial continuity as a function of drilling density.

Filling the Mineral Envelope with Blocks

The geologic interpretation stage provides the mineralized envelope(s) that are filled with blocks. Blocks form rough boundaries of a mineralized zone, so it is important that the proportion of each block within the mineralized zone be assessed and entered into the model, as a failure to take this into account can result in serious errors in tonnage. The splitting of blocks along the wireframe boundaries is required to minimize this potential error.

Sample Search Strategy

The sample selection process is a very critical step for local grade estimation. There is no interpolation technique that can compensate for a lack of samples or the selection of irrelevant samples. A number of articles have addressed the issue of conditional bias resulting from improper sample selection strategy (Krige, 1996; Pan, 1998). The variogram function is an essential tool at this stage to build a reliable sample selection strategy. Spatial distribution constraints and maximum number of samples per drill hole are useful additional restrictions that can help optimize the selection process when sampling occurs on an irregular grid, which is often the case for underground deposits.

Grade Interpolation

The interpolation method chosen will depend mainly on the style of mineralization. An indicator approach, based on coding the presence/absence of a specific grade range, may be more appropriate when different types of mineralization are mixed within the same zone. Other transformation techniques may be considered as well. Kriging techniques of interpolation are recommended since they take into account the sampling pattern, the geometry of the blocks, and the grade continuity. Another important factor to consider is the use of service variables. A typical example of a service variable is the interpolation of (grade $\times$ density) in sulfide deposits rather than grade. In this example, the service variable allows the density factor to be built into the interpolation.

Block Model Validation

The final outcome of grade interpolation of blocks within the mineralized envelope is typically called a block model. This is the resource model, which provides the best possible local estimates, and yet is globally unbiased as well. A number of checks must be carried out to validate this model.

The first step is to perform a series of visual checks. Details of the local grade distribution in the model are investigated in 3D along with the sample information. A visual inspection of the continuity of grades and the values of estimated grades near known sample points is carried out. Any differences should be investigated further by revisiting the modelling methodology.

The second step in the validation procedure consists of assessing the presence/absence of a global bias in the model. The declustered statistics provide a global mineral inventory estimate, which is used as a calibration tool. The global grade estimated from the block model should be similar to the global grade estimated from the samples. Again any discrepancies should be investigated until consistency between the two sets of statistics is obtained.

The third step of the validation procedure consists of comparing the variance of the block grade distribution obtained by interpolation with the expected variance calculated from the variance of dispersion within the blocks. This variance of dispersion can be calculated using the information carried by the variogram model (Isaaks and Srivastava, 1989). Usually, interpolation techniques will show a significantly lower variance compared to the sample distribution. The lower variance is expected because the change of support from sample to block, while maintaining the same global mean, will result in a reduction of the dispersion of the frequency distribution. If the drilling coverage is not dense enough with respect to the variability shown by the variogram, regression methods such as kriging may result in an over-smoothing of the grade variability, producing a block grade distribution with a variance lower than expected according to the Krige relationship. Using an over-smoothed model may lead to conditionally biased estimates of recoverable resource at a given cut-off (Fig. 6).

'Change of support' techniques can be used to correct the global block grade histogram, however, without additional drilling, it is impossible to reproduce the proper variability in the model without reducing the quality of the local grade estimates. In this case, stochastic simulation of grade is an alternative technique to be considered for mine planning in order to report unbiased recoverable mineral resource. Simulation focusses on reproducing variability while block modelling is designed to minimize local estimation error.

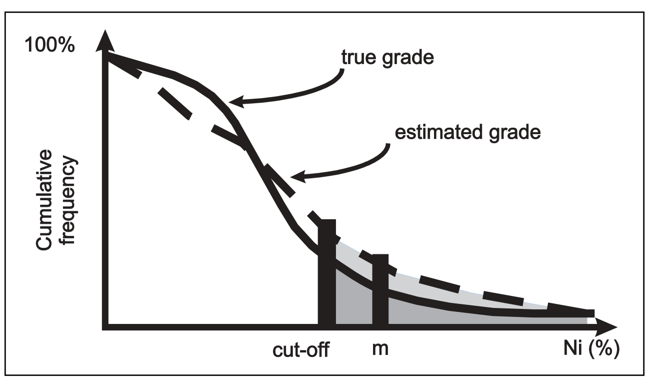

Fig. 6: True vs estimated grade distribution indicating conditional bias.

Resource Estimation

The purpose of resource estimation is to determine a preliminary value of the mineral deposit to the company and a base for reserves. Although there is not sufficient information as to the exact mineability of the resource, it serves as an approximation of the potential.

In some open-pit situations, estimation of the resource can be reported by calculating the blocks above a chosen cut-off grade; assuming selective mining of each block above cut-off without respect to their spatial distribution. But for some open-pit operations and for most underground mines, the spatial distribution of blocks above cut-off is a key factor in defining a mineral resource. For example, small isolated pods of ore within waste will not meet criteria of minimum ore width and/or maximum internal dilution and therefore should not be included in the resource. In this case, effort must be taken to create envelopes of mineable ore material. The material within these mineable envelopes can then be quoted as resource.

It is the responsibility of the resource geologist, project geologist and mining engineer supervised by the senior geologist, and an experienced geostatistician to achieve this objective.

Resource Classification and Reporting

Resource classifications provide an assessment of the confidence in the resource estimate. It is the responsibility of the project geologist, senior geologist, and geostatistician and mining engineer supervised and reviewed by the manager to classify and report the resource estimate.

Mineral resource classifications are based on an understanding of the continuity of the geological structures or lithological formations hosting the mineralization and the continuity of the grade between the drill holes. Although the categorization is primarily dependent on the information derived from drill holes, additional information on the continuity of the mineralization can be gained from down-hole geophysical surveys using electromagnetic techniques or other geophysical methods (Cochrane et al., 1998).

The resource classifications are directly related to the appraisal stages of the project. For an inferred resource, geological and grade continuity are assumed, but not established. At the inferred category, scoping-stage evaluations can be carried out to determine if further exploration or technical investigations are warranted. At the indicated category, geological and grade continuity have been reasonably established, but short-range grade variability is not well known. The information is sufficient to carry out pre-feasibility stage assessments and verify the economic viability of the deposit. At the measured category, the geological continuity of the deposit and the local grade continuity including short-range variability have been established with high confidence.

Although additional in-fill drilling is required to improve the classification of the resource from indicated to measured, stochastic simulations may also be used to assess the impact of the short-range grade variability. At the established mining camps such as Sudbury and Thompson, applying assumptions from deposits with similar styles of mineralization that have been mapped and drilled on a very tight grid may also assess the effect of short-range variability.

Resource classification is also dependent on the size of the mining unit and its relation to short-range variability. A resource may be classified as measured using a bulk mining method, whereas, it may still be classified as indicated for a more selective method. At the measured category, the information is considered to be sufficient to establish project feasibility.

Risk Assessment

Any estimate is imperfect, but the risk associated with the estimate can and should be assessed so that company financial decision-makers, mining engineers, mineral processors, and planners are aware of and can make more appropriate choices or incorporate flexibility into their designs. This includes things such as project financial evaluation, expected mill head grades, metallurgical test results, geomechanical (rock mechanics) studies, ore tonnage, selection of production schedule, and so on. At the initial stages of a project there are a lot of unknowns and risk assessment is an important step to take.

It is the responsibility of all people involved in the resource modelling process (Fig. 1) to ensure that a measure of the project risk is assessed. The project, senior, and resource geologists, mine engineer and geostatistician will assess the deposit and mining risk, while the financial analysts will assess the financial and economic risk.

In order to assess the risk associated with the deposit characteristics, stochastic simulations are created such that variability in head grades, mine plans, and production schedules can be examined. This allows further analysis as to the range of possible project rates of return. Simulations provide an ongoing improvement tool to assist in improving the quantity and quality of the raw data and support the risk analyses required. Simulations can also be used to establish the effectiveness of any future grade control procedure as well as any benefit that might be gained from additional drilling. In this way, the impact of future work to add value to a project can be assessed before additional investments are considered. Simulations serve as checks on themselves. The average of all the simulations should yield the block model results obtained earlier. Simulation is actually a decomposition of kriging, providing multiple, equally probable realizations. Each realization reproduces the correct variogram and statistics seen in the data. In any case, simulation is an effective method to measure risk but it cannot be used to reduce risk. Only acquisition of additional relevant information can reduce risk.

Conclusion

ITSL has assembled a team of qualified personnel to complete the economic assessment of its exploration. This team includes exploration technicians, project geologists, senior geologists, geostatisticians, mining engineers, accountants, senior management, and independent consultants. It is a team effort that requires ongoing verification of each other's work at each stage to ensure a solid resource calculation is obtained. The resource team is also responsible for performing a quality assurance and quality control program in order to measure the effectiveness of the methods in meeting the specific objectives at each step of the modelling process. Depending on the stage of development of the project or its size, an independent consultant may be called on to either verify the results obtained in house or do an independent study of the project.

This paper focusses on the specific issue of resource estimation. The actual economic value of a mineral deposit is not in its in situ resource but the metal that can be recovered at a profit after mining and processing. This metal is measured as the recoverable ore reserve. The translation of mineral resource into ore reserve presents different challenges depending on the type of mining. In some open pits, for example, the material within an area can be sorted into ore and waste and handled accordingly. Underground operations have less flexibility because of the restrictions of stope layout. The assumptions and limitations of the mineral resource model must be carefully considered when the recoverable ore reserves are estimated and reported.

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