Implementation of reporting code guidelines for mineral resources and mineral reserves using a general mine planning package

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ABSTRACT

The mining industry worldwide has recognized in the past the need to apply specific rules and guidelines in the reporting of mineral resources and reserves. The high financial investment and risk associated with any mining project and the ever stricter environmental and social controls were the forces behind this recognition. For years the industry experienced the development and enforcement of several codes for reporting accepted by different countries. The implementation of any code can be a confusing task as the guidelines are sometimes general and open to different interpretation. The use of computers in the estimation and reporting of mineral resources and reserves is necessary, particularly when trying to implement particular code guidelines. This paper discusses ways to implement a reporting code in a computerised resource/reserve estimation study. The implementation is demonstrated using a gold deposit project as an example. The effects of mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors are taken into consideration. This paper also discusses well established reporting codes and the possibility of reaching a single, universally applied code that could be used by Greek mining companies.

1. INTRODUCTION - THE NEED FOR A REPORTING CODE

1.1 Historical overview

The Council of Mining and Metallurgical Institutions (CMMI) started working in 1994 to create a set of standard international definitions for reporting Mineral Resources and Mineral Reserves, based on the existing JORC Code (the Australasian Code for Reporting of Mineral Resources and Ore Reserves). Representatives from mining and metallurgical institutions from the United States (SME), Australia (AusIMM - JORC), Canada (CIM), the United Kingdom (IMM, now the IMMM) and South Africa (SAIMM) formed the CMMI Mineral Resources/Reserves International Reporting Standards Committee (CMMI - CRIRSCO). At the same time, the United Nations Economic Commission for Europe (UN-ECE) has been developing an International Framework Classification for Reserves/Resources - Solid Fuels and Mineral Commodities (the UNFC). In 1997, the CMMI - CRIRSCO reached a provisional agreement (the Denver Accord) on definitions of Mineral Resources and Mineral Reserves. At a joint meeting in 1998 between the CMMI - CRIRSCO and the UN-ECE Task Force, it was agreed to incorporate the CMMI - CRIRSCO standard reporting definitions for Mineral Resources and Mineral Reserves into the UNFC, thus giving truly international status to the CMMI - CRIRSCO definitions.

1.2 Reporting codes - Current state

As a consequence of the CMMI initiative, significant developments have taken place towards producing consistent reporting standards for Mineral Resources and Mineral Reserves including the release of updated versions of the JORC Code in Australia in 1996 and 1999, and publication of similar Codes and Guidelines by the professional bodies in South Africa, the USA, Canada, UK, Ireland and Europe. The similarity of reporting codes and guidelines in those countries represented by the CMMI is

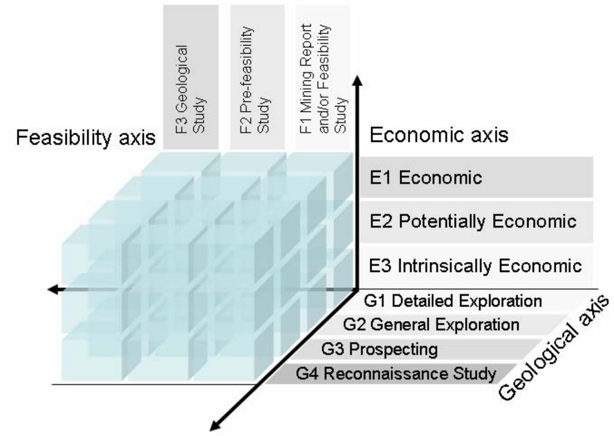

Figure 1: UNFC as applied to coal, uranium and other solid minerals (UN-ECE, 1997).

now at a point where the development of an International Code is being pursued.

At the same time, the United Nations Framework Classification for Reserves and Resources of Solid Fuels and Mineral Commodities (UNFC) was created and endorsed by the United Nations Economic and Social Council (ECOSOC) in 1997 (UN-ECE, 1997). The UNFC for minerals has been applied in over 60 countries worldwide and in 2004, the Classification was extended to also apply to petroleum (oil and natural gas) and uranium, and was renamed the UNFC for Fossil Energy and Mineral Resources. Figure 1 shows the UNFC classifications for reserves and resources.

The IMMM Working Group Reporting Code (the Reporting Code from this point on), effective since 2001, is consistent with the international developments described above. It sets the minimum standards, recommendations and guidelines for Public Reporting of Mineral Exploration Results, Mineral Resources and Mineral Reserves in Europe. It was formed by the Working Group on Resources and Reserves of the former Institution of Mining and Metallurgy (IMM), now the Institute of Materials, Minerals & Mining (IMMM), established in 1999. In 2000, the European Federation of Geologists (EFG), the Geological Society of London (GSL) and the Institute of Geologists of Ireland (IGI) joined the efforts of the IMMM Working Group. Figure 2 shows the classifications of Mineral Resources and Mineral Reserves according to the Reporting Code.

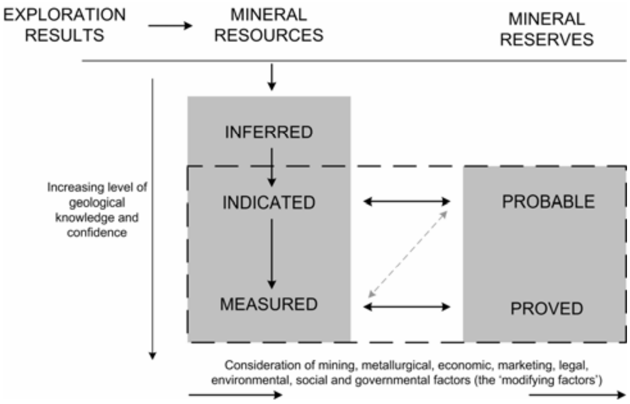

Figure 2: Relationship between mineral resources and mineral reserves according to Reporting Code (IMMM, 2003).

1.3 Resource/reserve classification and reporting in Greece

There is no unique system for the classification of the mineral commodities reserves/resources in Greece. Mining companies and Institutes have their own classification systems, commonly based on other countries' classifications, making the correlation of these classifications difficult to implement.

Three main categories are used in Greece for mineral commodities reserves/resources: "proven", "possible" and "probable". As the limits between the three categories are not clearly indicated, the results from their evaluation may not be considered reliable (UN-ECE, 1998). Several classification systems have been proposed for the reserves/resources of the country, but none has been adopted so far. Solid fuels are probably the only exception to this, as the Institute of Geology and Mineral Exploration has already established and applies a consistent classification system for the estimation of the lignite reserves of the country. This system has been adopted by the State and the Public Power Corporation.

2. IMPLEMENTATION OF A REPORTING CODE

2.1 Overview

The Reporting Code does not regulate estimation methodology. It establishes a system of Resources/Reserves classification and sets minimum standards for public reporting. It is up to the person responsible for resource and reserve estimation to choose and configure the appropriate estimation methodology.

However, according to the Reporting Code, documentation detailing Mineral Exploration Results, Mineral Resources and Mineral Reserves estimates from which a Public Report is produced, must be prepared by or under the direction of, and signed by, a *Competent Person*. A Competent Person is a corporate member of a recognised professional body relevant to the activity being undertaken, and with enforceable Rules of Conduct. A Competent Person should have a minimum of five years experience relevant to the style of mineralisation and type of deposit under consideration. If the Competent Person is estimating or supervising the estimation of Mineral Resources or Mineral Reserves, the relevant experience must be in the estimation, evaluation and assessment of Mineral Resources or Mineral Reserves respectively.

Resource geologists and mining engineers carrying out resource/reserve estimation commonly use specialized modelling software. This means that they not only need to understand the deposit under consideration, but can also use the appropriate software methods to model it accurately (Duke and Hanna, 1999).

2.2 Mineral resources estimation

The implementation of the Reporting Code is demonstrated using a gold deposit in South-Eastern Europe. It is a porphyry related epithermal gold complex with most of the gold focused in three closely related zones. An extensive program of reverse circulation drilling (RC) and diamond drilling (DD) in all three zones has been completed and provided a solid basis for quality resource estimates and mine planning of an open pit operation at low to moderate cut-off grades.

In order to estimate resources with a level of confidence, grade modelling requires that the spatial continuity be described by continuous mathematical functions (variogram models), the properties of which should reflect the properties of different directional experimental variograms in three dimensional space. The importance of this step in resource estimation is commonly overlooked, particularly by geologists or engineers with little or no knowledge of geostatistics, and when a Reporting Code is not enforced. In the example examined here, sets of indicator variogram models for various indicator thresholds were developed for the oxide zones in each of the mineralized areas. Three different nested structures were modelled plus a nugget effect. The proper selection of lag and direction parameters during calculation of experimental variograms, and the consistent fitting of variogram models ensures reliable execution of kriging estimation. The modelled variograms were used by kriging in order to calculate weights for samples included in the estimation of each block.

The estimation process is controlled by an ellipsoidal search area. Three different configurations of the search area geometry and search criteria are used for each of the three zones (Table 1). These configurations reflect different levels of confidence in estimating a block, and are used to classify a block in one of the three resource categories (Fig. 3). They also control whether a block should be estimated and, therefore, included in the resources or not by apply-

Table 1: Sample search configurations for different resource categories.

Category	Measured Resources			Indicated Resources			Inferred Resources		
Zone	1	2	3	1	2	3	1	2	3
Major	50	50	50	75	87.5	50	75	87.5	75
Semi-Major	50	50	50	75	87.5	50	75	87.5	75
Minor	5	5	5	7.5	8.75	5	7.5	8.75	7.5
Bearing	90	45	105	90	45	105	90	45	105
Plunge	0	15	0	0	15	0	0	15	0
Dip	10	0	-15	10	0	-15	10	0	-15
Min. Samples	16	16	16	16	16	16	8	8	8
Min. Octants	4	4	4	4	4	4	2	2	2
Max. Samples	48	48	48	48	48	48	48	48	48

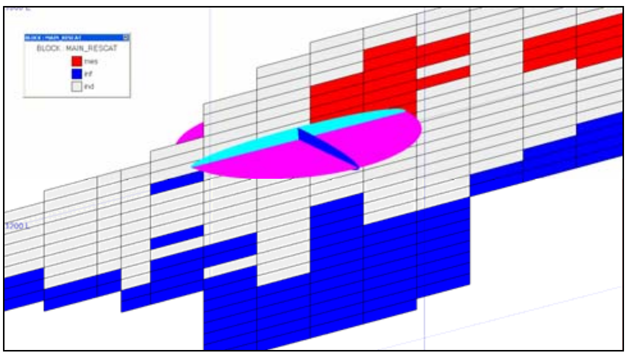

Figure 3: Search ellipsoid and block model section coloured by resource category.

ing a minimum number of samples in the search area.

If the search ellipsoid is spherical (major, semi-major and minor radii are equal) the anisotropic distance is equal to the Cartesian distance. However, if the search ellipsoid has radii of 100, 50 and 10, points in the direction of the semi-major axis have their anisotropic distances expanded by a factor of 2 = (100/50) and points in the minor direction have their anisotropic distances expanded by a factor of 10 = (100/10). Either un-weighted or weighted distances can be stored. If un-weighted, then all samples are given the same weight. If weighted, the weights used for grade estimation are applied. Suppose we are estimating a block and have two samples. Sample 1 is at a distance of 10 and Sample 2 is at a distance of 100. Suppose, also that Sample 1 has a weight of 0.95, and Sample 2 has a weight of 0.05. The un-weighted distance is (10+100) ÷ 2 or 55. The weighted distance is (0.95×10 + 0.05×100) or 14.5.

An octant search is commonly used as a declustering tool to reduce imbalance problems associated with samples lying in particular directions. If there are more samples in one direction than another, then this option limits the bias. In the example discussed here, octant search was used and a minimum number of octants containing samples was applied in order to produce an estimate and control resource classification (Table 1).

During estimation, all necessary information for the classification of block estimates is stored in block model variables and is used to generate a classification code for each block. This information includes the number of samples used for the estimation of the block, the number of drillholes that contained these samples, and the block and kriging variance (Fig. 4).

Kriging variance, for example, is associated with drillhole spacing and semivariogram ranges of influence. Appropriate variances can be chosen to define resource confidence categories.

2.3 *Mineral reserves evaluation*

The conversion of Mineral Resources to Mineral Reserves requires consideration of factors affecting extraction (‘modifying factors’), including mining, metallurgical, economic, marketing, legal, environmental, social and gov-

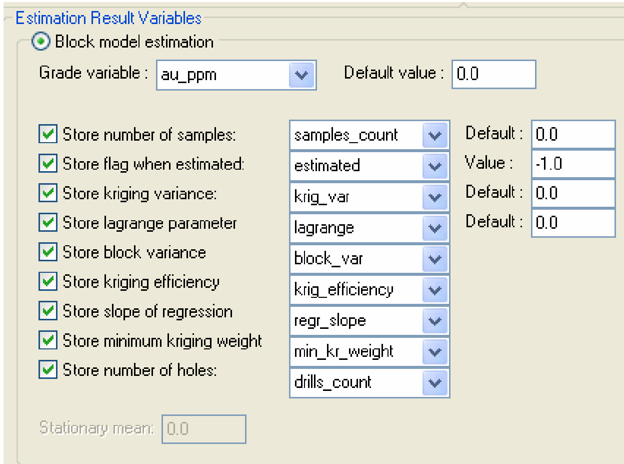

Figure 4: Storing of estimation quality parameters during block estimation with kriging - estimation panel from Vulcan 3D software.

ernmental, and should in all instances be estimated with input from a range of disciplines. The most comprehensive way of applying these factors to the resource model for the calculation of Mineral Reserves in the case of surface mine extraction, is through the use of a pit optimization algorithm, such as Lerchs-Grossmann (LG).

Consideration of the mining method is an essential component of ore reserves evaluation, particularly when the profitability of a project is conditioned by the ability to mine selectively. This risk is significant when the selective mining unit is small compared to data spacing, resulting in over-smoothed estimates (Deraisme, 2005). Early kriging techniques catered only for calculating the average grade of a fixed volume of ground which, in structurally complex orebodies would not reflect ultimate selective mining of the orebody, but today techniques do cater for estimating recoverable reserves from exploration drilling (Snowden, 1996). Non linear estimation techniques, such as Indicator Kriging, Probability Kriging and Uniform Conditioning were developed to address the problem of building an ore reserve model from widely spaced data.

With the resource estimates and classifications stored in the block model it is possible to calculate the ore content in each of the blocks as well as a number of financial parameters associated with the selected mining and processing method. The resource estimation process described in the previous section is designed to generate estimates based on a specific approach to ore selection. The proportion of each oxide zone in each block is estimated using an indicator coding of the samples and the indicator variogram models. The metal grade distribution for each oxide proportion is estimated using an indicator coding based on indicator grade thresholds and corresponding indicator variograms.

The resource information for a particular grade threshold is used to calculate parameters such as mining cost, processing cost, selling cost, rehabilitation cost, revenue and net profit. These values are associated with the extraction of a particular, already exposed block and are based only on the Indicated and Measured Resources of the block. As shown in Figure 2, only Indicated and Measured Resources can be converted, after consideration of the modifying factors, to Mineral Reserves. The financial parameters calculated for each block can also reflect different rock types and zones of the deposit, where certain geotechnical and metallurgical conditions apply. These parameters relate directly to the modifying factors that need to be applied in order to convert Mineral Resources to Mineral Reserves.

The net profit from a block, sometimes referred to as the *dollar value*, reflects net value of a block after its extraction and processing. The LG pit optimisation process is based on this value and an overall slope angle for the pit. The method works on the resource block model, and progressively constructs lists of related blocks that should, or should not, be mined. The final lists define a pit outline that has the highest possible total value, subject to the required pit slopes. This outline includes every block that is "worth mining" when waste stripping is taken into account, and excludes every block that is not "worth mining". It is not a purpose of this paper to examine in depth the LG algorithm.

The produced outline or optimum pit shell contains all the blocks that can be converted from Mineral Resources to Mineral Reserves after the application of all applicable modifying factors (Fig. 5).

One factor that is commonly overlooked in the optimisation process is the effect of the ramp or ramps to the overall pit slope. Ideally, the slope angle used in the optimisation process should reflect the presence of a ramp on the pit walls. When this is the case, it is possible to design the actual optimum pit following the optimum pit shell (Fig. 6).

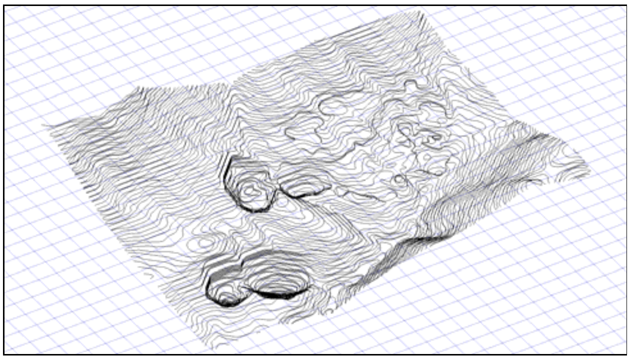

Figure 5: Optimum pit shell from LG optimization process.

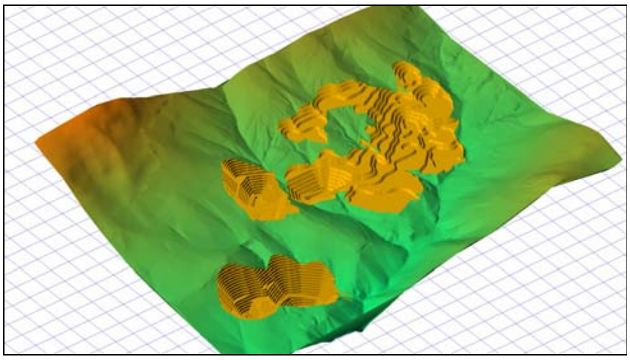

Figure 6: Pit design model based on LG optimum pit shell.

The pit design that follows the optimum pit shell can be used to calculate total Mineral Reserves or per bench, mining block, etc. The pit design produced following the procedure described is based on the Indicated and Measured Mineral Resources that successfully converted to Probable and Proved Mineral Reserves respectively, after the application of modifying factors according to the Reporting Code.

2.4 Reporting

According to the Reporting Code, Public Reports referencing a company's Mineral Exploration Results, Mineral Resources or Mineral Reserves must include a description of the style and nature of mineralization. All relevant information concerning the status and characteristics of a mineral deposit that can influence the economic value of that deposit must be disclosed, and the company must promptly report any material changes in its Mineral Exploration Results, Mineral Resources or Mineral Reserves.

As reports are prepared for different reasons and may contain more or less detail according to their intended purpose, the contents of a report should be determined by the Competent Person to be appropriate for its use on the basis of relevance (materiality) and where appropriate, backup documentation, such as audit reports, should be referred to or made available (IMMM, 2003).

The Reporting Code as well as other Codes applied worldwide, provides a checklist of issues or topics that need to be addressed when reporting Mineral Resources and Mineral Reserves. The checklist can be used for both qualitative and quantitative statements produced in a Public Report. The documentation of the criteria used in the Report allows for some degree of discipline to be introduced into a procedure which can otherwise be very subjective. It is then possible for an interested party to review the information reported and reach an independent decision if necessary.

3. CONCLUSIONS - RECOMMENDATIONS

The geostatistical tools available today allow risk to be assessed more comprehensively than in the past. Informed decisions can be made based on spatial continuity and probability as well as interpreted geology. A Competent Person or team must be responsible for the reporting of Mineral Resources and Mineral Reserves. The Competency of the Person responsible with the Reporting of Mineral Resources and Mineral Reserves must be considered relative to the particular deposit and mining method as well as the effective use and understanding of mine planning and geostatistical software. All estimates, assumptions and decisions can and should be well documented in Public Reports closely following the terminology and guidelines of the Reporting Code. Decision makers reading a Public Report need to understand and acknowledge that all estimates and decisions stated have an associated risk and a measure of uncertainty must be given to them, which is based on a well constructed Mineral Resource and Mineral Reserve classification system. This paper aimed at clarifying some of the practical issues of following the Reporting Code guidelines in a Mineral Resource / Reserves estimation study.

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