MICA
Minerals Intelligence Capacity Analysis

FACT SHEET

Mineral Resources and Reserves Estimation

This factsheets clearly defines the meanings of resources and reserves and discusses how exploration and mining companies calculate these figures. The basic geostatistical principles and process that are used in calculating these figures are covered, as are the different types of input data that are required for these methods.

Scope

There frequently is confusion in the understanding of the terms 'resources' and 'reserves', and they are sometimes, incorrectly, used interchangeably. It is important to clearly define these terms and ensure their correct usage, particularly if comparisons are to be drawn between deposits or investment decisions are to be made based on them.

Mineral resources are defined as natural concentrations of minerals or bodies of rock that are, or may become, of economic interest due to their inherent properties (for example the contained quantity of a metal [known as its 'grade'] or high crushing strength of a rock that makes it suitable for use as an aggregate [an assessment of the deposit's 'quality']). The mineral will also be present in sufficient quantity that there are reasonable prospects for eventual economic extraction.

The part of a mineral resource which has been fully evaluated and is deemed commercially viable to work, is called a mineral reserve. This process includes the assessment of several 'Modifying Factors' including (but not restricted to) mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors. In the context of land-use planning, the term mineral reserve should be further restricted to those minerals with legal access and for which a valid permission for extraction also exists (i.e. permitted reserves). Without a valid planning consent no mineral working can legally take place.

The relationship between resources and reserves is shown in Figure 1. A mineral resource may be classified as inferred, indicated, or measured, whilst a mineral reserve may be classified as either probable, or proved. These categories will depend on the associated degree of geological certainty, feasibility of economic extraction, accessibility and legal status (i.e. planning permission).

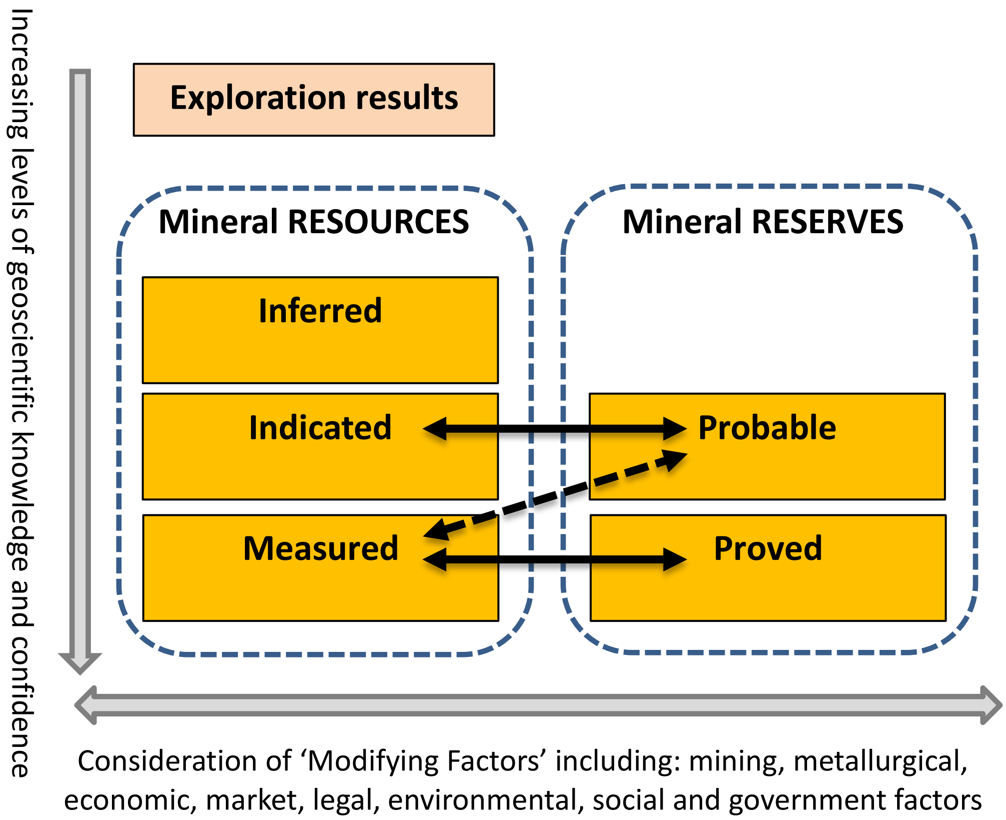

Figure 1. A cartoon showing the relationship between mineral resources and mineral reserves.

The process of resource estimation is used to define a mineral resource in three dimensions, with the ultimate aim of determining both the size (typically reported in tonnes) and grade (generally expressed as the metal or mineral content in wt. % or g/t) of the resource. A 3D ore deposit model (or block model as they are known) is used to show the extent of the deposit below the surface but also the distribution of metal or mineral within the deposit (i.e. zones of high- and low-grade) (Figure 2). With increasing amounts of information and consideration of other factors, such as economic, social and environmental aspects, a mineral resource may be upgraded to a mineral reserve. However, it is important to note that a reserve typically only forms a very small part of a resource.

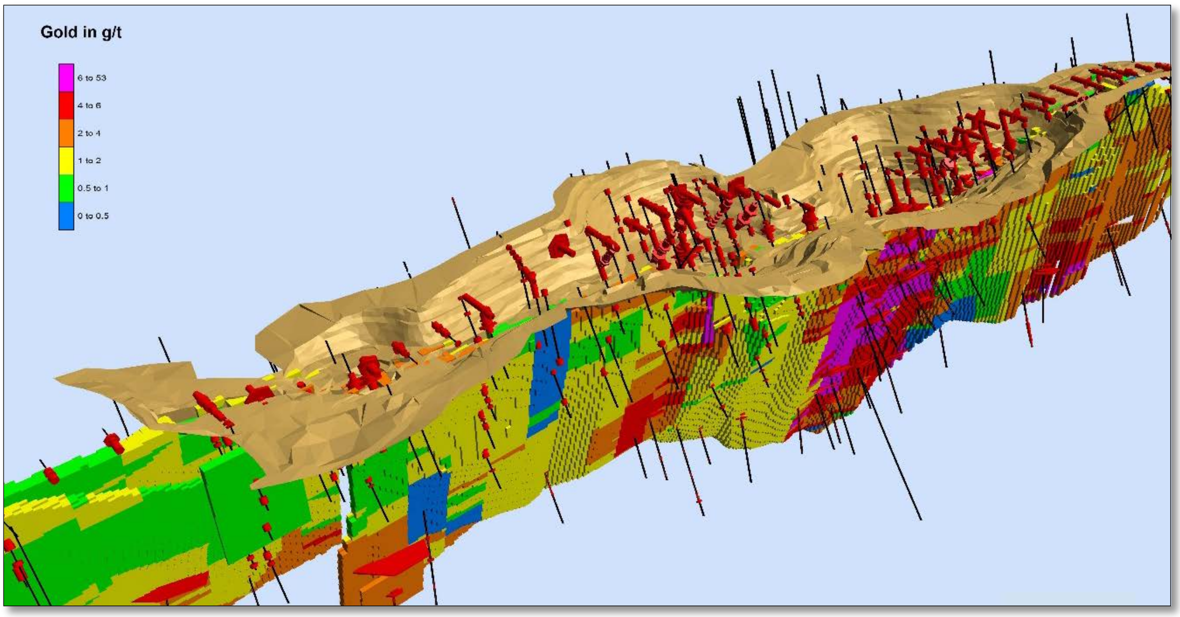

Figure 2. Example of a 3D ore deposit block model showing the distribution of low grade (blue and green) and high grade (red and pink) zones (used with permission of Goldstone Resources).

Contexts of use, application fields

Many of the individual steps involved in the process of estimating a mineral resource (e.g. geochemical assay and geostatistical analysis) are transferable to many other application fields, including environmental monitoring, groundwater and mineral exploration. However, resource estimation is a specifically concerned with determining the size and quality of a mineral resource with a view to commercial exploitation, hence the process is largely utilised by mining companies.

Input parameters

Input parameters will vary depending on the estimation method selected. For example, traditional resource estimation methods (e.g. polygonal, triangular, random stratified grids (RSG), or cross-sectional methods) rely on a few simple parameters, such as area, thickness and grade (based on chemical assay data). Geostatistical estimation techniques, such as Kriging, block modelling, and inverse distance weighting (IDW) are typically more sophisticated than traditional methods and therefore rely on a greater number of input parameters. For instance, Kriging requires the selection of an appropriate model type (e.g. global variograms, relative variograms, or directional variograms) and parameters that best describe the relationship between the distance from one observation to the next and the difference in the observed values at those points. There are three key parameters to consider (Figure 3):

1. Nugget – this represents sample variability over small distances caused by either small-scale geological or mineralogical controls, or by sampling and assaying errors.
2. Range – the distance (in field units) at which samples become independent of each other (i.e. a long range might indicate geological continuity, whereas a short range might suggest variability over a short distance).
3. Sill – a measure of the variance between sample values (i.e. a high sill value indicates a high degree of variance, whilst a low sill value indicates a small amount of variance).

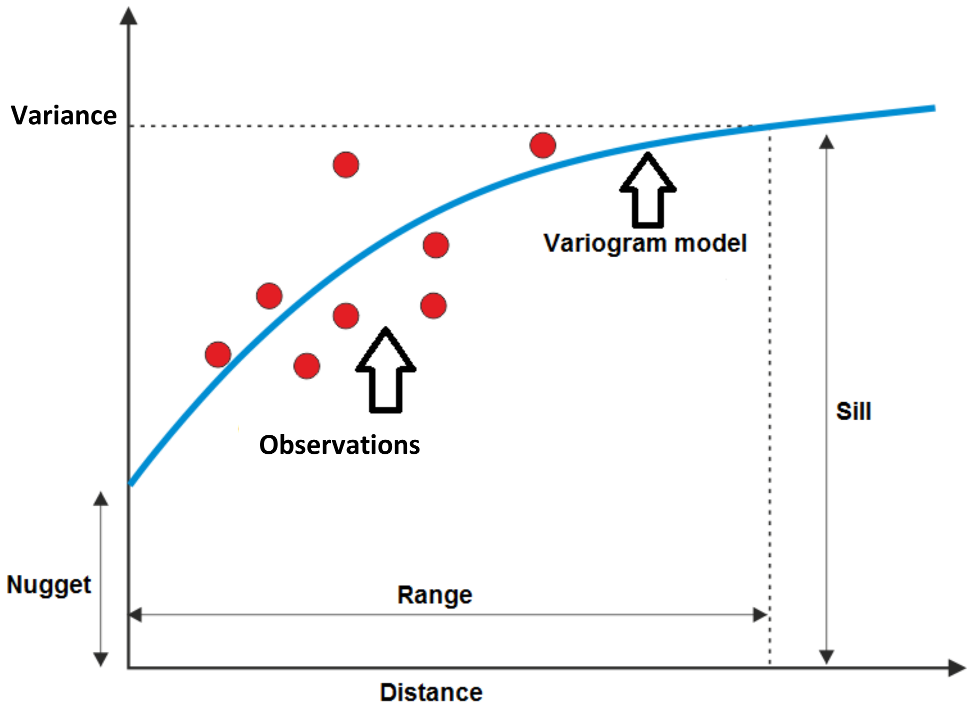

Figure 3. Example variogram showing the nugget, range and sill.

Type(s) of related input data or knowledge needed and their possible source(s)

During exploration for a mineral resource a number of data sources may be used, these might include: topographic base maps; geological maps; geophysical survey data (e.g. radiometrics); geochemical (e.g. rock, soil or stream sediment) data and; historic exploration data (if they are available). These data are typically recorded in a geographic information system (GIS) and are interrogated (e.g. using prospectivity analysis – Figure 3) to define a target, or series of targets. Once a target has been identified core drilling is used to gain information about the geology, structure and mineralisation in three dimensions. The number of drill holes and their spacing will depend on the size and type of mineral deposit. Drill core is carefully logged by a geologist to record important information about host-lithology, structures, distribution of mineralisation, etc. Some of the core material will also be sub-sampled and sent to a laboratory for assay. All of the data and information gained from the exploration programme and drill campaign will be statistically interpolated (e.g. using methods such as Ordinary Kriging or Regression Kriging), with the intention of producing a resource estimate.

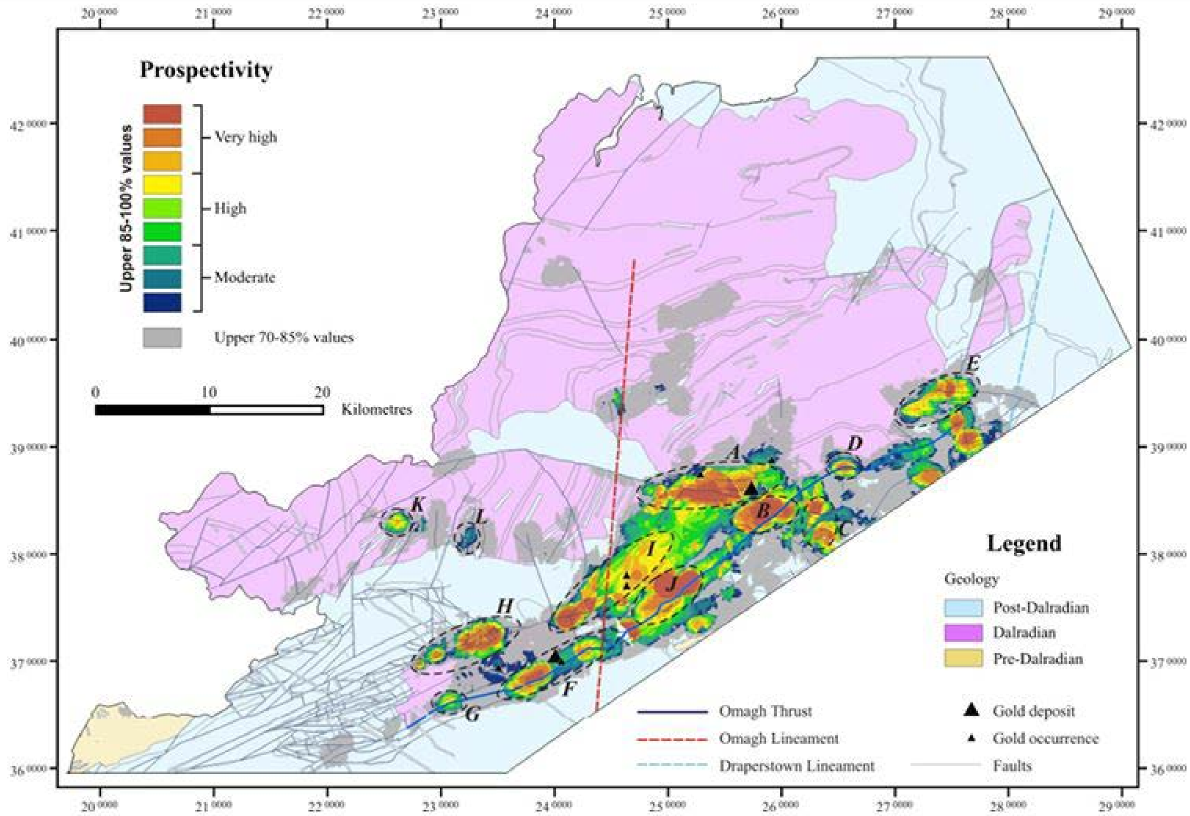

Figure 4. An example of the type of output generated in a GIS using prospectivity analysis techniques. Areas in red would be considered as targets for further work or drilling.

Model used

Resource estimation can use a number of different models depending on which is most appropriate for the particular circumstances. Geological modelling maybe used to understand the structure of a mineral deposit, for example is the deposit folded or faulted. Genetic mineral deposit models are used to understand the broad-scale features of a deposit and what might be expected in terms of size, grade, ore mineralogy, and host-lithologies. Genetic models may also be used in the validation of 3D block models. Geostatistical modelling, for example inverse distance weighting (IDW) and Kriging are widely utilised in modelling mineral resources.

System and/or parameters considered

Mineral resources are constrained by geology (i.e. certain deposit types only occur in specific geological settings) and by their very nature have a geographical location. Resource estimation occurs at the individual mineral deposit scale, although this can be hugely variable between hundreds of thousands of tonnes and many billions of tonnes. The boundaries of a metallic mineral deposit may be diffuse, i.e. the metal grade may gradually decrease towards the deposit boundaries, or at depth. However, the distribution of grades in a deposit is likely to be highly complex and certainly not uniform (Figure 2). These boundaries will be defined as part of the resource estimation process by a series of cut off grades (COG). Cut off grades are used to delineate ore from waste, low-grade ore from high-grade ore, mineralised rock from non-mineralised rock, etc.

Time / Space / Resolution /Accuracy / Plausibility

The scale of a resource estimate will largely be defined by the size and type of deposit, and the range of COG used to delineate economic and sub-economic mineralisation. Mineral resource estimates do have a temporal component in that a resource will eventually become depleted; this period is often termed the life of mine (LOM). Again, this is subject to the type and size of deposit, but also a host of economic and technological factors.

Mineral resources may also change (increase or decrease) over time depending on market conditions, prices, economics and technology. The latter can include both technological developments that increase or decrease the demand for a mineral and improvements in the methods used to extract a mineral which results in greater quantities becoming economic to extract.

The resolution and accuracy of a resource estimate will, to some extent, be determined by the amount of data gathered to produce the resource estimate. For instance, a small, complex deposit (e.g. vein-hosted gold) might require a higher sampling density (i.e. a greater number of drill holes between 50–100 m apart) than a large, relatively simple deposit (e.g. coal) that would require fewer drill holes with a spacing of about 400–500 m. This would mean that the resource estimate for the vein-hosted gold deposit is based on a greater number of actual measurements/observations and thus reduced interpolation. It also reduces the distance, and therefore the variance, between observed points.

Indicators / Outputs / Units

Mineral resource estimates are typically reported in tonnes, with the grade being expressed as g/t or wt. % of metal or mineral. In some cases the metal may be reported as the oxide (e.g. tungsten as WO_3 or rare earth elements as RE_2O_3) rather than as the pure metal.

The tonnage and average grade figures are derived from the 3D resource block model (Figure 2), which is comprised of a number equally sized of blocks, with each block representing a volume of ore at a given grade. Each block will have a unique set of attributes (e.g. density, rock type, grade, confidence level, etc.). Block models can be viewed in specialised software packages (often the software package used to create the model), in which the model may be rotated, tilted or sliced to produce different views of the deposit. The models can also be viewed as a static image. Grade envelopes (areas of similar average grade) are often coloured to allow easy identification of high- and low-grade areas of the deposit (e.g. in Figure 2 areas of low-grade are coloured blue and green, whereas higher grades are represented by orange and red colours).

Treatment of uncertainty, verification, validation

Ultimately, a resource estimate is a model that relies on large amounts of data, but also human judgement and interpretation. Data and information used to produce a resource estimate are subject to different levels of quality control and validation. For example, assay laboratories will typically have strict quality control and quality assurance protocols that allow errors to be quantified. However, core logging is an interpretive exercise that relies on the skill and experience of the person undertaking the logging, therefore errors associated with logging are much harder to quantify. In terms of errors directly associated with the production of a 3D block model it is not always possible to quantify the model uncertainty. This is particularly true for models produced using traditional estimation methods (e.g. triangular methods); however, geostatistical methods, such as Kriging, do allow uncertainties to be calculated.

In many countries, companies that are seeking investors are required to report their resource and reserve estimates in accordance with an internationally recognised system of reporting. These systems (or reporting codes) will include a requirement for resource and reserve estimation to be conducted by a ‘competent person’ or appropriately ‘qualified person’. Importantly these systems of reporting will also recommend that resource estimates are subject to auditing by an independent, competent person. Many of these reporting codes, such as JORC, PERC, NI 43-101 and SAMREC, adhere to a common ‘template’ known as CRIRSCO (see publications /references and key relevant contact sections of this fact sheet for more information).

Main publications / references

CRIRSCO. 2013. *Committee for mineral reserves international reporting standards, International Reporting Template*

JORC. 2012. *Australasian code for reporting exploration results, mineral resources and ore reserves.*

NI 43-101. 2011. *Standards of disclosure for mineral projects.*

PERC. 2013. *Pan-European standard for reporting of exploration results, mineral results and reserves.*

SAMREC. 2016. *The South African code for the reporting of exploration results, mineral resources and mineral reserves*.

Rossi, M.E. and Deutsch, C.V. 2013. *Mineral resource estimation.* Springer Science Business Media.

Related methods

- MICA Factsheet '*Geochemical mapping for mineral exploration*'
- MICA Factsheet *'Remote sensing and geophysics'*

Some examples of operational tools

A number of 3D resource modelling software programs are commercially available, including:

- Leapfrog GEO – 3D geological modelling software (http://www.leapfrog3d.com)
- Datamine Studio RM – resource modelling software (http://www.dataminesoftware.com)
- ThreeDify GeoModeler – http://threedify.com/geological-software/

Software programs are listed for information only, no endorsement or recommendation is provided or implied.

Key relevant contacts

There are a number of resource reporting committees worldwide that publish internationally recognised reporting codes, against which mineral resources and reserves may be reported. These reporting codes, and their updates, are often made freely available via an online portal. Below are listed some of the available reporting codes.

Region	**Code**	**Reporting code portal (website)**
Europe	PERC	http://www.vmine.net/PERC/index.asp
Australasia	JORC	http://www.jorc.org/

South Africa	SAMREC	http://www.samcode.co.za/samcode--ssc-mainmenu-66/samrec-mainmenu-67
Canada	NI 43-101	http://web.cim.org/standards/MenuPage.cfm?sections=177&menu=178

Those listed above comply with the CRIRSCO International Reporting Template; more information on this is available here: http://www.crirsco.com/welcome.asp