Radial basis function supported implicit geological modelling tool for mining industry

Geological modelling of a deposit is the most crucial task being accomplished post exploration campaign. A geologically constrained ore body model has long been hailed as vital for a mineral resource statement. The accuracy of geological model depends upon the correct interpolation of ore and waste interfaces from the exploration database. Traditionally, manual digitization is being followed for delineation of ore and waste interfaces during the process of creating geological model which is quite time consuming and relies heavily upon the concepts of experienced modeller who is involved in the process. With the recent advances in fast scattered data interpolation methods, the construction of the geological surfaces using volume functions is now a practical alternative to traditional modelling process. The interpolated surfaces contained in the volume function is not explicitly defined or digitized rather it is generated through the radial basis functions implicitly, thus the process is called implicit modelling. In this present paper, the concepts of implicit geological modelling technique are addressed and radial basis function which is being used as spatial interpolation technique for implicit modelling process also elaborated. Finally the benefits of implementing the implicit modelling to the resource modelling exercise are highilighted.

Keywords: *Geological modelling, implicit, radial basis functions.*

1. Introduction

Geology is a science rather than an engineering discipline because it models the real world instead of building structures within it. These models evolve continually with the collection of new data and the scientist's improving understanding of the physical processes that govern the creation of the geological environment. In some cases, the finding of a rich ore body, either by skillful exploration or by chance, has been the key to success. Yet there are many examples of rich ore bodies not producing profitable mines and of mediocre ore bodies turning into successful long term enterprises. Advanced geostatistical methods combined with improved hardware and software capability allows rapid processing and interpolation of huge amounts of drillhole data. The problem is that there is sometimes a significant lack of communication and interaction between these two very distinct disciplines geoscience and geostatistics which can result in reduced confidence in resource classification and, sometimes, poor business decisions. This is the opportunity and the future of geological modelling. Traditionally, the process of resource evaluation begins with the manual digitization of the lithological sections. This process of manual digitization is called explicit modelling which is quite time consuming and relies heavily upon the concepts of experienced modeller who is involved in the process. However an 'implicit' model of a solid is given by a function defined throughout space. This volume function is modelled from spatially interpolating sampled drillhole data and the surface of the solid is extracted as triangulations from this function. The surfaces to be modelled are therefore not constructed directly, as done in the explicit method, but instead are finite approximation of surfaces with infinite detail.

2. Geological modelling

The basis for spatial modelling of potential mineralisation is the geology, which in most non-primary mineral systems can be expressed as the underlying lithology, with some form of mineralisation system superimposed. In data-rich (typically well drilled) areas, sectional interpretations of the lithology and mineralisation are triangulated to construct 3D domain models for use in grade estimation (Osterholt, et al., 2009). Using traditional mine planning software, the time to construct and subsequently update these models can be significant and results in single geological models that are updated annually for reporting purposes. When considering exploration areas, the modelling time can often increase as additional non-data constrained interpretations are required to produce appropriate triangulation models. To address the range of possible geological interpretations at exploration stages, a different approach to geological modelling is needed. Implicit modelling tools are capable of rapidly building geologically robust triangulation models of lithology and form the basis of a geological modelling workflow presented in Fig.1.

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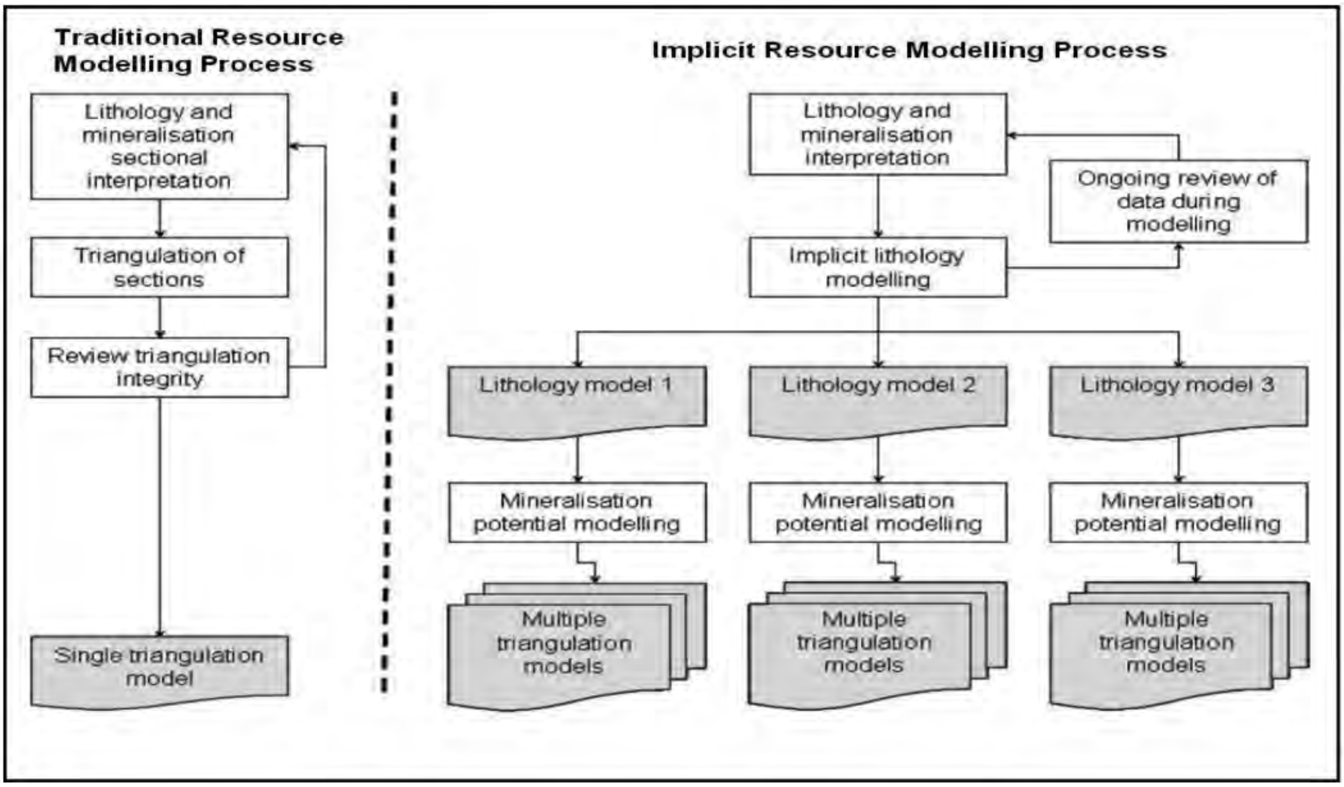

Fig.1 Flow diagram showing a traditional geological modelling process for resource estimation compared to workflow using implicit modelling approach

Modelling zones of potential mineralisation forms the second part of the workflow, including combining data (where available) with a method of representing the understanding of the mineralisation processes.

Traditionally, accuracy of the resultant models depended on the experience and training of the modeller. In mining, geological models are used to predict the presence of economic quantities of minerals, and then quantify the amount of material available. Models are nowadays a fundamental part of mine planning. Prediction has an extrapolative rather than interpolative character, and thus involves risk and leads to decision-making (Hodkiewicz, 2013). Resource geologists traditionally favoured the use of sectionally hand-digitized wireframe models for resource estimation (e.g. those created with Surpac, Datamine, Vulcan or other mining software packages). Automated methods were generally not considered appropriate by those traditionally doing modelling for estimation purposes. They were looked on as ‘black boxes’ that allowed the computer to do the interpretation, rather than the geologist. Recent advances in the soft computing methodologies have led to the challenging of the traditional methods through the automatic creation of geological models (implicit geological modelling).

Geological shapes of any geometry can be manually digitised, but the limitations of this methodology are as follows:

- Manual digitisation is time consuming if complex shapes are being modelled;
- Models consisting of explicit surface triangulations cannot be automatically updated as more data becomes available;
- Any edits or additions involve complex manipulation of the model and thus is approached on campaigns rather than on a continual basis; and
- Interpretations of the geologist are written into the model, therefore the model cannot be easily replicated by other geologists, placing an unknown risk to any downstream mining procedures.

3. Spatial interpolation by radial basis function (RBF)

Interpolation is a method that produces an estimate or interpolated value of a quality which is not known at a point but is known at other points such as from drillhole data. The accuracy of interpolated value depends upon the algorithm being utilized and the parameters presumed by the user. Radial basis function is used as basis of interpolation by most of the geological and mine planning packages for implicit modelling. RBFs have various applications in practice, due to their simplicity, generality and fast learning stage. Radial basis functions are a generalization of the original multiquadric equations (Hardy, 1971). The basic hypothesis of the multiquadric analysis is that any smooth mathematical surface, and also any smooth arbitrary surface (mathematically

The main features of RBF are:

1. The hidden nodes implement a set of radial basis functions (e.g. Gaussian functions).
2. The output nodes implement linear summation functions.
3. The network training is divided into two stages: first the "weights" from the input to hidden layer are determined, and then the weights from the hidden to output layer.
4. The training/learning is very fast.
5. The networks are very good at interpolation.

RBF interpolation, being a global interpolation method, requires all the data points to be used to calculate the coefficients (the weights assigned to each value). One of the limitations of RBF is the fact that large datasets result in data storage problems. An RBF network is non-linear if the basis functions can move or change size or if there is more than one hidden layer.

4. Implicit modelling process

Implicit modelling defines an approach to 3D modelling that is fundamentally different from CAD-based, semi-manual software, using a mathematical function to profile 3D geological surfaces directly from primary observations without laborious manual manipulations. The main advantages are: speed, cost, better use of complex data sets and repeatable models. This modelling approach may be applied to discrete variables such as lithology (where it may be used to create geometric models of lithological units/ contacts), to continuous variables such as geochemical grades to model the distribution of grades at points or over block volumes, or to binary indicators of continuous variables.

A simple illustrative example of such a function would be that of a sphere with an unit radius: $x^2 + y^2 + z^2 - 1 = 0$ (which is in the form $f(x,y,z) = C$, where C is a constant). This equation describes the infinite number of (x,y,z) coordinates that lie on the surface of the sphere. Note that the surface of the sphere is only implied in the equation, as the coordinates are functional arguments. The actual coordinate position of the sphere therefore cannot be directly determined from the equation. In order to determine the position of the sphere in space, various (x,y,z) coordinates are inserted into the sphere equation and the scalar values returned will indicate whether the point is inside (< 0) or outside (> 0) of the sphere surface (= 0). This is conventionally done on a three-dimensional grid. By using grid-based evaluation methodologies, one can spatially converge to coordinate positions where the function value approaches zero and the approximate position of the sphere surface can be determined (e.g. Boomenthal, 1998). Research into automated processes to generate shapes of any geometry using surface function methods have not resulted in trivial solutions (e.g. Sirakov et al, 2002; Xu and Dowd, 2003). Geologists therefore have had limited choice other than to hand digitise complex geological surfaces and grade boundaries. Such geometrical restrictions do not exist when implicit surfaces are modelled with volume functions. In addition, since geological data is inherently volumetric, the implicit representation of surfaces is an ideal one. Grade distribution, for example, can be defined as a volumetric function and the grade isosurfaces evaluated at any resolution in the volume of interest. Such use of volume functions and its implicit surfaces to represent grade envelopes and geological boundary surfaces is herein termed 'implicit modelling'.

Unlike explicit modelling where sections are created independently by manual digitization and fitted together to try and create 3D model (Fig.5), Implicit modelling is generated by computer algorithms directly from a combination of measured data and user interpretation. The modelling requires a geologist's insight, but this is made in the form of trends, stratigraphic sequences and other geologically meaningful terms. This approach is faster, more flexible and fundamentally better suited to modelling geology. Models can also satisfy important geological constraints, e.g. lithological units can fill the space under the ground with no gaps and spaces, cutting through any section at any position will always be consistent with other sections. Initially the real exploration data is coded into numerical values with the surface contact intercepts attributed with a value of zero. Once the data is interpolated in space this zero isosurface is extracted from the function as contact surface of two lithologies as shown in Fig.6. Typical 3D output of specially interpolated data generated through RBF supported implicit modelling are shown in Figs.5 to 7.

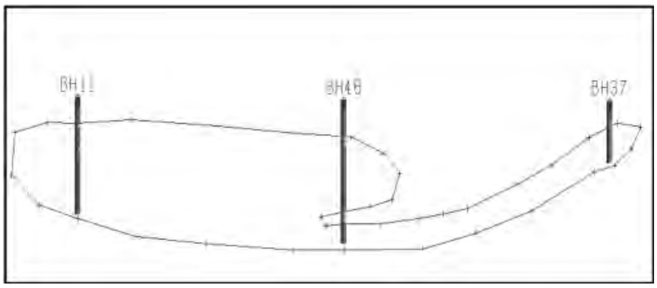

Fig.5 Creating sections by manual digitization based on the interpretation of geologist

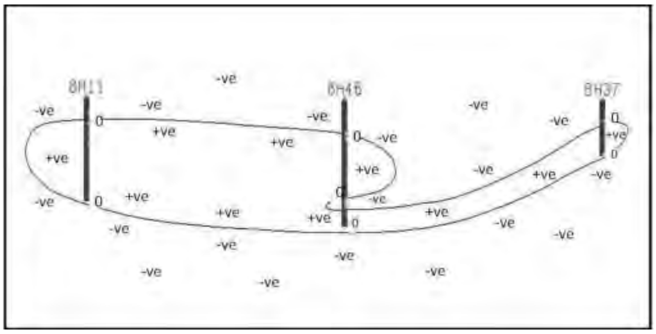

Fig.6 Contact surface delineation through special interpolation

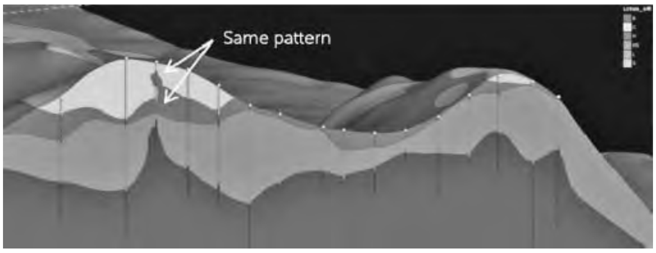

Fig.7 3D geological implicit modeling (Source: Leapfrog Geo)

The advantage of using implicit modelling tools is that they are very quick, However, they do not represent a silver bullet to geological modelling. Input and control by a geologist needs to be applied to assure reasonable results. This typically takes the form of:

- Reviewing consistency between different data types,
- Introducing additional interpretation data (i.e. limited control sections), and
- Simplifying the interpretation in data rich areas.

Through all the modelling process, particular attention needs to be placed on the scale of the data with respect to the scale of the final model. It is not possible to precisely fit the triangulations to very closely spaced data or detailed interpretations in structurally complex areas without post-modelling manual adjustment. In all cases where these modelling approaches have been applied, the conceptual understanding of the geology has improved, as the geologist can quickly explore the implications of different interpretations. By applying different geological interpretations derived by an expert panel (e.g. increased fold amplitude or reduced throw on a fault), a series of lithological models can be produced relatively quickly. These can then be used as the basis for mineralisation modelling and subsequent grade estimation.

Potential benefits of implicit geological modelling include:

- The ability to model complex geological objects and process sparse to very large datasets.
- The ability of model iso-grade wireframes rapidly directly from drillhole data without the need for time-consuming domaining or variography.
- The rapid speed in which the modelling can be accomplished represents one to three orders of magnitude in time savings over manual digitisation.
- Being able to identify grade trends that aid the identification of drillhole targets, directly from processing of non-gridded data.
- Unlike manual digitisation, where geological interpretation is written into the models, implicit modelling allows the separation of interpretation from the process of surface generation. The ability to separate geological intuition from the modelling process allows multiple models to be constructed that are all conditional to the drillhole data.
- Implicit models can be rapidly updated as new drillhole data becomes available. This keeps the geological models dynamic, as the modelling methodology can now keep up with speed of data acquisition.

5. Conclusion

Since past couple of years, mining industry has been facing increasing pressure to produce results using fewer resources. In terms of geological modelling, this translates directly to less time generating accurate and meaningful results. Radial basis function supported implicit geological modelling packages expand the geological modelling expertise for the exploration geologists taking on their own projects at varied levels of complexity and adding value with relatively little effort or time investment. This allows more time to focus on interpretation and allows for faster revisions to the model. The learning curve is far quicker than for traditional modelling techniques and the skills set required to produce successful models is greatly reduced.

Faster computers and advanced softwares now allow a skilled driver to frame a series of data handling steps that generate three-dimensional models. The heavy lifting traditionally undertaken by a geologist drawing hundreds of lines is now completed in a fraction of the time and in 3D by fast processors and efficient mathematical algorithms. As on today many leading geological and mine planning softwares like Leapfrog, Micromine, Minesight and Maptek etc. were already incorporated this implicit algorithm into the modelling process tools. Present paper addressed upon implicit geological modelling process and the algorithm behind the process which is radial basis function as spatial interpolation tool. The potential benefits of the implicit modelling process also highlighted which has come up as a revolution to the mining industry over the traditional methods of the resource modelling.

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INVESTIGATION INTO LAND SURFACE DEFORMATION DUE TO HARD ROCK UNDERGROUND METAL MINING USING DIFFERENTIAL INTERFEROMETRIC SYNTHETIC APERTURE RADAR (D-INSAR) TECHNIQUE

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