Paper 114

Implicit Ore Delineation

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ABSTRACT

Mineral resource estimation requires accurate, valid models that are created using flexible, efficient modelling techniques. Irregular, complex 3D orebody boundaries must be represented based on sparse data.

This paper compares the efficiency, flexibility and accuracy of an alternative approach to 3D modelling of orebody boundaries that offers several advantages over traditional "explicit" methods. The implicit modelling method, based on a method of global interpolation using Radial Basis Functions (RBFs), provides a viable alternative to the traditional contour method of geometric modelling. The implicit method extracts an isosurface of the orebody boundary from an implicit 3D volume function. This study shows that the "implicit" modelling method is more efficient and has a similar or better accuracy than the model created using the traditional "explicit" method.

This study concludes that the implicit method of geometric modelling is as accurate as the traditional modelling method. In addition, the implicit method is much more flexible and efficient, which allows for the creation and continuous update of multiple geometric models that are conditional to the same data. The implicit modelling approach presents a new "conditional geometric modelling" workflow that meets the needs of the mining industry for mineral resource estimation.

INTRODUCTION

The purpose of this study was to compare the geometric modeling accuracy, flexibility and efficiency of a recently developed implicit modeling method to those of the traditional contour method employed by industry-standard general mining software packages (GMPs). Real-world drill hole data was used to construct geometric models of the Doris Hinge gold deposit. One traditional model was created using MineSight® software and 79 implicit models were created in four separate stages using Leapfrog software.

The modeling efficiency of the traditional method was measured, as well as that of the four different stages of implicit modeling. The accuracy and volume of each of the models were measured. The volumes of each of the implicit models were compared to that of the reference model by calculating the percent volume difference. The mesh differences between selected sets of models were measured in order to determine where the implicit model meshes varied the most from the traditional model.

Representation of orebody boundaries is primarily used in the mineral resource industry for the purpose of resource and reserve estimation. Orebody boundaries are complex, irregular 3D surfaces that are often constructed from spatial data derived primarily from sparse, irregularly-spaced drill intercepts. To constrain grade continuity, and contribute to successful mine planning (Grace, 1986; Prenn, 1992; Sinclair and Vallee, 1993 and Sinclair and Blackwell, 2002) geologists require accurate, valid models of the geological continuity of orebodies that can incorporate various geological interpretations (Dominy et al. 2002). These models must be accurately created and updated with new information in a minimal amount of time.

Current CAD-based tools available in GMPs have been shown to be inefficient and inflexible. This study surveyed a range of GIS spatial data structures and interpolation techniques that could be used to create geometric orebody models. It was concluded that a recently developed implicit modeling approach that extracts a boundary surface from an implicit volume function provides a viable alternative to the traditional contour modeling method.

The implicit modeling method (Cowan et al. 2003) utilized by Leapfrog software was used in this study to model real-world, spatially-referenced data from the Doris Hinge gold vein deposit in Canada. A traditional reference model was created using MineSight® software for the purpose of comparing relative accuracy, flexibility and efficiency.

The economic viability of a mining operation relies on reliable mineral resource estimation, which requires the

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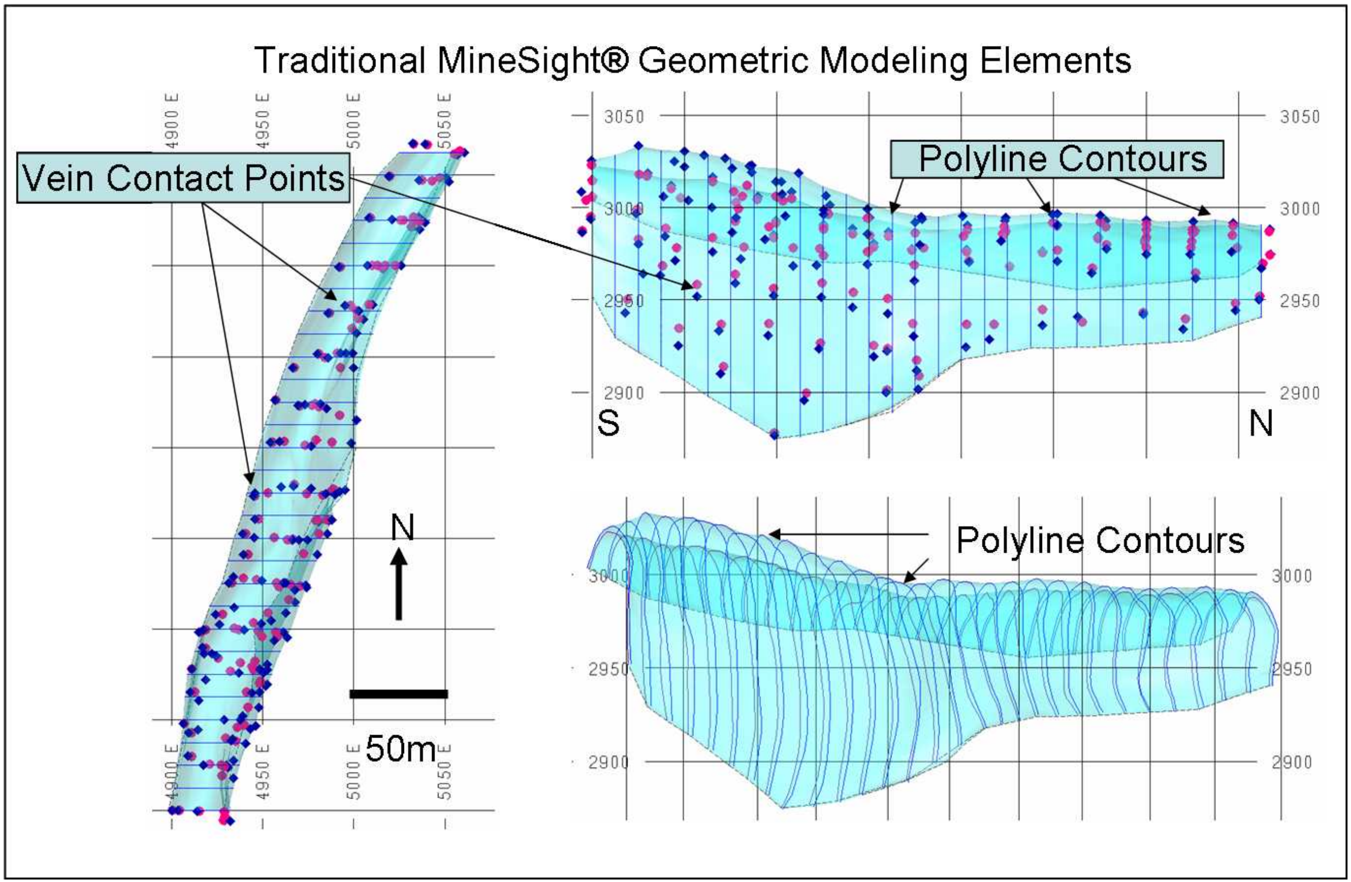

Figure 1: Traditional Modelling Elements

accurate 3D representation of orebody location, configuration and volume. For example, if the orebody is not where the model predicted, if its configuration is different from what was represented, and/or if its volume is different than anticipated, then the mine development plans need be changed, a different mining method must be considered, and, finally, the economics of the project will have to be reevaluated.

Zhu et al. (2003) emphasizes this point by stating that due to the high risk of mining projects, uncertainties in the modeled orebody geometry and spatial estimation of properties such as tonnage and grade will have a great effect on the cash flow and profit. In this regard, Francis et al. (2000) note that 10-15% of the cost of mining ore results from insufficiently accurate orebody delineation.

METHOD

Doris Hinge Drilling Data

Surface drilling information outlining the Doris Hinge gold deposit was provided by the Miramar Mining Corporation (Carpenter et al., 2003; Sherlock et al., 2003). For the purpose of this study the drilling data was sorted into two phases: phase 1 (preliminary holes drilled between 1995 and 2000), and phase 2 (follow-up holes drilled between 2001 and 2003). In general, both sets of holes were drilled on vertical W-E cross-sections spaced 12.5m apart and oriented nearly perpendicular to the axis of the Doris Hinge fold structure.

The vein contact points were selected from the drill hole database based on the coded identification of the vein/wall rock contact in the drill hole database. Once identified, the x, y, z coordinates of each of the contact points were extracted from the database using Leapfrog™ software. A total of 239 phase 1 and 190 phase 2 vein contact points were extracted using this procedure.

Phase 1 contact points were sorted into hanging wall and footwall point sets. A total of 125 hanging wall and 114 footwall vein/wall rock contact points were selected and extracted from the phase 1 drill-hole database. The 239 phase 1 contact points were used to create all of the geometric models in this study.

Geometric Modeling

A total of 80 different geometric models of the Doris Hinge deposit were created. One model was created using the traditional modeling method (Figure 1), which is referred to as the "traditional" or "reference" model. Implicit modeling generated 79 geometric models in four separate stages, which are referred to as "implicit" models (Figure 2). The four stages of implicit modeling are designated as Preliminary, Stage 1, Stage 2, and Stage 3.

Implicit models fall into two categories: semi-automatic and interpretation. Semi-automatic models are generated using only drill hole contact points. Interpretation models, on the other hand, incorporate subjective geological interpretation in the form of digitized polylines. Preliminary and Stage 1 models are semi-automatic models. Stages 2 and 3 are interpretation models.

Model Evaluation

Since the Doris Hinge deposit has not yet been developed underground, the true location, shape and volume of the vein is unknown. The 190 phase 2 contact points represent what is "accepted" to be the true location of the vein surface for the purpose of this accuracy evaluation. Accuracy is determined by measuring the perpendicular distance between the nearest triangle (vertex, edge or face) on the geometric wireframe model surface and the phase 2 contact points, which is similar to the procedure described by Jones (1995).

The time required to perform each step of the geometric modelling process was recorded for the traditional and two different implicit procedures in order to determine relative modelling efficiencies.

Volumes of implicit models were compared with that of the MineSight® reference model by calculating the percent volume difference.

RESULTS

Accuracy

The implicit method generated a wide range of geometric models with accuracies that were comparable to that of the MineSight® model (Table 1). In the implicit modeling process, the accuracy of the semi-automatic models was systematically improved with the incorporation of successive levels of geological interpretation. The two stages of

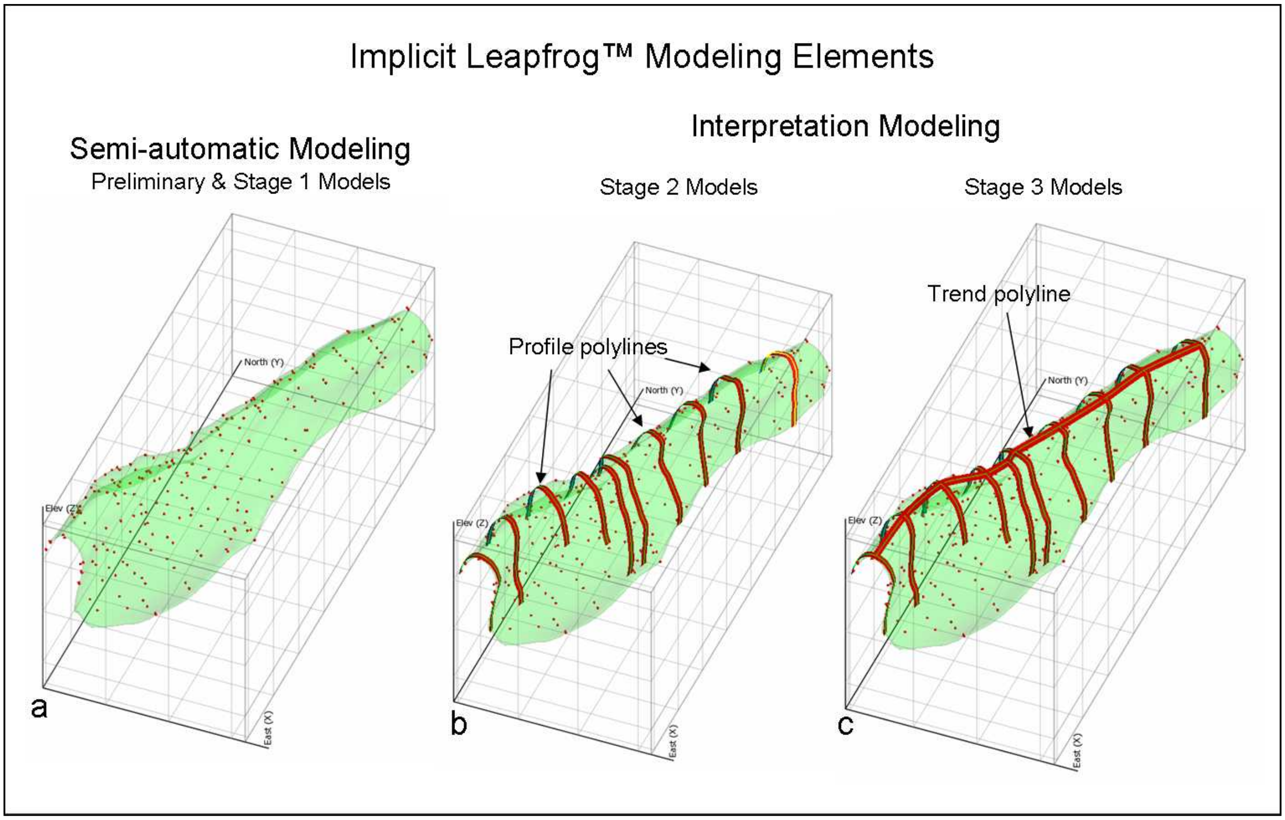

Figure 2: Implicit Modelling Elements

Table 1. Summary of Accuracy Results

	Summary of Model Accuracy Results			
	Root Mean Square Error (RMSE) distance (meters)			
MineSight® Model	2.06			
Leapfrog® (implicit) Models				
	Isometric	Maximum (least accurate)	Mean	Minimum (most accurate)
Preliminary Modeling Semi-automatic models (27 models)		3.06	2.58	2.29
Stage 1 Modeling Semi-automatic models (16 models + 1 isometric model)	3.48	3.12	2.36	2.15
Stage 2 Modeling Interpretation models (16 models + 1 isometric model)	2.27	2.40	2.15	2.05
Stage 3 Modeling Trend / Interpretation models (18 models)		2.15	2.09	2.03

interpretation modeling created models of equivalent accuracy to that of the MineSight® model. The MineSight® model required validation, while the implicit models were automatically validated.

Flexibility

The MineSight® model was inflexible in that one subjective interpretation was built into a single deterministic model. Hours of work is required to regenerate the model using a different interpretation. Multiple models reflecting different geological interpretations would require days to produce

Efficiency

The MineSight® reference model required nearly eight hours to construct. In contrast, the seventy-nine implicit models created in the study, on average, required only 13 minutes each to create. In the time it takes to create one single model using the traditional method, between 30 and 40 implicit models could be produced. Theses implicit models, in turn, could be updated with new information in a similar amount of time. This level of efficiency would allow for maintenance of "evergreen" models that remain up-to-date, which would facilitate mine reconciliation on a regular basis.

Volume Difference

The volumes of all of the implicit models were larger than that of the MineSight® model. When evaluating the differences it was found that the implicit and traditional models varied in three particular areas of the deposit. It is interesting to note that the boundaries of all models underestimated the location of the phase 2 points, which indicated a thickness to the vein. A comparison of the meshes showed that there is relatively equal distribution of areas where the implicit models define an "outer" orebody boundary. In certain areas, the Leapfrog model contact outlined a larger cross-sectional area than the MineSight® model,

Conditional Geometric Modeling

Considering the accuracy, flexibility and efficiency of the implicit method of geometric modeling, a suite of accurate models that are conditional to the same data could be created that would assist in quantification of uncertainty.

Quantification of uncertainty is becoming more and more important to the mining and exploration industry. This study represents the first time that "conditional" geometric models have been created. The workflow developed in this study could be used to establish a standard method of "conditional geological modeling" in the mining industry.

CONCLUSIONS

The results of this study indicate that the implicit modeling technique is accurate, flexible and efficient, which meets the general requirements of geometric modeling for the purpose of resource estimation. The key findings of this study confirm that the implicit method of geometric modeling provides a viable alternative to traditional methods. In addition, the implicit method is flexible and efficient.

Multiple geometric models can be created that are conditional to the same data in a fraction of the time required to construct a single model using traditional techniques. This study provides the first example of what the authors term "conditional geometric modeling." This modeling workflow offers an alternative to the standard, traditional modeling approach used in the mining industry. The new "conditional geometric modeling" workflow provides a series of accurate models that represent a range of geologically-realistic orebody boundaries that can be used in mine planning or for quantifying the uncertainty of resource estimations.

In addition, models can be generated very efficiently, which enables resource and reserve models to be updated with new drilling information on a daily, rather than a semi-annual or annual basis. This ultimately provides for the maintenance of "evergreen" models, which would provide for regular mine production/reserve reconciliations that increase the efficiency of mining operations.

In the future the implicit method offers the promise of incorporating further geological conditioning in the form of variable continuity of the model and further enhancements to the automatic generation of contact points.

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