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Modeling a Porphyry Deposit with Locally Varying Anisotropy

J.B. Boisvert and C. V. Deutsch

Geomodeling with locally varying anisotropy (LVA) is of increasing interest. This paper presents a case study where LVA is applied to model gold grade in a copper-gold porphyry deposit. The extension of the methodology from 2D to 3D is the main contribution of this paper. As such, the focus of the text is on the 3D nature of the data; the methodology is described elsewhere.

The Data

The data available consist of approximately 300 drillholes for a copper-gold porphyry mine. More details on the geology of porphyry deposits can be found in (Guilbert and Park, 2007). The data has been altered slightly to protect its origin; however, the spatial features remain the same. Data is available for both Cu and Au; however, only the Au grades are considered, although both variables display similar locally varying anisotropy. The results are provided for the Gaussian transformed values since the original data units are not relevant; the same spatial features are present for the Gaussian transformation.

The data displays show very clear nonlinear anisotropy (Figure 1). Selecting a single direction of continuity for such a deposit is difficult. The best results would likely be obtained with an omni-directional variogram because any direction selected is inappropriate for some locations in the model (Figure 5 and Figure 6); however, taking advantage of the known locally varying directions of continuity can improve model performance. This type of deposit is an ideal candidate for kriging with LVA as the continuity is clearly shown in the data but there is not sufficient data density to fully define the complex geology and control the resulting geostatistical models.

A grid size of 5m in the x and y directions and 2m in the z direction is used for this model. A model of size 100x100x100 cells is used for a total of 1M cells.

Generating the LVA Field

The data were block kriged to generate a smooth map that can be used to determine the orientation of the locally varying anisotropy (Figure 1 left). The LVA field is generated manually for this case study and consists of three distinct zones. Three areas of the model are defined as (1) within the circular feature, where visually there appears to be no anisotropy (2) the circular mineralized zone and (3) a transition zone between zones 1 and 2. Plan sections were examined every 20m and the core of the deposit was manually defined by the center and radius of a circle (Figure 1 middle) for each slice. Within this circle an anisotropy ratio of 1:1 is assigned to the LVA field. Outside the 1:1 core of the deposit, the magnitude of the anisotropy increases linearly to 10:1; this transition zone has a thickness of 20m. The direction of continuity for this LVA field is always tangential to the circle centered at a manually selected location (Figure 1 right). Such an LVA field effectively captures the radial nature of the non-linear geological features (Figure 1) as well as the isotropic barren core.

The LVA field generated is subjective and should be subjected to the same sensitivity analysis as discussed in paper 203 for a better understanding of the uncertainty inherent in this deposit; however, the purpose of this case study is to demonstrate the methodology in 3D. As such, only this single, geologically realistic but subjective LVA field is carried forward.

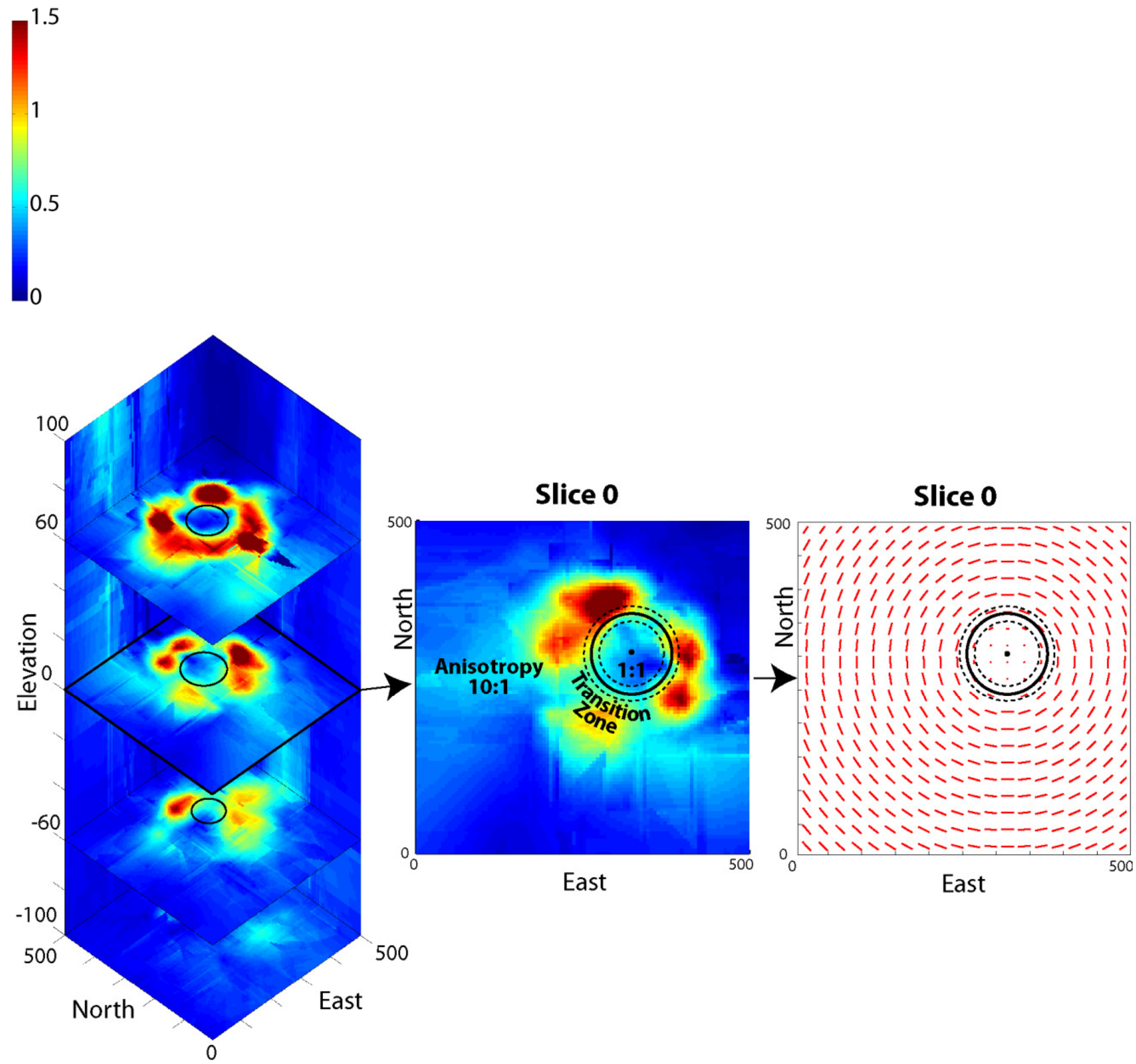

Figure 1: Left: Multiple slices of the block kriging map used to generate the LVA field. Middle: For each slice the LVA field is 1:1 inside the circle (defined manually for each slice) and 10:1 outside. Right: The LVA field. Length of the line is proportional to the anisotropy ratio.

Estimation with LVA

The parameters for ISOMAP-L are required to implement estimation and simulation with LVA. A total of 64 landmark points on a regular pattern of 4 x 4 x 4 are distributed evenly in the modeling area. For the calculation of the shortest path distances (SPD) required for kriging with LVA (see paper 102 in this report) a single offset is used. After application of ISOMAP-L, the resulting 3D grid can be visualized in the first three coordinates of the 63 dimensional Euclidian space the grid has been embedded into (Figure 2). Of interest in this visualization of the grid is the overlapping of multiple gird cell locations (highlighted on Figure 2 right). This can occur because there are no restrictions placed on the embedding; cell locations are free to be placed in any orientation such that the initial distance matrix is best reproduced (see paper 102 for details). However, in this example, the overlapping of the grid cells occurs because the grid has been embedded in 63 dimensions and is only displayed here in the first three. If the grid could be visualized in 63 dimensions, this overlapping would not be seen.

Kriging with a horizontal omnidirectional variogram is compared to kriging with LVA. The variograms used to model the deposit are shown in Figure 3 with associated cross validation results in Figure 4. There is some improvement in the correlation when applying LVA; however, kriging with LVA realizes greater gains when measured by the covariance. Covariance can be a better assessment of model performance because it considers the standard deviation of the resulting models.

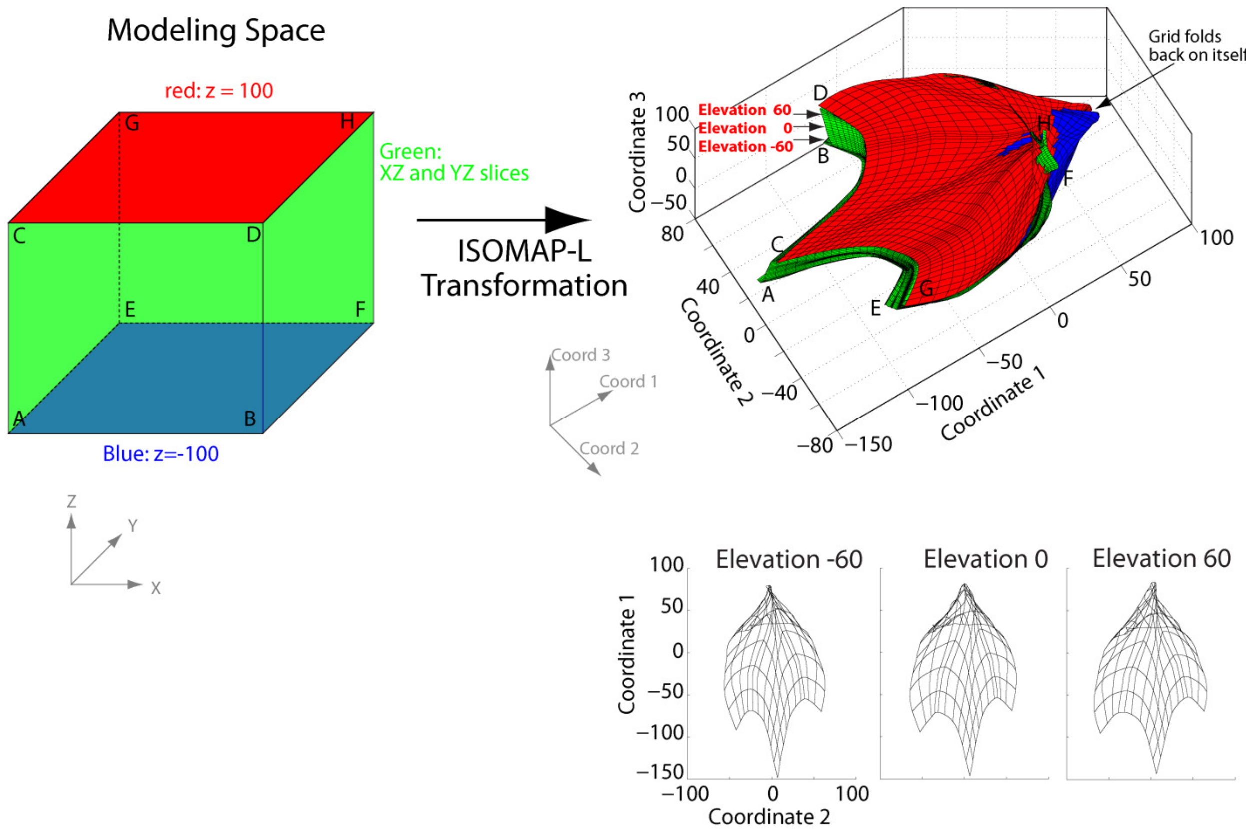

Figure 2: 3D visualization of the embedded grid. Left: the original grid shown in Cartesian coordinates. In both figures, the red surface is the upper slice of the model (z = 100) while the blue surface is the lower (z = -100). The green surfaces represents the XZ and YZ boundaries of the block model. Slices of the grid in 2D are shown below right.

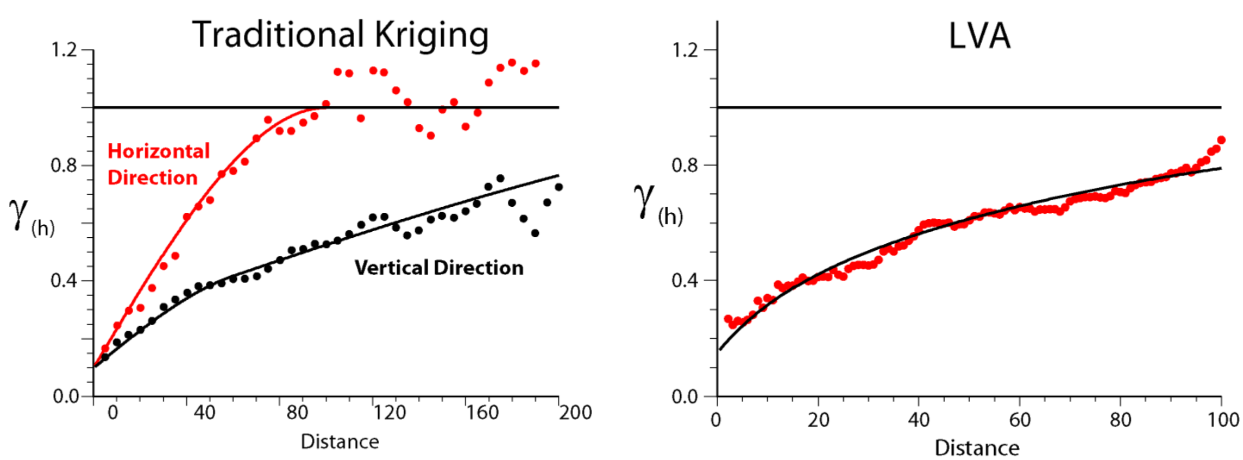

Figure 3: Variograms used to build models.

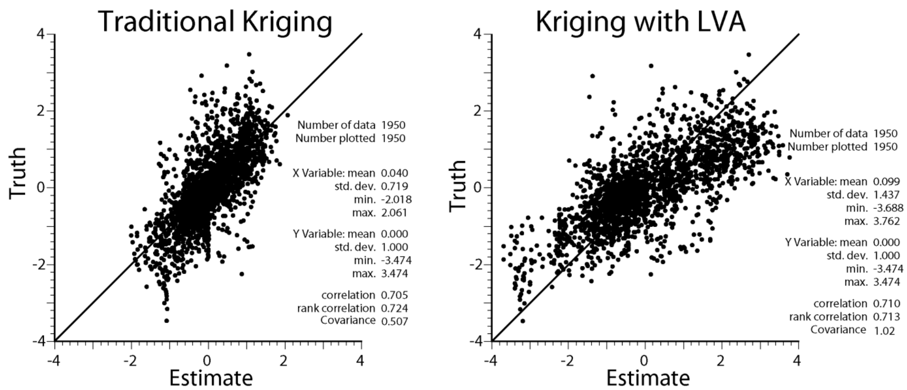

Figure 4: Cross validation using traditional kriging (left) and LVA kriging (right).

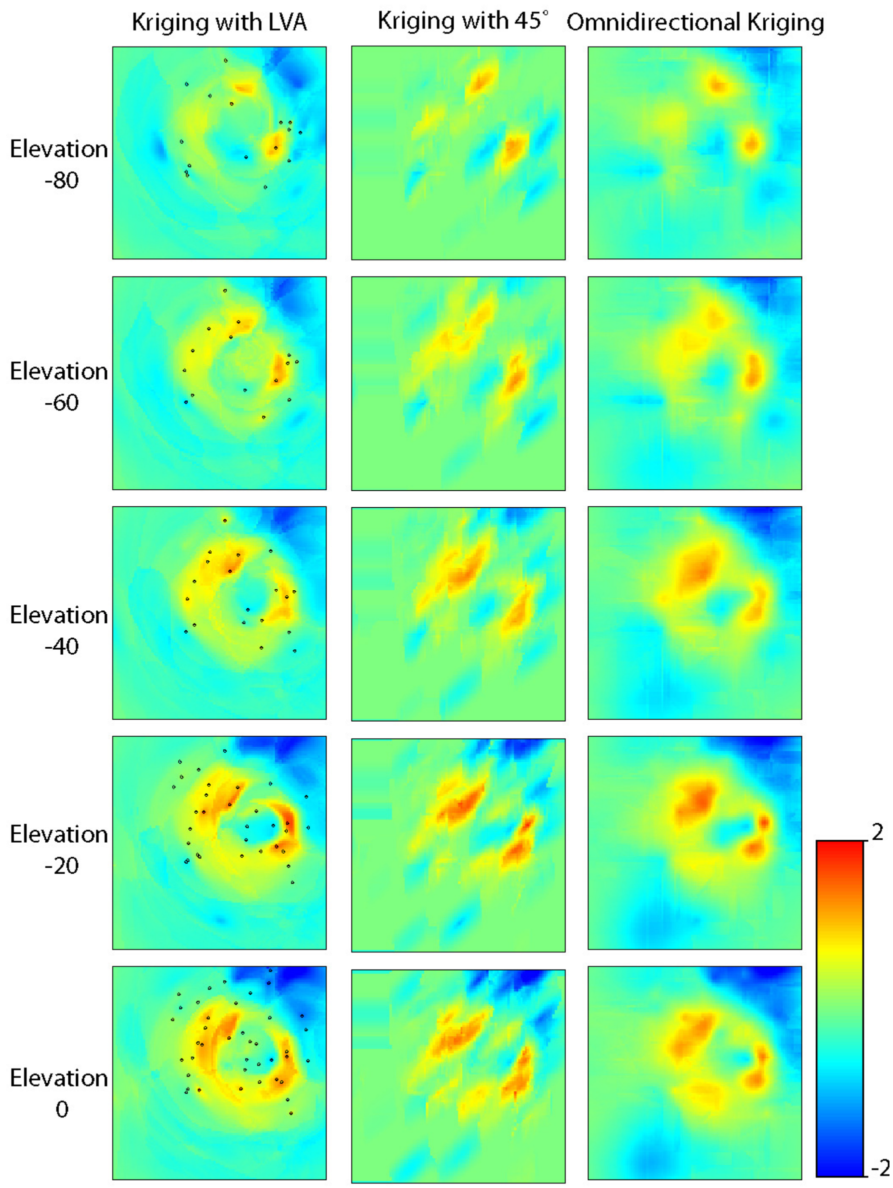

Figure 5: Left: kriging with LVA. Middle: Kriging with constant anisotropy in the 45˚ direction. Right: Kriging without horizontal anisotropy. Elevation -80m through 0m. Sample data are shown on the LVA kriging maps only.

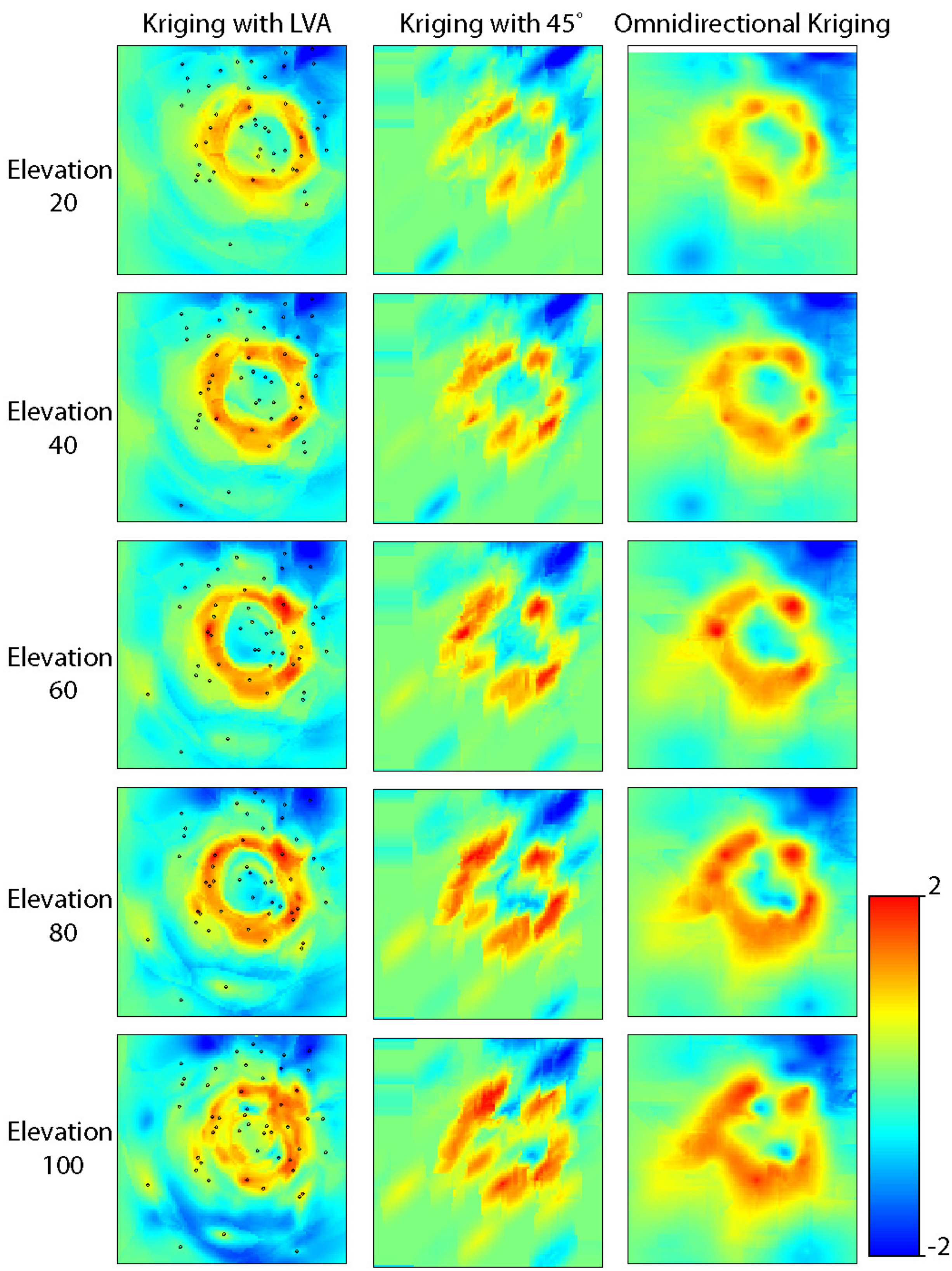

Figure 6: Left: Kriging with LVA. Middle: Kriging with constant anisotropy in the 45˚ direction. Right: Kriging without horizontal anisotropy. Elevation 20m through 100m. Sample data are shown on the LVA kriging maps only.

The goal of this modeling is to generate realistic geostatistical models that incorporate locally varying anisotropy. The conceptual model of this deposit suggests that the mineralized zone is concentrated in a radial pattern. Traditional techniques do not adequately account for this information. When applying traditional methods with either a single direction of continuity or no anisotropy the high valued Au zones are often disjointed and interrupted where they are expected to be more continuous (Figure 5 and Figure 6). When the data density is sufficient to adequately describe the geology, such as in elevation -20m, traditional methods assuming an isotropic deposit tend to do well; however, this is not the case when the data density decreases, such as in elevation -60m.

Further study of the kriging maps in Figure 5 and Figure 6 indicates that the assumption of a circular barren core may be too simplistic. Consider elevation -20m, in some areas an ellipsoidal core may be more consistent with the available data. In practice, such modifications can be made iteratively to the LVA field if deemed necessary.

Conclusions

The methodology proposed in papers 102 and 103 was applied to a natural geological deposit that displayed clear LVA. Locally varying features were effectively incorporated into geostatistical estimation. The main purpose of the example in paper 203 was to demonstrate the selection of the various input parameters required to implement the methodology. Specifically, the generation of the LVA field and the selection of the necessary parameters for SPD calculation and ISOMAP-L implementation were discussed. The purpose of this paper was to show the application of kriging with LVA to a 3D example that displays LVA. There are two main issues with extending the LVA modeling methodology from 2D to 3D, the first is the increased CPU time required for determining the SPD in 3D (Figure 7). The second issue is the increased difficulty in modeling the LVA field. In the case of the Cu-Ag porphyry deposit, the LVA could be adequately visualized in 2D slices of the data and manually fit to generate a realistic LVA field. Such data visualization can be more difficult in 3D when the LVA is not axis aligned. Overcoming the difficultly of modeling the LVA field in 3D must be case specific. The benefits of modeling with LVA were apparent in both the reserve calculations for the NCB thickness (paper 203) as well as here with the increase in covariance. When LVA is present and can be quantified in the form of an LVA field, the proposed methodology effectively incorporates LVA into modeling; however, the uncertainty in the LVA field should be considered. Multiple LVA fields can be generated and carried through a sensitivity analysis.

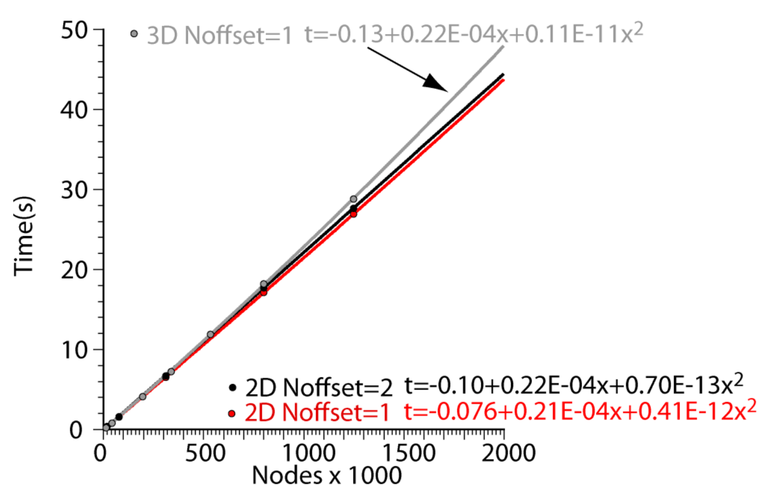

Figure 7: Time required to calculate the SPD for a single landmark point in 2D or 3D. SPD's were calculated with the Boost Graphical Library (Siek et al., 2001).

References

Guilbert J, Park C (2007) The geology of ore deposits. Waveland Press Inc., Illinois.

Siek, J., Lee, L. and Lumsdaine, A., 2001. The Boost Graph Library: User Guide and Reference Manual. Addison-Wesley. 352 p.