

Incorporating complex geological features into geostatistical property modeling

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Geostatistical modeling of reservoir properties is common in the assessment of expected reservoir flow. Typically, static properties such as porosity, saturation and permeability are modeled with geostatistical techniques to quantify the level of uncertainty in reservoir characterization. Lately, practitioners have become concerned that purely statistical techniques do not sufficiently integrate all geological knowledge available; rather statistical assumptions such as Gaussianity and simplistic assumptions on geometry such as global directions of anisotropy or simple stratigraphic coordinates dominate. The proposed methodology can incorporate complex information regarding deposit geometry in the form of locally varying anisotropy (LVA) to generate numerical property models that better reflect the level of geological knowledge available. Specifically, surfaces from seismic data, geological interpretations and dip meter data can be used to assess local orientations of continuity in the deposit and generate an appropriate LVA field. This work presents a novel technique for integrating faulting and LVA information in a single numerical modeling step.

Multiple surfaces representing local orientations from seismic data and faulting from either seismic or geological interpretations can be of first order importance when assessing reservoir response. Numerical models that conform to these features are required. Stratigraphic coordinates can be used to conform property models to two surfaces (top and bottom), but cannot easily consider a single domain with multiple surfaces. By using LVA, any number of intermediate and bounding surfaces can be honored. LVA is considered in this work following the technique presented in Boisvert and Deutsch (2011). In addition to LVA, multiple faults at various dips are difficult to incorporate directly into coordinate transformations. Coordinate systems can be modified to consider vertical faulting, but the proposed methodology is effective in 3D, with a large number of faults and with various dips. A novel technique for incorporating faulting by modifying the shortest path calculation to use offsets based on fault displacement is proposed.

Consider a simplistic example (Figure 1) of a deposit that conforms to a top, bottom and intermediate surface and perhaps contains a single vertical fault (see the associated presentation for a complex example). The intermediate surface would likely be imaged from a combination of seismic data and detailed geological interpretation. With this knowledge, an LVA field that represents the orientation of anisotropy can be generated (Figure 1). The LVA field defines the local orientation and magnitude of continuity (the 'major direction of continuity' in geostatistical terminology). The vertical fault (east=60m) is integrated into the property model by joining blocks along the fault in the calculation of the shortest path with the Dijkstra algorithm. In short, the distance between a block on one side of the fault and a block on the opposite side separated by the appropriate offset is negligible; in Figure 2 the distance A-C is the summation of segments 1+2+3, segment 2 would have an anisotropic distance of ~0m. The anisotropic distance A-B (without fault) is effectively the same as the anisotropic distance A-C (with fault). Geologically this is appropriate as it is typically assumed that at the time of deposition A and C were in close proximity and should be highly correlated. Further details on the use of the shortest path in numerical modeling can be found in Boisvert and Deutsch (2011).

The anisotropic distance (Figure 2) is used in the kriging system of equations to estimate (kriging) or simulate (SGS), with a small modification to ensure positive definiteness (Boisvert and Deutsch, 2011). Figure 2 indicates how LVA is incorporated into modeling; along the major directions of continuity the anisotropic distances are shorter, resulting in a higher correlation in the kriging system of equations, thus 'smearing' the grades along the orientation of the LVA field defined in Figure 1. Estimation using ordinary kriging with and without faulting shows reasonable reproduction of the three surfaces and the fault

(Figure 3). The abrupt end to the high valued zone in the center is due to the lack of high grades in the left and right wells. The identical data and LVA fields are used in both the faulted and non-faulted scenarios with everything east of 60m shifted upwards by 20m. Simulated realizations using SGS could be generated to better characterize reservoir heterogeneity.

The proposed methodology can be used to incorporate multiple surfaces that represent orientations of continuity for the variable of interest, typically determined from seismic data or a geological understanding of the domain. Moreover, any number of faults can be integrated with the LVA in a single modeling step. The main difficulty in implementing the proposed methodology is the generation of the LVA field (Figure 1) and modeling of the faulting including offset orientation and magnitude. With these input parameters known, modeling (kriging or SGS) is straightforward. Some useful programs for modeling with LVA can be requested from the author.

References

Boisvert and Deutsch. 2011. Programs for kriging and sequential Gaussian simulation with locally varying anisotropy using non-Euclidean distances. *Computers and Geosciences*. Volume 37. 495-510.

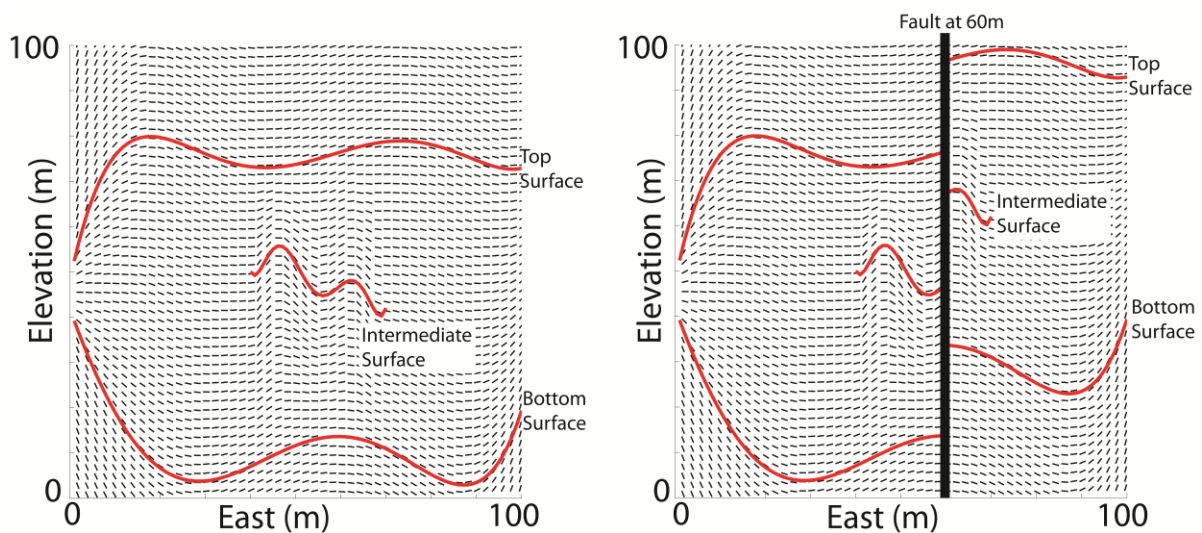


Figure 1: LVA field and surfaces used for the synthetic example. Short black lines represent the orientation of the locally varying anisotropy (i.e. the local direction of maximum continuity). Left: no fault. Right: fault at east=60m. Magnitude of anisotropy is a constant 100:1 ratio.

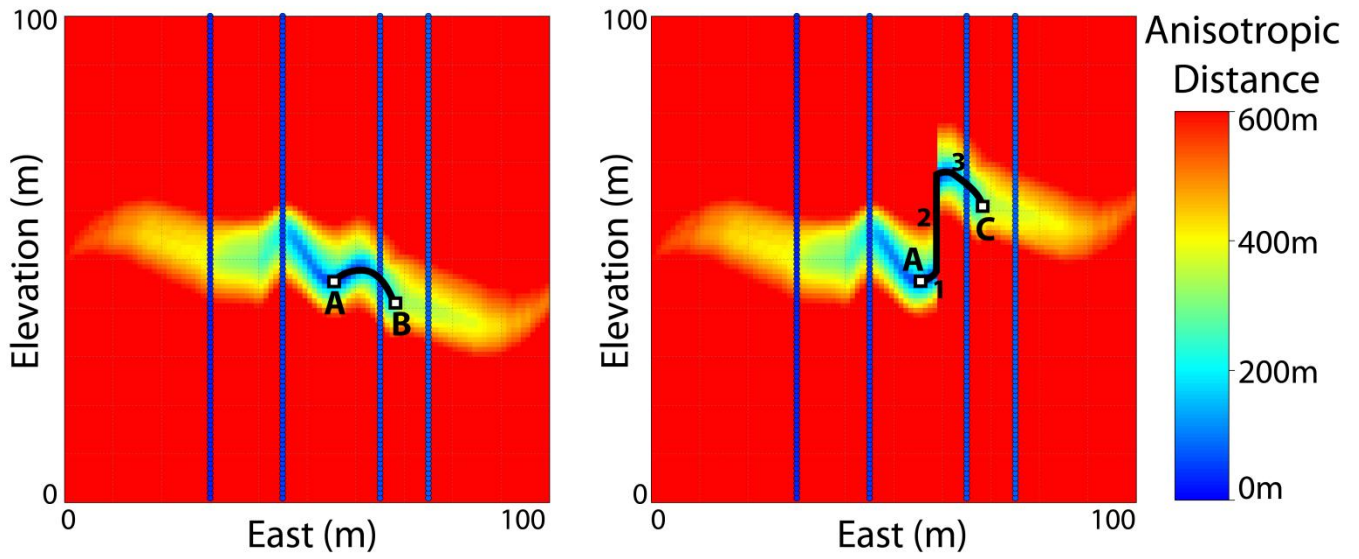


Figure 2: Anisotropic shortest distance from A to all other blocks following the LVA field in Figure 1. The shortest path between A-B and A-C is indicated. Path A-C would be the summation of segments 1+2+3 with line segment 2 having an effective anisotropic distance of ~0m.

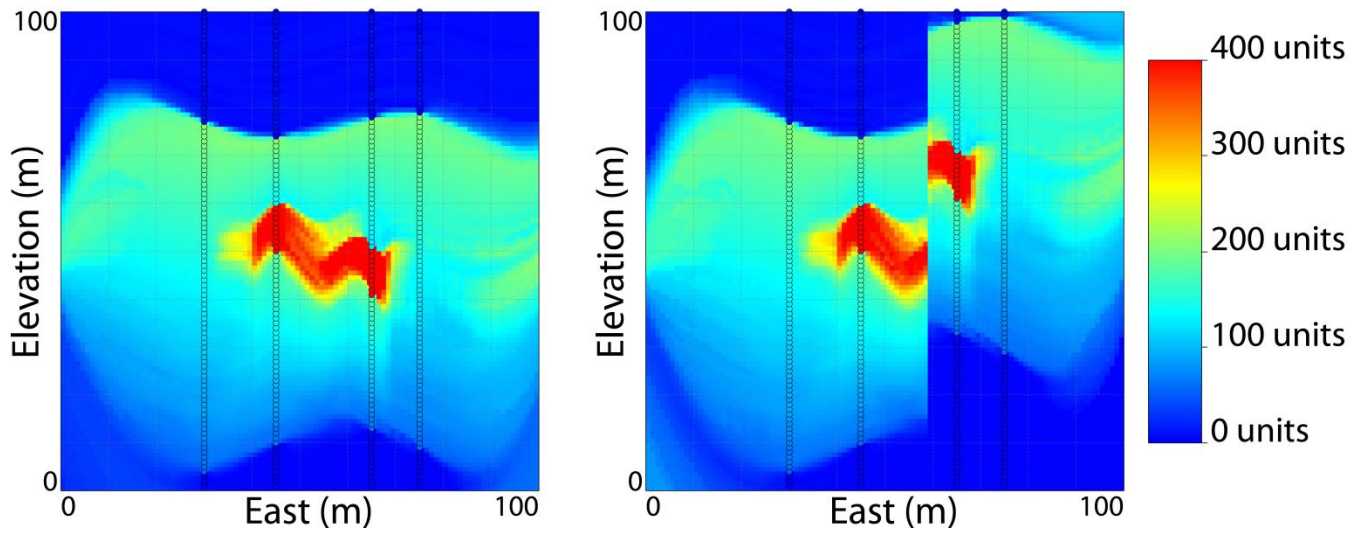


Figure 3: Ordinary kriging result using LVA. Left: no fault. Right: vertical fault at 60m east. Variable units not specified.