3D STOCHASTIC INVERSION OF POTENTIAL FIELD DATA USING STRUCTURAL GEOLOGIC CONSTRAINTS

PEJMAN SHAMSIPOUR[1] AND ERNST SCHETSELAAR[1]
[1] *Geological Survey of Canada, 615 Booth Street, Ottawa, Ontario, K1A 0E9*

BACKGROUND

A variety of techniques have been utilized to invert potential field data (Oldenburg and Pratt, 2007). Most methods are under determined and have non-uniqueness properties, i.e., there are an infinite number of models that fit the geophysical observations. The purpose of any well-founded method is to provide a model that is consistent with all the available geophysical, petrophysical and geological information. Lelièvre and Oldenburg (2009) investigate options for incorporating structural orientation data into under determined inversions.

Herein, we propose a stochastic inversion method that integrates structural information data including bedding and foliation. The idea of this work originates from geostatistical interpolation approaches which add gradient information to the cokriging system (Lajaunie *et al.*, 1997; Chilès and Delfiner, 1999). We adapted this to stochastic inversion of potential field data introduced by Shamsipour *et al.* (2010). The algorithm is tested on a synthetic model consisting of a folded high density layer buried in a homogeneous background. The results illustrate the capability of the method in improving the reconstructed image of the subsurface. The method is applied on a case study in the Lalor area in Manitoba, Canada in order to characterize the deposit and host environment by integrating seismic information and borehole data.

SYNTHETIC EXAMPLE

The gravity data produced by a synthetic model consisting of a high density fold which is shown in Figure 28 (a) is calculated. The synthetic geological structure has a placed in a homogeneous background. The 3D domain is divided into 20*20*15 = 6000 with edge length of 1 m. We assume there is no noise in the gravity data, meaning C0 = 0. We use the gravity data and inversion based on cokriging to estimate the density distribution. The result is shown in Figure 28 (b). The solution appears to be close to the surface rather than at the same depth as the real structure, as expected in unconstrained inversion. In order to improve the inversion result, we can use a few point pairs along an EW-oriented profile across the anticline, defining zero gradients of density. The inversion result using depth weighting and these point pair constraints is shown in Figure 28 (c). Note that the point pairs help to recover to some extent the shape of the anticline. In order to estimate the density values more closely to the actual values, we can assume that we have gradient information between one point in the folded layer and one point in the homogeneous background. The inversion result using point pairs and this known density

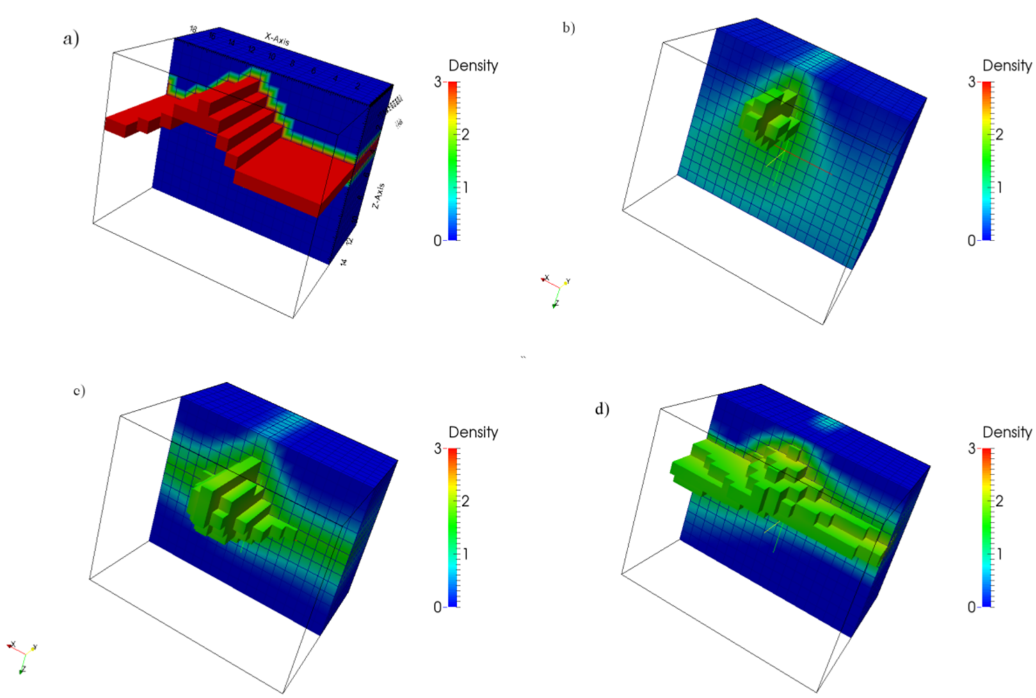

Figure 28. (a) Synthetic model, (b) Inverted data without constraints, c) Inverted data using point pairs and depth weighting with b = 0.7 and (d) Inverted data using point pairs and one known gradient. All the figures are shown at section y = 10,5 m and the threshold is r > 1.5 g=cm^3.

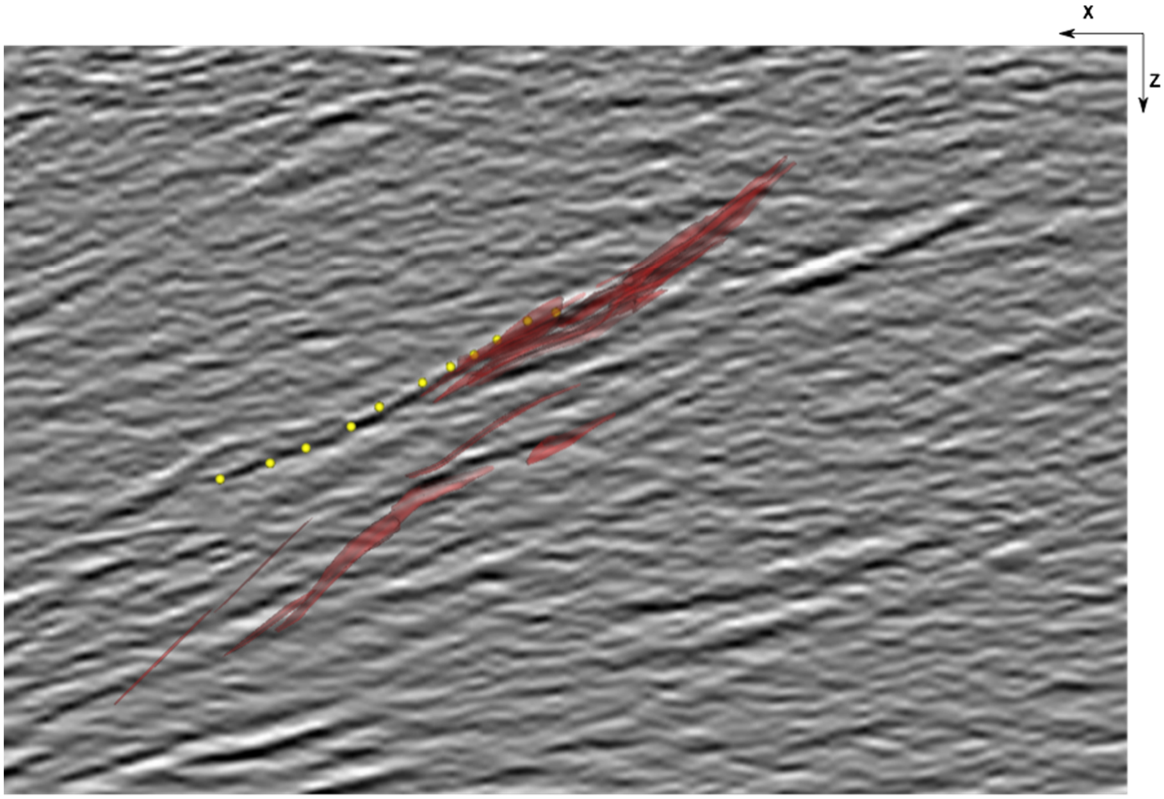

Figure 29. Seismic section from which 12 point pairs were extracted. The deposit is shown in red and point pair locations are in yellow.

gradient is shown in Figure 28 (d), the top showing a very clear resemblance to the initial synthetic model. All solutions shown in Figure 28 perfectly reproduce the gravity data as there were no observation errors in the gravity data.

CASE STUDY

As part of the TGI-4 program, the Geological Survey of Canada accessed geological, petrophysical, and geophysical data over the Lalor Lake volcanogenic massive sulphide (VMS) deposit at Snow Lake, Manitoba, Canada. The Lalor Lake deposit hosted in the Chisel Basin of the Flin Flon Greenstone Belt, 15 kilometres from the HudBay concentrator in Snow Lake in central Manitoba, Canada. The deposit is the largest volcanogenic massive sulphide (VMS) deposit in this region. In March 2007, an electromagnetic survey identified several large deep targets including the Lalor Lake VMS deposit. An exploration drill program on the Lalor Lake continued between 2007 and 2012. This extensive drilling program has determined three mineralization zones including a zinc zone, a gold zone and a gold-copper zone. The deep high grade gold at the gold-copper zone attracts extended exploration at greater depth (more than 1500 m). One objective of the TGI-4 program is to characterize the deposit and host environment by integrating all the available data including geochemistry, drillhole, lithological descriptions, borehole geophysical logging, electromagnetic data, surface potential field data, and a recently acquired 3D seismic data set. Borehole gravity data was also acquired in the first part of 2014.

The case study presented here is an application of our stochastic inversion approach using point pairs from seismic reflectors as structural constraints. In order to show the efficiency of the algorithm, we consider a simple scenario where only one part of the area is inverted and information from one borehole is used in the inversion.

In order to determine the point pairs, we use seismic reflectors of the VMS ore zone in a 3D seismic cube. Figure 29 shows the seismic section from which 12 point pairs (shown in yellow) were extracted to define structural gradient constraints. These points follow approximately the contact between hanging wall and foot wall rocks.

The inversion result with and without using point pairs is shown in Figure 30. Note that the use of structural constraints helps to recover the orientation of the deposit at depth which is in agreement with the seismic reflectors associated to the ore zone Figure 29. As we can see, using constraints helps to recover the orientation of the deposit at depth which is in agreement with results from 3D seismic.

DISCUSSION

The presented inversion algorithm allows adding structural orientation constraints to the stochastic inversion method. The algorithm is successful in recovering the structural orientations, particularly near the surface. At depth where the point pairs are the only constraints, they are not sufficient to recover exact orientations because of the low

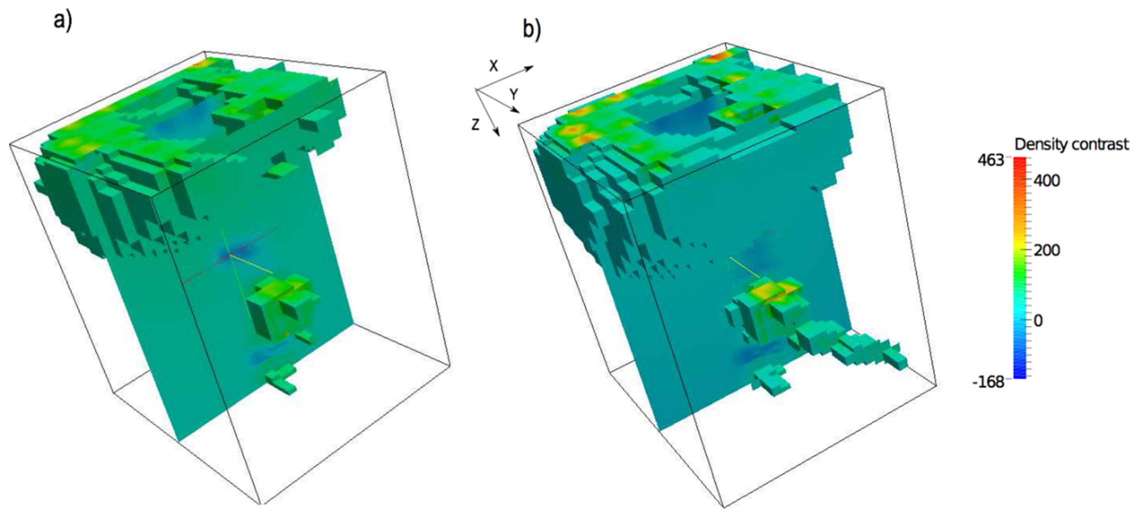

Figure 30. a) Inverted results without using point pairs and information of one borehole b) Inverted results data using point pairs obtained from seismic data and information of one borehole. Densities contrasts with threshold r > 22 Kg/m^3 are shown.

resolving power of inversion. This issue can be resolved by either adding depth weighting or applying known gradients from drillhole data.

At depth, inverted density contrasts tend to be close to zero. Thus adding point pairs at depth defining zero gradients cannot clearly help to recover the geological structure. However, addition of just a few points with known gradients can surprisingly help to recover the structural orientation. Such known gradients can be deduced from geological information or borehole data. Including the point pairs along the vertical axis (magnetic synthetic example) can also help to decrease the low resolution effect at depth.

Note that a practical difficulty of the method arises when the point pair is located in the immediate vicinity of true density constraints (e.g. from drill hole data) that are in conflict with the zero gradient defined by the point pair. In such situations the inversion produces singularities in the solution. Consequently, the user needs to assure that the point pairs chosen are not in conflict with hard density constraints.

CONCLUSIONS

Integrating structural geologic constraints into geophysical inversions by incorporating point pairs that define structural gradients notably improves the recovered model and can easily be applied to any linear geophysical problem. This improvement is highlighted in potential field inversion where the recovered model suffers from the lack of resolution at depth. In addition to the synthetic example, promising results were obtained from the inversions of gravity data acquired over the Lalor VMS deposit, Flin Flon greenstone belt, Canada, in which zero-gradient point pairs were extracted from seismic reflectors.