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Using stochastic crosshole seismic velocity tomography and Bayesian simulation to estimate Ni grades: Case study from Voisey's Bay, Canada

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ABSTRACT

Modeling of grades is a key step and the major source of error in appraisal stage of mining projects. We used a geostatistical approach to explicitly integrate seismic travel time data, as well as acoustic and core logging data into the estimation of nickel grades in the Voisey's Bay deposit. Firstly, the crosshole seismic travel times are inverted using a stochastic tomographic algorithm. This algorithm allows for the inclusion of acoustic log data and seismic covariance into the inverse problem, leading to high-resolution velocity tomographic images of the orebody. Secondly, grade realizations are generated using a Bayesian sequential Gaussian simulation algorithm, which integrates the ore grades measured on the core logs and the previously inverted tomographic data. The application of the presented method to the Voisey's Bay deposit yields an improved knowledge of the geology setting and generates grade models with realistic spatial variability compared to conventional methods.

1. Introduction

In the mining industry, building an interpretative model of a deposit is the first step to move from resource to reserve, as it forms the basis for the resource estimation process. Since the primary source of information comes from drill-hole samples, the interpretative model of the deposit is highly dependent on the spatial distribution of these samples. However, most of the new discoveries are located at depths between 500 m and 2000 m. At these depths, the costs of drilling increase dramatically and the ability of the drill-holes to accurately sample the mineralization decreases, such that increased depth of drilling limits the quality of the information. High resolution geophysical methods such radio-frequency (0.1 − 5 MHz) electromagnetic methods (Fullagar et al., 2000), borehole radar tomography (Bellefleur and Chouteau, 2001; Zhou and Fullagar, 2001) or seismic tomography (Enescu et al., 2002; Wong, 2000; Xu and Greenhalgh, 2010) provide the geologist with new information that can be incorporated into the process of orebody modeling. In addition, it has been shown that sonic logs can be used to constrain seismic tomography between drill-holes, resulting in a significant increase in the accuracy of the tomographic images (Gloaguen et al., 2007; Perozzi et al., 2010).

Geostatistical simulations are increasingly used for orebody modeling and mine planning in both open-pit and underground mining ventures (David, 1988; Dimitrakopoulos, 1998; Journel, 1974; Journel and Huijbregts, 1978). Drill-holes data are often complemented with other secondary, or so-called "soft" data (e.g., data from geophysics, geotechnics and geochemistry) to improve the understanding of the deposit model. In this framework, an optimal estimate of the mineralization grades, and thus the available resources, is likely achieved by integrating these different types of complementary data. The importance of integrating "hard" and "soft" spatial data has long been recognized in the petroleum industry, where reservoir properties such as permeability and porosity need to be inferred from a limited number of drill-holes (Doyen, 1988; Journel and Alabert, 1990; Le Ravalec-Dupin et al., 2001; Xu et al., 1992). Integrated modeling has also been used in the mining industry in ore reserve estimation (David, 1988; Journel and Huijbregts, 1978). Recently, integrated techniques have been used to merge core log data with crosshole tomographic data for orebody modeling (Dimitrakopoulos and Kaklis, 2001).

The present study describes a novel approach for integrating crosshole seismic velocity tomography with Ni grade data measured on diamond drill-hole core samples to better estimate the spatial variability of the ore grade. The benefit of this approach lies in the use of a kernel multivariate density estimator of the joint distribution between velocity and Ni grade data, to evaluate the likelihood function. The likelihood is used to obtain a conditional probability of Ni grades for a given velocity value.

2. Geological and geophysical settings

The Voisey's Bay intrusion belongs to the Nain Plutonic Suite and transects the collisional boundary between the Proterozoic Churchill Province to the west and the Archean Nain Province to the east (Fig. 1a). The Voisey's Bay Ni–Cu–Co deposit is associated with two 1.334 Ga troctolite intrusive chambers, the upper Eastern Deeps and

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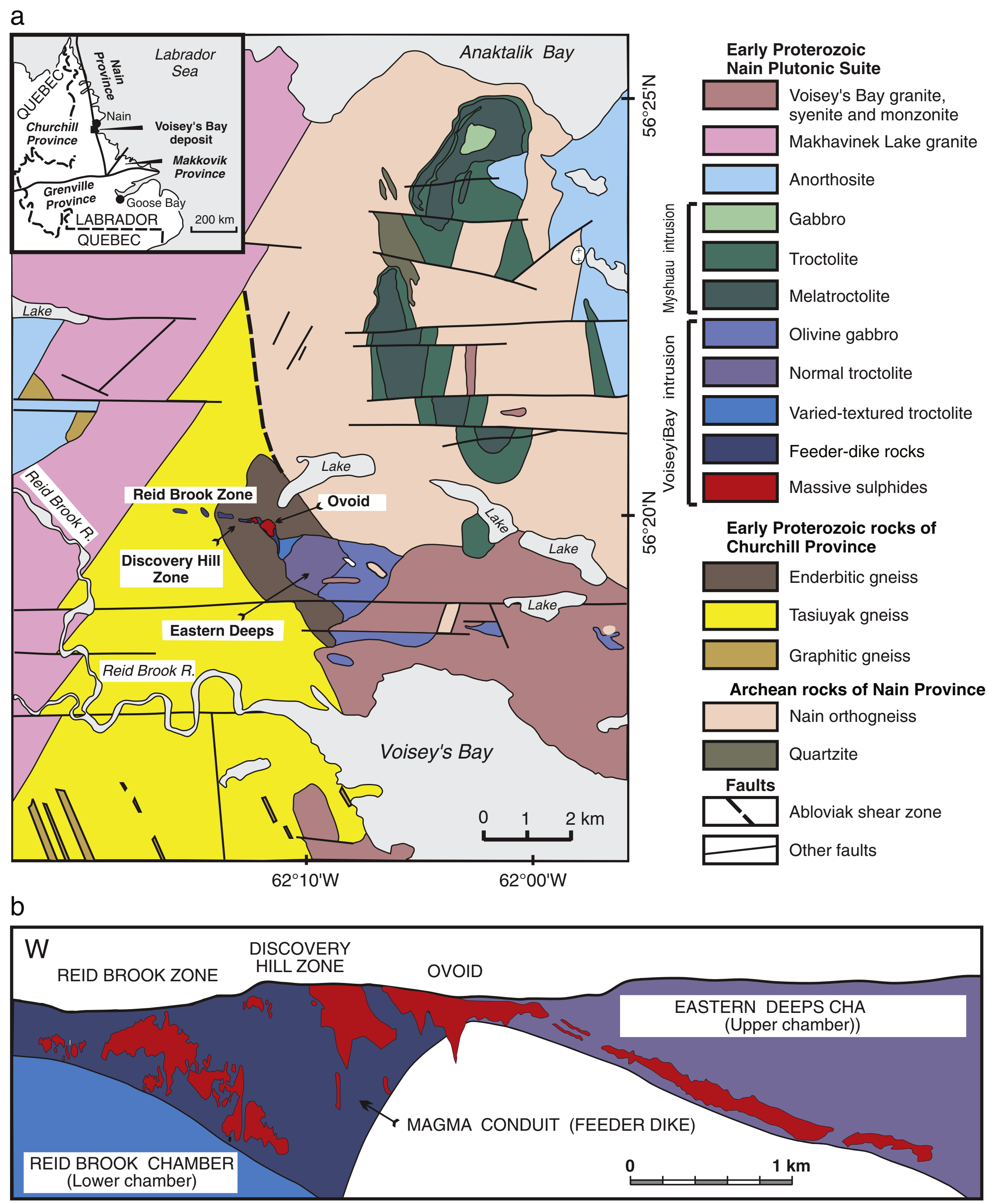

Fig. 1. a) Regional geology of Voisey's Bay; b) Generalized longitudinal cross-section of the Voisey's Bay deposit (modified from Naldrett and Li (2007)).

the lower Reid Brook (Fig. 1b), which are connected by a 10 to 100 m thick dyke (Naldrett and Li, 2007). The complexity of the geological settings and the spatial variability of mineralization both contribute to high uncertainties with regards to the shape and the grades of the deposit between the boreholes. A detailed description of the geology of Voisey's Bay can be found in Evans-Lamswood et al. (2000); Naldrett and Li, (2007). The mineralization in Voisey's Bay deposit is composed of massive, semimassive, and disseminated pyrrhotite, pentlandite, and chalcopyrite. The seismic property (P-wave velocity) of those sulfides as well as of most common silicate rocks is well known from laboratory studies (Birch, 1960; Christensen, 1982; Salisbury et al., 1996, 2000, 2003). These study shows that the properties of mixed and disseminated sulfides lie along simple mixing lines connecting the properties of end-member sulfides and felsic or mafic gangue. Thus, velocities increase dramatically with increasing pyrite content, but they actually decrease with increasing pyrrothite, chalcopyrite and pentlandite content along trend which can be calculated using the time average relationship of Wyllie et al. (1958).

A crosshole seismic tomography survey that recovers seismic velocities was thus deployed at the Voisey's Bay deposit in order to refine the geological model and better estimate the spatial distribution of grades.