SUMMARY OF RESULTS AND IMPLICATIONS FOR EXPLORATION

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GEOPHYSICAL PERSPECTIVE

Analysis of passive seismic data using ambient noise interferometry has received a lot of attention by the geophysical community in recent years, and is recognized as an important new research area (see Wapenaar *et al.*, 2002; Wapenaar 2004; Wapenaar *et al.* 2004, Draganov *et al.* 2007; Dragonov *et al.*, 2013). Without the need for any sources, one of the primary benefits of the approach is the cost-effective acquisition of seismic data. However, the applicability of the method to the mining environment and potential difficulties related to the inherent geological complexity found in such environments needed to be determined. The analysis of the ambient noise data acquired over the Lalor Lake mine demonstrated the potential of the interferometry method for mineral exploration by generating geologically meaningful reflections. The underground mining activity and human activity at surface proved to be useful sources of ambient noise that could be used to generate virtual shot gathers and produced 3D seismic volumes with geologically-significant reflections. Comparison of the results with the 3D dynamite survey acquired at Lalor is encouraging even if, in general, results of the passive survey show fewer reflections. Most importantly, the analysis of the data led to new data processing ideas that may significantly improve the final seismic images made from passive recordings in mining areas.

Up to very recently, seismic exploration for mineral exploration utilized only P-wave energy reflected or scattered at mineralized bodies. Results from the analysis of VSP data acquired near the 777 deposit in Flin Flon demonstrate that other wave modes have a higher potential for the detection of massive sulphide orebodies. In particular, the strongest and most identifiable reflections on the VSP data are shear wave reflections (SS) and mode-converted reflections (PS). These waves are present on all three components of the VSP data and are stronger than the P-wave reflections (PP) typically used to generate images of the subsurface. The study also indicates that multi-component geophones are needed to properly measure all wave modes due to complex shape of the ore zones and their geometrical relationship with seismic sources placed at surface and receivers located in deviated boreholes. This work demonstrates that VSP can provide a means to image dense bodies in the subsurface, even in complex seismic environments.

A novel approach for integrating structural geologic constraints into 3D geophysical inversions has been established during this project. Constraints are easily incorporated using point pairs that define structural gradients and notably improve the recovered model. The approach can be applied not only to potential field data, but to any linear geophysical problem. Improvement from this approach was demonstrated on the inversion of gravity field data acquired over the Lalor VMS deposit. Results from the inversion recovered the contact between the hanging wall and footwall with the addition of a limited number of zero-gradient point pairs extracted from seismic reflection data. The hanging wall-footwall contact, a significant horizon for exploration in the Snow Lake mining camp, cannot be recovered with unconstrained inversion of surface gravity data.

The borehole gravity measurements at Lalor proved to be useful to obtain density estimates at depth away from boreholes in areas where density could not be determined accurately from surface gravity measurements alone. For instance, density changes associated with the main units near the deposit could not be determined from surface gravity data whereas a sharp density decrease obtained from borehole gravity clearly marks the contact between mafic volcanic and volcaniclastic rocks in the hanging wall and gneiss and schist in the footwall of the massive sulphide lenses of the Lalor deposit. Thus, detailed knowledge on the spatial distribution of densities obtained from borehole gravity data can help to map key lithological units at depth in a mining area. In addition, , another advantage of the borehole gravity method resides in its capacity to investigate excess of mass that could potentially be associated to mineralized bodies, especially near existing ore zones. At Lalor, an excess mass of 0.7 mT (spherical body) computed for the Bouguer anomaly at DUB279 suggests a possible up-plunge continuation of the main sulphide ore zone towards the South beyond current drilling extent. This density anomaly is located near an unexplained electromagnetic anomaly and has been identified as a potential follow-up drilling target.

INTEGRATED PERSPECTIVE

One of the key results from the TGI4 method development project is the demonstration that seismic methods can map contacts between volcanic rocks with felsic and mafic protolith compositions near volcanogenic massive sulphide deposits affected by intense hydrothermal alteration and post-volcanic metamorphism. Felsic and mafic host rock lithologies, previously only identifiable through trace element geochemistry in the intensely altered and metamorphosed footwall of the Lalor VMS deposit, were linked to acoustic impedance contrasts and seismic reflections. This provides, in addition to direct detection of ore, a novel approach to map favourable subsurface host rocks using seismic data where visual interpretation of drill logs would fail to unequivocally distinguish such compositionally-contrasting protoliths and in areas where no drill information exists. It is important to note here that this result could *only* be obtained by integrating geochemical, geological, petrophysical, and seismic data in a spatially collocated 3D common-earth model. In addition, it should be noted that intensely metamorphosed hydrothermal footwall alteration observed at Lalor is typical of most volcanogenic massive sulphide deposits in the Snow Lake mining district and other volcanogenic massive sulphide mining districts elsewhere (Galley *et al.*, 2007).

Knowledge on the location of mafic/felsic contacts in the most altered part of the footwall has implications for the understanding of the geological evolution near the deposit, and can also be used to guide exploration in the Snow Lake mining camp. As shown in this Open File, the shallowest reflection in the footwall corresponding to the contact between mafic-felsic protoliths is close to or at the hanging wall-footwall interface (F4 on Figures 10 and 12). Thus, this reflection is an excellent proxy for the hanging wall-footwall contact which is only partly imaged on the seismic data. The ability to follow the shallowest footwall contact in 3D is of *primary* importance for exploration in this mining camp as most of the deposits are found at or near the hanging wall-footwall contact. Here, the 3D model was key to establish the nature of the shallowest footwall reflection whereas the 3D seismic data allowed its mapping in areas with no borehole information. The location of this proxy reflection to the hanging wall-footwall contact is now known for the 3D seismic area located north-east of the Lalor deposit.

The integration of densities obtained from borehole gravity data in the 3D geological model allowed to establish a consistent spatial association between apparent density lows and Zr/TiO_2 peaks indicative of felsic volcanic rocks throughout the hanging-wall and footwall successions. Similar to the 3D seismic data, this also includes rocks affected by intense hydrothermal alteration and metamorphism in the proximal footwall of the VMS ore zones. This important result indicates that the density contrasts between volcanic protoliths (e.g. gneiss and schist) remain intact despite their intense hydrothermal alteration and subsequent metamorphic recrystallization. In addition, offsets in the apparent density logs computed from the borehole gravity data supports the presence of a fault structure (see Figure 23). This structure brings rocks intersected in the drill holes south of DUB279 over rocks intersected in DUB279 with a displacement that is in agreement with the apparent offset between intervals of sulphide mineralization in holes DUB279 and DUB260 (Figure 23). The offset between the density anomaly patterns is also consistent with fold and fault structures inferred in underground mapping campaigns juxtaposing contrasting intensities of alteration and different geological units. The presence of this fault and its associated offset both have implication for exploration south of the main more zones at Lalor.

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