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Application of Seismic Interferometry in Crystalline Rocks - A Case Study From the Lalor Mining Area, Canada

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SUMMARY

Approximately 300 hours of ambient noise data covering an area of 4 km² were acquired over the Lalor mining area, Canada, to test the capability of seismic interferometry to image ore deposits in the crystalline rock environment. The interferometry survey consists of 336 receivers located along 9 parallel lines oriented southwest-to northeast and 7 southeast-to-northwest lines. Alongside the ambient noise survey, a larger 3D active source seismic survey was also acquired in the area and used to evaluate the interferometry results. The seismic wave field is retrieved by crosscorrelating the noise between all receiver locations in each hourly segment of passive seismic data. The crosscorrelated results of all segments are spatially summed to generate virtual shot gathers. The virtual data is processed along all 2D lines with conventional methods similar to those applied to active 3D data. The DMO-stacked section obtained reveals a number of events, some more coherent than observed on the similarly processed active seismic section. Of particular interest is an event possibly associated with the massive sulphides. A comparable event is also observed on the active seismic data. These results demonstrate the benefits of ambient noise measurements in crystalline rock environment for mineral exploration purposes.

Introduction

During the past 20 years, a number of studies demonstrating the effectiveness of reflection seismic exploration for deeply-seated mineral deposits in crystalline rock environments have been published (Cheraghi et al., 2012 and references therein). Despite the many successes, issues such as the low signal-to-noise (S/N) ratio and scattering nature of the crystalline environment, in addition to issues related to data acquisition (e.g., economical considerations, inaccessible areas, and sparse surveys resulting in low fold) remain challenges requiring further consideration (Cheraghi et al., 2012). Recently, impulse responses (Green's functions) have been retrieved from ambient seismic noise to determine exploration-scale velocities and structures (e.g. Draganov et al., 2013).These results suggest that interferometry could also help address some of the challenges related to wave propagation in the crystalline rock environment (e.g., cost, scattering, surface wave velocity) and may offer a valuable imaging complement to traditional exploration methods.

As part of the TGI-4 program, the Geological Survey of Canada acquired ~300 hours of passive seismic data at each of 336 receiver locations near Lalor Lake (Figure 1) to evaluate the benefits of interferometry for the exploration of VMS deposits. The Lalor deposit, a 27 Mt volcanogenic massive sulphide (VMS) orebody, is the primary focus of this study. The deposit is located approximately 10 km west of Snow Lake, Manitoba, Canada (Figure 1), at a depth of about 800 m. Receivers for the interferometry survey consisted of 10 Hz vertical component geophones placed along 9 southwest-northeast oriented lines (direction A) and 7 orthogonal lines (direction B). The station spacing along each line is about 100 m. The line spacing in direction A and B is about 360 m and 400 m, respectively.The interferometry data was acquired prior and during a larger conventional 3C-3D seismic dataset aimed at defining the signature of the deposit and geological structures at greater depths (see Figure 1). Our study presents the virtual seismic shot gathers retrieved from the ambient noise and the processing of those virtual shots using a conventional approach. Our results are also compared to the 3D active seismic data available over the same area.

Interferometry processing over the Lalor area

Ambient noise was continuously recorded at each receiver location for a period of ~300 hours. To create virtual shot gathers from ambient noise, the Green's function is estimated by crosscorrelating noise for each possible pair of receivers (Draganov et al., 2013) in each hourly segment (i.e., about 110000 calculation/segment for a total of 33 million calculations in the survey). The results from all hourly segments are spatially summed to generate the final shot gathers. To better understand the characteristics of the derived wavefield, each 2D line of the interferometry survey was processed with conventional steps similar to those applied to the active 3D data. It should be noted that the 2D virtual sections have lower fold and resolution than the active data. Results for the active survey also used 3D processing algorithms. Figure 2 presents a comparison of DMO corrected stacked section along line R 141 (see Figure 1). The geological model in the background is based on an interpretation of surface and borehole geological data. In general, the active survey provides better images of the subsurface units to a depth of 3 km while the interferometry image is clear to more than 1 km (Figure 2). The UC reflection near the top of the Balloch basalt is more coherent in the interferometry data than the active section (see Figure 2a-b). The Lalor deposit is imaged as reflection VM in Figure 2a-b. The deeper reflection BB (near the base of the lower Chisel sequence) is partly imaged in the interferometry survey (Figure 2a-b).

Conclusions

The Lalor survey provides an opportunity to evaluate the potential benefits of the interferometry method for mineral exploration. The DMO-stacked section (R 141) obtained from the processing of virtual shot gathers reveals many events, some more coherent than on the active seismic section processed with a similar approach. Of particular interest is an event possibly associated with the known massive sulphides, that is also observed on the active source seismic data. These results are encouraging and demonstrate the benefits of ambient noise measurements and interferometry in crystalline rock environment for exploration purposes.

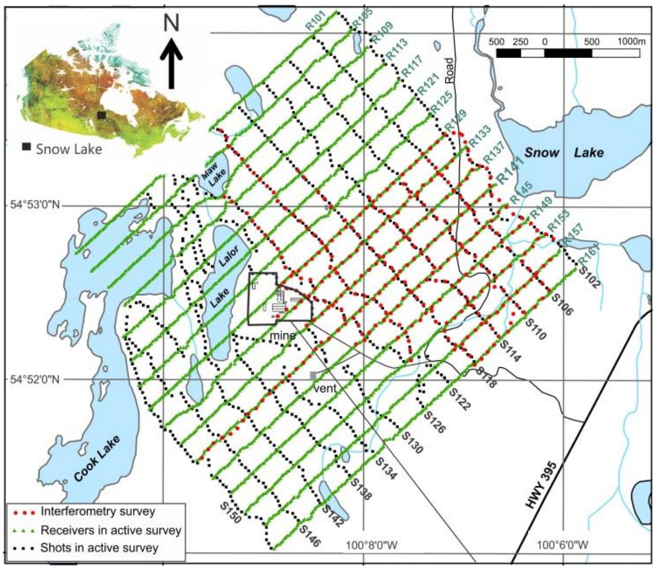

Figure 1 *Geometry of the active 3D survey and the interferometry survey in the Lalor mining area. The active and interferometry surveys cover approximately 16 km² and 4 km², respectively. The mine area and ventilation shaft is also shown. The inset figure shows the location of Snow Lake, Manitoba.*

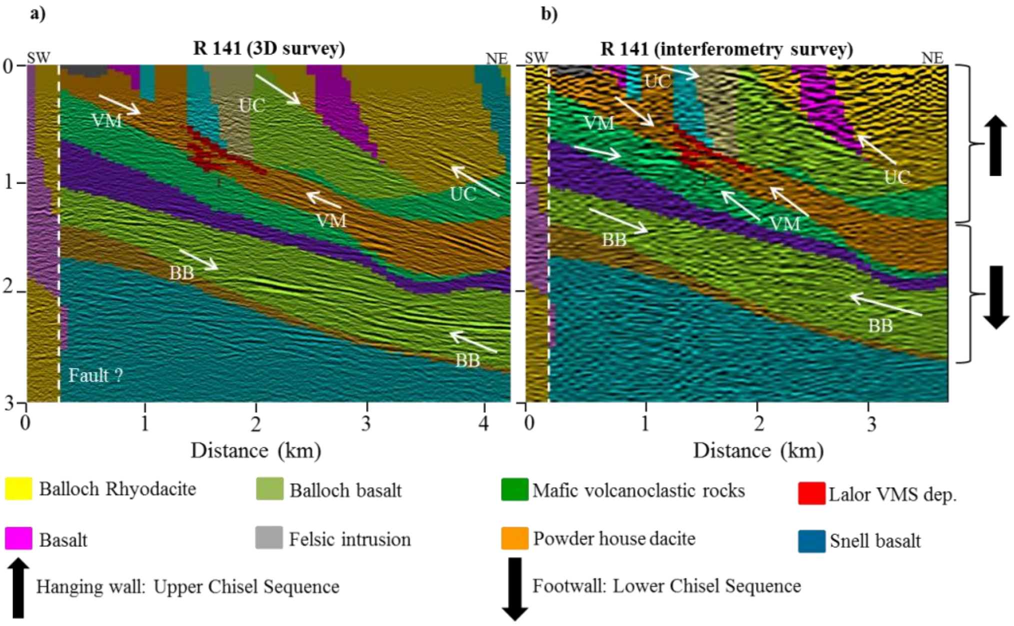

Figure 2 *The DMO-corrected stacked section along line R 141 superimposed on the geological model (courtesy of Hudbay Minerals Inc.) from a) the active 3D survey, b) the interferometry survey. The subvertical dashed line in the geological model is interpreted as a possible fault. See text for interpretation of UC, VM, and BB reflection.*

References

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Draganov, D., Campman, X., Thorbecke, J., Verdel, A., Wapenaar, K., [2013] Seismic exploration-scale velocities and structure from ambient seismic noise (> 1 Hz). *Journal of Geophysical Research*, 118, 1−16.