Passive Seismic Ambient Noise Surface Wave Tomography Applied to Two Exploration Targets in Ontario, Canada

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SUMMARY

As mineral exploration seeks deeper targets and targets under cover, the need for low cost and low impact subsurface imaging is increasingly important. A recent addition to the toolbox of geophysical methods is ambient noise surface wave tomography (ANSWT) which produces an S-wave velocity image of the subsurface using naturally occurring seismic signals from waves, oceans, trains, etc. - no active controlled seismic sources required. In this presentation, we provide a brief introduction of the ANSWT method and review two recent projects: Marathon Phase III and Schumann Lake, both projects located in Ontario, Canada.

Key words: Exploration under cover, passive seismic, geophysics, seismic velocity model, ambient seismic noise, new technologies

INTRODUCTION

Seismic signals for ANSWT imaging come from natural (ocean swell, earthquakes, atmospherically-induced) and anthropogenic (trains, cities, roads, etc.) sources. ANSWT uses cross-correlation between receiver pairs to extract the Green's function – or something similar enough to the Green's function. The dispersion of the surface (Rayleigh) waves emerging from the cross-correlated data is used to generate a near-surface velocity model. When used repetitively, this approach can also be used to measure change in subsurface velocity over time - monitoring. This method is based on the proportionality of the Green's function with the cross-correlation noise seismograms recorded in a diffuse seismic wavefield and have a relatively recent but rich academic pedigree [Lobkis and Weaver, 2001; Shapiro and Campillo, 2004; Roux et al, 2005; Campillo, 2006; Snieder, 2007].

The velocity model is that prodiced is a proxy for structure or changes in sub-surface rock types or properties. As such, the results from ANSWT can be used on it's own, jointly inverted with other geophysical or geological data, or used to improve imaging of active source P-wave reflection data in some cases. The scale of ANSWT imaging ranges from near-surface engineering surveys (e.g. S-wave profiles for seismic hazard assessments of critical structures like nuclear power stations) to deep imaging as far down down as crustal/upper mantle (MoHo) depths.

The key technology for the ANSWT method is the recent development of autonomous seismic recorders ("nodes") that enable reliable, low-cost, continuous recording of GPS-time stamped seismic data for weeks or months at a time. Nodes facilitate low-cost collection of dense passive seismic data for ANSWT imaging and also provide other types of subsurface imaging and information. Nodes can also be used to collect active-source seismic data, or to produce continuous field data comprising both active and naturally occurring signals.

The ease of deployment of such nodes (hundreds per day for a small team of a few people) and the non-invasiveness of the passive measurements has contributed to the rapidly rising popularity of this technique in the mineral and petroleum exploration industry.

MARATHON PHASE III

ANSWT methods are currently being used by Sisprobe at the Marathon PGM-Cu deposit in Ontario, Canada. The deposit consists of mainly disseminated magmatic sulfides hosted in the Two Duck Lake gabbro at the eastern contact of the late Proterozoic Coldwell Complex. A preliminary noise survey in 2017 (Phase I) showed that wind-induced wave action, mainly on Lake Superior, generates sufficient ambient noise to proceed to a production scale survey. In 2018, 90 sensors were deployed at 300 m spacing in an array elongated parallel to wave propagation and approximately perpendicular to the intrusive contact (Phase II). The seismic stations used were GSX-1 single channel units, which collected seismic data with vertically oriented (1C) geophones. Seismic data with a sampling period of 4 ms was recorded for a total of 26 days.

Representative samples for each lithology, within the survey area, were collected and measured for density and P-wave velocities at Western University. These measurements were used to constrain interpretations of lithological boundaries determined from the 3D velocity inversion model. The geological boundary between the Two Duck Lake gabbro and the Archean metavolcanic footwall was successfully resolved, and the survey also identified a high-velocity anomaly down dip from the Marathon PGM-Cu deposit at a depth of 600 m.

To validate the velocity anomaly, a 6 km gravity line was completed along the area overlying the high-velocity anomaly. Using both ANSWT and gravity methods in combination with the structural association of the anomaly along a feeder conduit, this anomaly is interpreted to be an accumulation of dense minerals such as olivine and sulfide in a conduit setting.

In Phase III, 1019 nodes were deployed in a denser array, covering the same area of the contact. The aim of this survey is to develop further the technology by extracting body waves from the ambient noise signal and to use these results to detect reflectors in the sub-surface structure. Phases I and II were supported by a booster grant from the European Union's EIT Raw Materials program and phase III by a grant from the Horizon 2020 program.

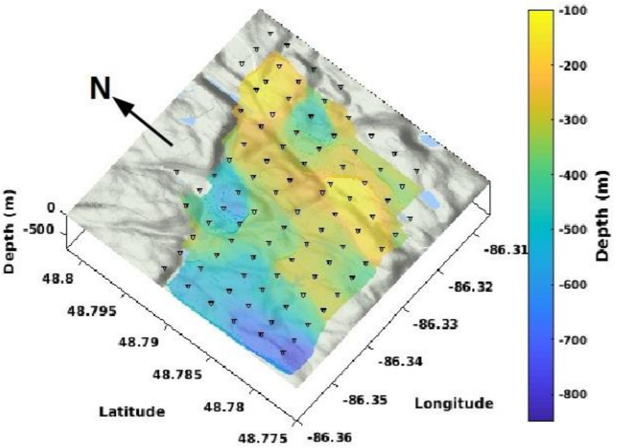

Figure 1: Marathon Phase II array iso-velocity surface

SCHUMANN LAKE

The second passive seismic project in the Schumann Lake area of Ontario deployed about 499 nodes with the same recording parameters as before and with a nominal interstation distance of 110m, for a 40 days recording period. An area of approximately 3.5x2km was imaged in this project. The objective was to map the thickness of the diabase intrusion that potentially covers blind hydrothermal vein cobalt-silver mineralization.

The noise cross-correlations show the fundamental mode of the Rayleigh waves traveling at an average velocity of about 3500 m/s over the seismic sensor array. Group velocities, estimated over a frequency band of 3 - 14 Hz, suggest a medium with high apparent velocities ranging between 2800 to 3800 m/s. Both phase and group dispersion curves define two layers with a difference of velocities of about 400 m/s. A depth inversion produces a Vs model composed of two layers: 1) a first layer with an average thickness of 150m and an average S-wave velocity of 3300 m/s; 2) a second layer extending to the base of the model (500 m deep) with an average s-wave velocity of 3650 m/s.

The base of the first layer closely corresponds to the base of the diabase comparing to the sparse amount of drilling in the area. The second velocity layer aligns with less dense sedimentary and volcanic rocks that typically host vein mineralization. Discrete areas of low velocity , located in 3D within the first layer, suggests fracturing and veining in the diabase.

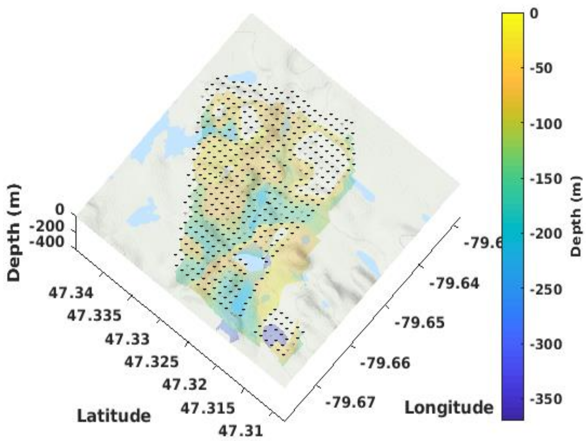

Figure 2: Maps of the thickness of the first layer corresponding to the overburden

CONCLUSIONS

Ambient noise surface wave tomography has the advantage of being a passive seismic technique – requiring only the ubiquitous background vibrations present near the surface of the earth – which is thus inexpensive, minimally invasive and easy to collect data for. Resolution decays with depth, and so the resulting images compare poorly with images from active P-wave reflection surveys. However, the low equipment requirements means these images can be produced at roughly 1/10 of the cost of active surveys. As such, ANSWT would be used earlier in the exploration chain, over wider areas.

These two case studies show the value of this exciting new technique in finding new ore bodies and delimiting rock types of different S-wave velocities.

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