Geological Sciences Research (GEOL492.6),

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Analysis of ambient-source low-frequency seismic data from the Athabasca Basin

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Problem

In this project, the student (Dylan Smith) will investigate low-frequency spectral seismic monitoring (LFSM) for detecting and delineating basement unconformities in Athabasca basin. During the summer of 2017, Dylan participated in field work with researchers from Cameco, who collected the data by using broadband seismometers. The principal goal of the present class project will be to analyse, present, and interpret these data. The uniqueness of this project will be in attempting using the LFSM technique in non-oil and gas setting. The research is focused on using a passive seismic method to model the overburden layer above a large unconformity offset in the Athabasca Basin.

The technology of using low-frequency (about 3 Hz) seismic data from ambient ("passive") sources has been around since (apparently) about 1970's, and yet it is still not broadly used. The main focus of this technique so far was for geotechnical investigations and earthquake hazard analysis. The greatest proponent of this method has been the company named SpectraSeis in Zurich, which was acquired by EGS in 2015.I n 2006, we started collaboration with SpectraSeis, but unfortunately, this collaboration did not last long.

The physical principles of LFSM mapping are still being debated. Nevertheless, as an empirical procedure, this technique this efficient and seems to work successfully in many cases. There are few technical publications on this subject, with Lambert et al. (2011) being the only one I (I.M.) could locate recently. Finding more literature on this subject will be the second goal of the present project.

The method uses the hypothesis that the ground being surveyed is comprised of a rigid unit overlain by a soft soil layer (i.e. overburden). Based on this model, seismic noise or natural microtremers can be used to characterize the depth of the layers.

The area of the survey (exact location being withheld for confidentiality) has a large north, northeast-striking fault with upwards of 150 metres of unconformity offset in the bedrock. The exact fault location has proven difficult to accurately identify with regular exploration techniques due to the scale of the fault. The geology of the area consists of three distinct layer. A soft soil layer (i.e.

overburden), a layer of sedimentary bedrock (i.e. sandstone), followed by an unconformity and igneous or metamorphic bedrock. The passive seismic test will be used to map the overburden layer and upper sandstone unit to model the up-dip expression of the fault.

The survey took place over 20 kilometres north to south, estimated along strike of the fault. Lines were surveyed every kilometre along strike with 25 to 50 metre station spacing.

Method

Passive seismic is a commonly used method in geotechnical assessment and environmental studies, but rarely has it been used in an exploration setting.

Traditionally regarded as a nuisance by seismologists, seismic noise has been shown from physical acoustics to be rich in information on the local structure of the subsoil (Micromed, 2012). Since there is background noise present everywhere, it represents an extremely useful exploration tool. The horizontal-to-vertical (H/V) ambient-noise seismic method is a novel, non-invasive technique that can be used to rapidly estimate the depth to bedrock (Keller, 2015). In contrast to “active” seismic methods (e.g. refraction, reflection, or surface-wave), which use an artificial source such as an explosive charge or hammer blow to excite a seismic response from the subsurface, the H/V method is a “passive” method that uses three-component measurements of ambient seismic noise (microtremors caused by wind, ocean waves, anthropogenic activity, etc.) to determine the fundamental seismic resonance frequency for a site (Keller, 2015).

The resonance frequency is determined through analysis of the spectral ratio of the horizontal and vertical components of ambient seismic noise. The H/V method has been used for microzonation studies to predict site response to earthquake seismicity and as a method to estimate unconsolidated sediment thickness, map the bedrock surface, and infer fault locations. (Lane et al., 2008).

Some locations can be approximated by using a two-layer model (Figure 1). If the thickness of the upper unit is close to the wavelength of the shear (S) wave in it, than this layer serves as a resonator, with the resonance frequency related to the thickness of the unit *h* and shear wave velocity V_{S1}:

$$f = \frac{V_{s1}}{4h}$$

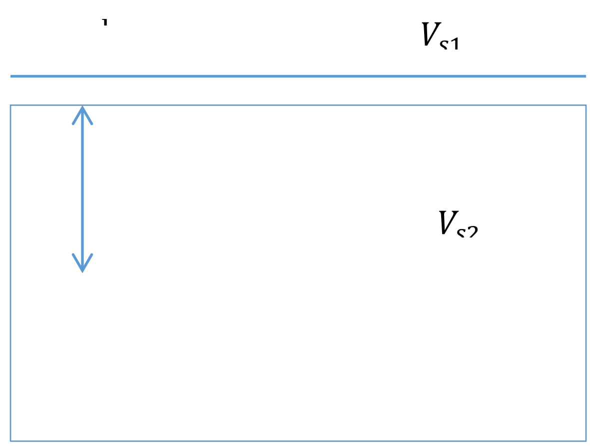

Figure 1: Simple two-layer model

It is very important to note that the H/V method only works with at least a 2:1 contrast between the two layers in the acoustic impedance (material density and seismic velocity product). If the geology of the area does not fit this model, then this method is ineffective.

The relationship between sediment thickness, h, and resonance frequency can be given by:

$$h = af^b$$

where parameters a and b are determined empirically from non-linear regression of resonant frequency data acquired at sites where h is known (e.g. adjacent to drill holes) (Lane et al., 2008). This is advantageous, because V_{s1} is not needed.

The student (Dylan) will search EGS, SpectraSeis, and other geophysical publications for LFSM theory and case studies. Concurrently with literature search, by using the data records and software provided by Cameco, Dylan will produce several attribute maps of the study area. The procedure of deriving these maps will include editing the records by removing strong earthquake arrivals, Fourier transforms to obtain the amplitude spectra, spatial interpolation and (maybe) filtering and pattern analysis to produce maps. These maps will need to be further examined for indications of the mineral-bearing unconformity.

A potentially interesting and new approach to attribute extraction could consist in computing cross-correlations of records from multiple sensors (where such data are available), performing spectral analysis of these cross-correlations, and identifying the spatial locations from which the cross-correlated signal might come. This method would be related to ambient-source tomography, which has been broadly used in earthquake seismology in recent years.

Expected results

The hope is that by using a large number of lines perpendicular to the fault, that the location and depth of the fault will be able to be modeled using the H/V curves. It is predicted that over top of the fault there will be a dip in the sandstone layer on the edges, followed by a less well-defined contrast through the fault, due to fractured rocks.

A research paper and presentation summarizing the results will be prepared. The results of this research should be significant for Cameco project. We expect that the results could be reported at the CSEG Convention and published in SEG or CSEG journals. Potentially, this research and data (if available) could serve as a basis for a MSc thesis.

Work plan

1) Data Collection
2) H/V Data analysis – Grilla software
3) H/V Compare with drilling tested areas
4) Deriving 2D Model
5) Deriving 3D Model

6) Results and conclusions

Recommended examining committee

1) Sam Butler
2) Kevin Ansdell
3) Igor Morozov

Grading:

Paper: 70%

Oral presentation: 30%

References and recommended reading

(please also check all technical publications on EGS/SpectraSeis website)

Keller (2015) ?

Lane, J. W., White, E. A., Steele, G.V, & Cannia, J.C. (2008). Estimation of bedrock depth using the horizontal-to-vertical (H/V) ambient-noise seismic method. Near Surface 2008 – 14th EAGE European Meeting of Environmental and Engineering Geophysics.

Lambert, M.A., B. Quintal, ETH Zurich, and S.M. Schmalholz, 2011. Detection of a viscoelastic inclusion using spectral attributes of the quasi-stationary seismic, SEG Expanded Abstracts 2011.

Micromed, 2012. Tromino User's Manual.