

## Characterizing the Whitehorse Trough with ambient seismic noise for geothermal potential

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### Summary

Northern communities can benefit from alternative sources of energy for electricity and residential heating. The presence of several radiogenic plutons, hot springs, warm water seeps, and sediment cover near Whitehorse, Yukon, provides the potential for favorable geothermal conditions. We aim to constrain the structure of the Whitehorse Trough to study its geothermal resource potential. We recorded seismic ambient noise data at 67 stations during the summer of 2024. Data were collected with 32 three-component nodal geophones, in four overlapping phases to ensure appropriate coverage of the 10 by 10 km study area. Here, we present observations of Rayleigh-wave ellipticity from the 3-component data. These ellipticity data provide initial constraints on the overburden thickness in this area with significant bedrock topography. This knowledge helps to assess the geothermal potential of the region, as sediment and sedimentary rock cover can trap heat in the subsurface due to lower thermal conductivity.

### Introduction

The warmest recorded year is 2024 [1]. The North of Canada is disproportionately affected by climate change, and is warming at more than twice the global average rate [3]. As part of low-carbon initiatives, geothermal energy sources are being considered for Yukon. Geothermal energy has lower environmental impacts compared to many other energy sources [7], and has the potential to provide energy, as well as direct heating, in the North. It does not suffer from daily/seasonal dependence like solar and wind energy [15]. In addition, geothermal energy may provide renewable energy in remote northern communities that currently rely on imported fuel for heating and power.

High heat flow [7] and shallow Curie point depths [17] in northwest Canada indicate that geothermal resources may be economically viable [11, 16]. Although sufficient ground temperatures for electricity generation are rare, temperatures to supply residential heating are more common, which is particularly useful in cold climates. The geothermal potential depends not only on the availability of heat, but also on the effective heat transport by fluid circulation. Circulation can be enhanced by the permeability of the rock mass, which can be increased by faults and fractures. Intrusive plutons with various levels of radiogenic heat production are abundant in southern Yukon. Some plutons are potential heat sources for geothermal energy. The sedimentary cover near Whitehorse may also trap heat due to its low thermal conductivity, but its thickness is largely unknown [6, 9]. Hot springs near Whitehorse demonstrate some existing heat sources and fluid pathways, but are poorly understood. Even less is known about the physical properties of the sediments (e.g. soil rigidity, seismic velocities, porosities) and the underlying bedrock.

Through the analysis of passive seismic recordings, this research aims to image the geologic structures (overburden, sedimentary rocks, and intruded rocks) of the Whitehorse Trough, in terms of their seismic properties, to study the geothermal resource potential of the region.

## Data and Methods

During the summer of 2024, we collected ambient seismic noise recordings from instruments deployed in the Whitehorse area (Fig. 1). We acquired seismic waveform data on 3-component, 5-Hz geophones between June 5 and August 24 2024. The 32 instruments were deployed in the Whitehorse area in several overlapping phases to achieve the desired coverage throughout the area (Fig. 1). Each deployment phase lasted 2-4 weeks. Data collection for passive seismic methods is less invasive and more logistically feasible than methods that use active sources (e.g., explosions and vibroseis trucks). This simplifies seismic data acquisition in urban settings, such as in Whitehorse.

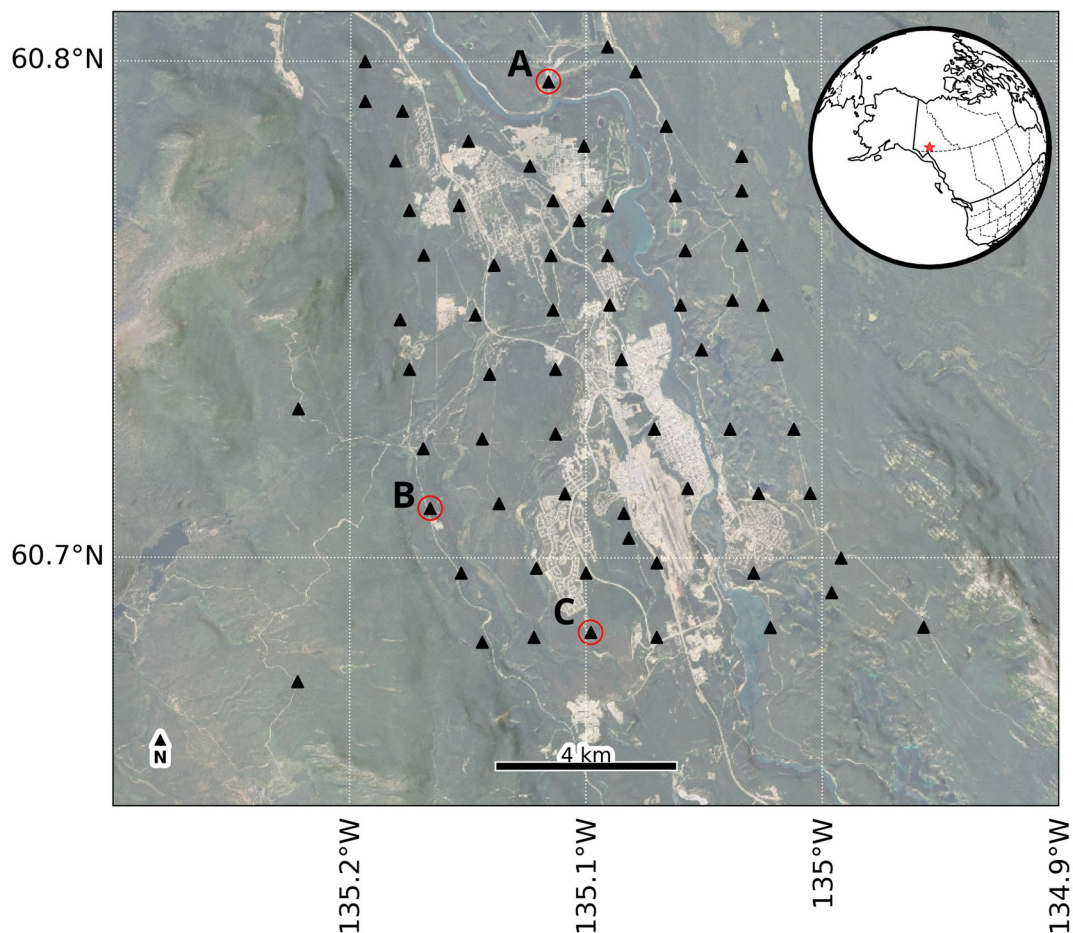


Figure 1: Map of the study area in the vicinity of Whitehorse, Yukon. Instrument locations are shown as triangles. Circled stations with labels A, B, and C correspond to examples of ellipticity spectra shown in Fig. 2.

These recordings contain Rayleigh surface waves that can be used to extract information about geological structures in the subsurface. Rayleigh-waves propagate with an elliptical particle motion, which can be measured with the ratio of horizontal to vertical components of ambient noise recordings [10, 12]. This ellipticity is dependent on the geologic structures, and they are particularly sensitive to strong velocity contrasts such as the overburden-bedrock interface. The ellipticity data can be used in an inversion to constrain the shallow subsurface structure [8]. The horizontal-to-vertical spectral ratio (HVSR) is sometimes used to process data for ellipticity inversion processes, but limitations apply [4]. For example, other wave types are also present in the recordings and can affect the measurement of ellipticity. Many studies that rely on the HVSR method make the assumption that the composition of the ambient wave field is dominated by horizontally polarized shear-waves, and interpret the fundamental spectral peak as due to resonance of these waves in the sedimentary overburden [14]. To extract spectra for Rayleigh-wave ellipticity, polarization filters are applied to reasonably isolate the Rayleigh-waves from other wave field effects [8].

The random decrement method can be used to extract the free surface vibration response of the ground by stacking random responses with the same initial condition [5]. We apply RayDec [8] software which uses the random decrement method to estimate ellipticity. Ellipticity spectra are processed in narrow bands by applying a Chebychev filter with a relative bandwidth of 0.2. RayDec detects zero crossings on the vertical-component seismogram to define time windows for stacking. The window length chosen here is 180 s. The corresponding windows for horizontal components are phase-shifted on the basis of the Rayleigh-wave particle motion. Assuming retrograde elliptical particle motion in an isotropic medium, the Rayleigh-wave particle motion on the vertical-component seismogram lags behind the radial-component by 90 degrees. Applying phase shifts consistent with this lag, and subsequently stacking data over many windows emphasizes Rayleigh-waves. This is since body waves can have vertical and horizontal components but no 90-degree phase shift and will stack destructively. Similarly, other wave types stack destructively. Therefore, the stacked spectra approximate Rayleigh-wave ellipticity spectra and are more appropriate for inversion with ellipticity forward models, compared to typical HVSR measurements.

We apply RayDec processing to data recorded at all stations in the study area (Fig. 2). For this, we initially remove time windows with an amplitude larger than 3 standard deviations from the median for the full day. This removes outliers and spikes from transient signals, so the remaining timeseries will be more stable. Then, the data are windowed between 8 PM and 8 AM MST, because there is less anthropogenic noise during the overnight hours. This minimizes potential directional noise sources and body-wave arrivals [4, 2].

## Results and Conclusions

Figure 2 shows examples of ellipticity spectra for different sites in Whitehorse. The example spectra are from dates with qualitatively long periods of stable ambient noise during the nighttime hours. These examples show the ellipticity results for each time window given by RayDec within the 12-hour time period listed above, and the median of these results. A general observation for the spectra in Fig. 2 is that multiple peaks are present. The Rayleigh-wave fundamental mode typically produces the lowest frequency peak on the ellipticity spectrum. When most of the energy is in the fundamental mode, this frequency provides an approximation

for depth to bedrock of the sedimentary basin. These examples have clear fundamental peaks, but have varying number of peaks. Multimodal spectra can be ambiguous to interpret at frequencies between 0.2 and 0.5 Hz because the higher frequency peaks could be due to multiple layers in the system, or the excitation of higher-order Rayleigh-wave modes [2]. Furthermore, identical ellipticity spectra can be produced by scaling shear-velocity and depth of the ground structure by the same factor, so more information is needed to invert the spectra and constrain subsurface properties [13].

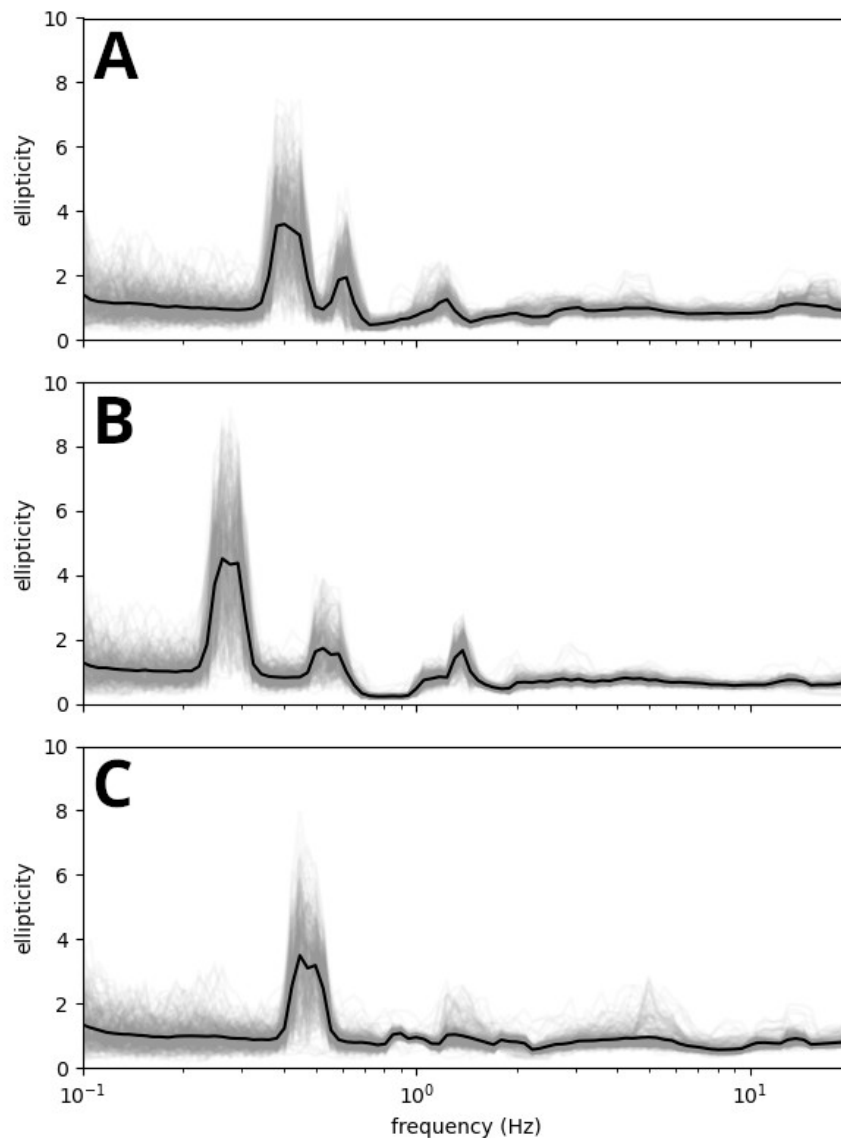


Figure 2: Examples of ellipticity spectra at three stations. The grey lines show ellipticities calculated for individual time windows, and the black line represents the median ellipticity for 12 hours of data from one day. Panels A, B, and C are for August 8, June 10, and June 16 respectively, and correspond to marked locations in Fig. 1.

Future work includes ambient noise surface-wave tomography. The dispersive information from tomography provides complementary information to the ellipticity spectra because they are sensitive to integrated seismic velocities of the subsurface rather than seismic impedance contrasts. Using seismic tomography methods, these dispersion measurements can be combined with the ellipticity measurements presented here to further constrain the basin shear-wave velocities and image structures in 3 dimensions. Performing a joint inversion of ellipticity spectra and dispersion curves will improve constraints on seismic velocities and structures throughout the region.

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