Mapping the Structure of the Nechako Basin Using Passive Source Seismology

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Introduction

The key objective of this project is to help assess the hydrocarbon and mineral potential of the Nechako Basin area in central British Columbia, using passive source seismology. The Nechako Basin has been the focus of limited hydrocarbon exploration since the 1930s. Seven exploratory wells were drilled, and oil stains on drill chip samples, as well as the presence of gas in drill stem tests, attest to some hydrocarbon potential. Seismic data collected in the 1980s were of variable quality, mainly due to the effects of volcanic cover. This study will utilize recordings of distant earthquakes and background noise to map the sediment thickness, crustal thickness and overall geometry of the Nechako Basin. An array of seven seismic stations was deployed in September 2006 (Table 1, Figure 1) to sample a large area of the basin. The results of this study will complement independent active-source seismic studies that are planned for the region by providing images using waves coming from within the earth and providing constraints on the shear-wave velocity. The results of this research will also complement magnetotelluric (MT) studies that are currently underway, providing critical new information on porosity, fractures and fluids. This paper describes the methods that will be used, the progress of the data collection to date, some preliminary results and future work.

Methodologies

Receiver Function Analysis

The primary technique used in this study will be receiver function analysis, in order to constrain the shear-wave velocity structure. In this method, locally generated P- to S-wave conversions (Figure 2; Cassidy, 1992, 1995; Eaton and Cassidy, 1996) will be used to map major discontinuities beneath the seven three-component seismic stations deployed across the Nechako Basin (covering an area of approximately 33 000 km^2). This method typically requires recording for approximately a two-year period in order to collect enough recordings sampling a wide range of directions and distances. The advantages of this method include site-specific information (mapping discontinuities directly beneath the recording site); S-velocity information (difficult to obtain from other studies); interface geometry, including dip angle and direction; and images obtainable for structure beneath strong near-surface reflectors, as the teleseismic energy is coming from below these near-surface reflectors, thereby providing images of both near-surface and crustal-scale structure. A similar study, conducted across the northern Coast Mountains of BC to image the coastal batholith, shows a pronounced change in crustal structure at the boundary between the batholith and the westernmost edge of the Nechako Basin. This attests to the capacity of this imaging method to resolve crustal architecture in this region.

Table 1. Location of broadband seismic stations in the Nechako Basin.

Seismic Station Location	Code	Latitude	Longitude	Elevation (km)
Anahim Lake, BC	ALRB	52.5103	-125.0844	1.237
Cack lake[1] seismic station, BC	CLSB	52.7587	-122.5551	0.792
Fletcher Lake, BC	FLLB	51.739	-123.1059	1.189
southwest Quesnel, BC	RAMB	52.632	-123.1227	1.259
south of Vanderhoof, BC	SULB	53.2786	-124.3576	1.171
Tatla Lake, BC	TALB	52.0147	-124.2536	1.127
Thunder Mountain, BC	THMB	52.5489	-124.1323	1.126

[1] unofficial place name

The receiver function method has recently been applied in studies of sedimentary basins around the world. In the Bohai Bay Basin (China), Zheng et al. (2005) used receiver functions to map the sedimentary thickness (2–12 km) and velocities to better understand the petroleum potential of this region. In the Mississippi embayment, Julia et al. (2004) combined results from detailed geotechnical, seismic reflection and receiver function studies to determine the velocity structure and density profiles of the sedimentary column, as well as sedimentary thickness. In Chile, Lawrence and Wiens (2004) combined receiver function

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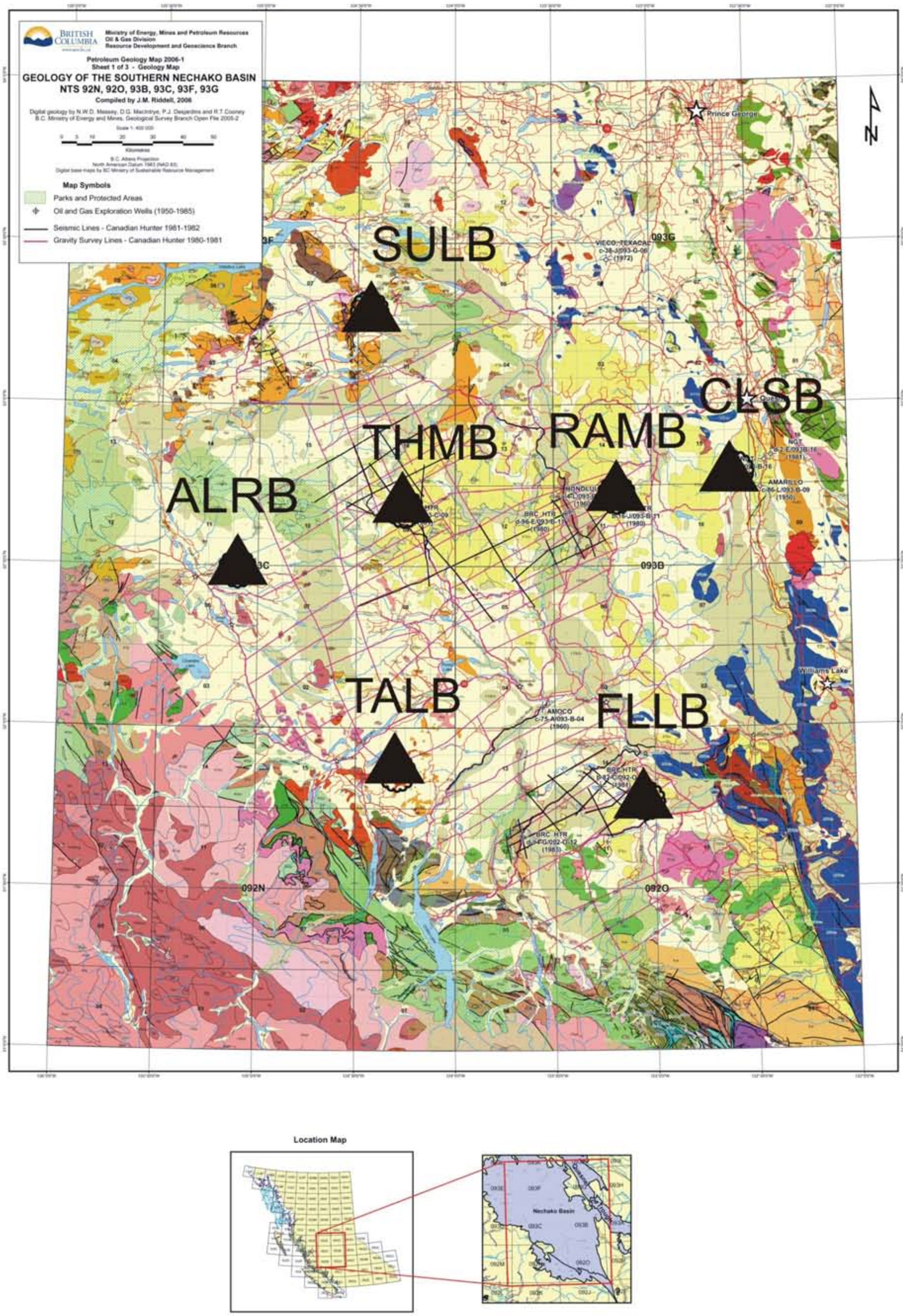

Figure 1. Location of the study area. Filled triangles (and four-character station codes) indicate the locations of the seven broadband seismic stations. Base map *from* Riddell (2006).

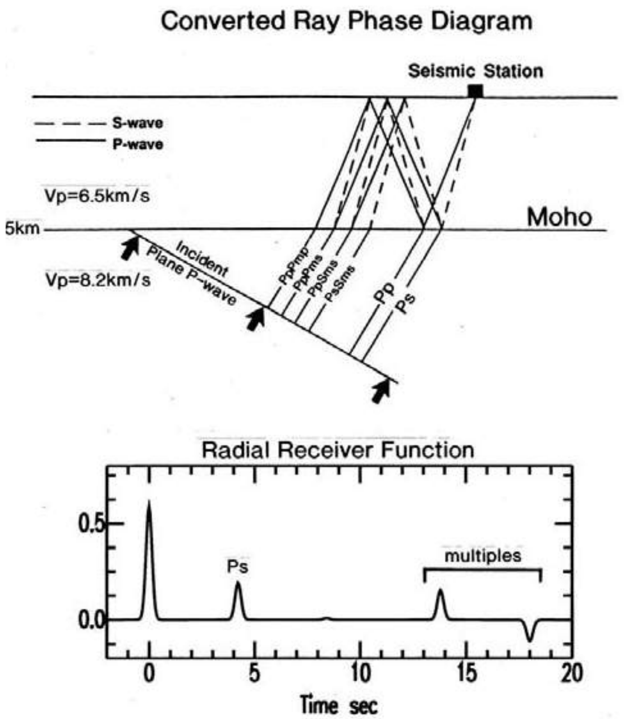

Figure 2. Diagram illustrating the receiver function method. When incident P waves from distant earthquakes encounter S-wave velocity boundaries beneath a seismic station (top), some of the energy is converted to an S wave (Ps). The amplitude and arrival time of the Ps phase, relative to the direct P wave, provides constraints on the velocity contrast and depth to the interface.

data with surface wave data to map the sedimentary rocks in Rocas Verdes Basin of Patagonia.

Surface-Wave Tomography Using Ambient Noise

Analysis of seismic 'noise' is being undertaken to constrain the velocity structure of the Nechako Basin. This method has been successfully used to map sedimentary basins in southern California (e.g., Sabra et al., 2005; Shapiro et al., 2005) and numerous other locations around the world. In this type of study, ambient noise recordings made at stations 20–100 km apart (or more) are compared and aligned. These recordings, typically dominated by Rayleigh waves, are modelled to constrain the velocity structure at various depths. This 'ambient noise' study will complement the receiver function technique (which provides site-specific information beneath the recording stations) by providing models that average the velocity structure between pairs of stations. By combining all possible station-pairs, a tomographic image beneath the basin will be obtained.

Data

In September 2006, seven three-component broadband seismic stations were deployed across the Nechako Basin area of central BC. The sites were chosen to sample a large portion of the basin, and to be close to existing boreholes

Figure 3. Photograph of Nechako seismic station RAMB, showing the typical station layout, with solar panels and satellite dish (seismic vault is not visible).

(Figure 1). These stations utilize solar power and satellite data transmission, in order that ground shaking can be recorded continuously and the data transmitted in real time and archived at data collection centres in Sidney, BC and Ottawa, ON. A typical station setup, consisting of solar panels, a seismic vault and a satellite dish with associated electronics, is shown in Figure 3.

During the first twelve months of operation, more than 100 large, distant earthquakes (teleseisms) were recorded (Figure 4). These data will be useful for the receiver function analysis described above. These events cover a wide range of azimuth and distance, providing a suitable dataset for examining geometry (dip angle and direction) of the structural boundaries beneath the seismic stations. In addition,

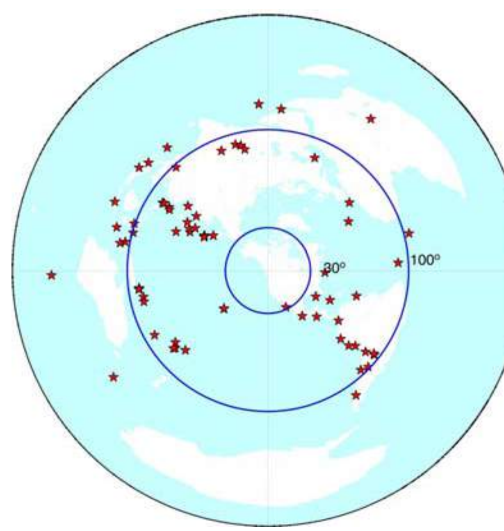

Figure 4. Distribution of teleseisms recorded during the first year of array operation. Stars indicate large (magnitude >6), distant earthquakes. The map is centred on the Nechako Basin seismic array, with distances of 3360 km (30°) and 11200 km (100°) indicated. This is the useful distance range for receiver function studies.

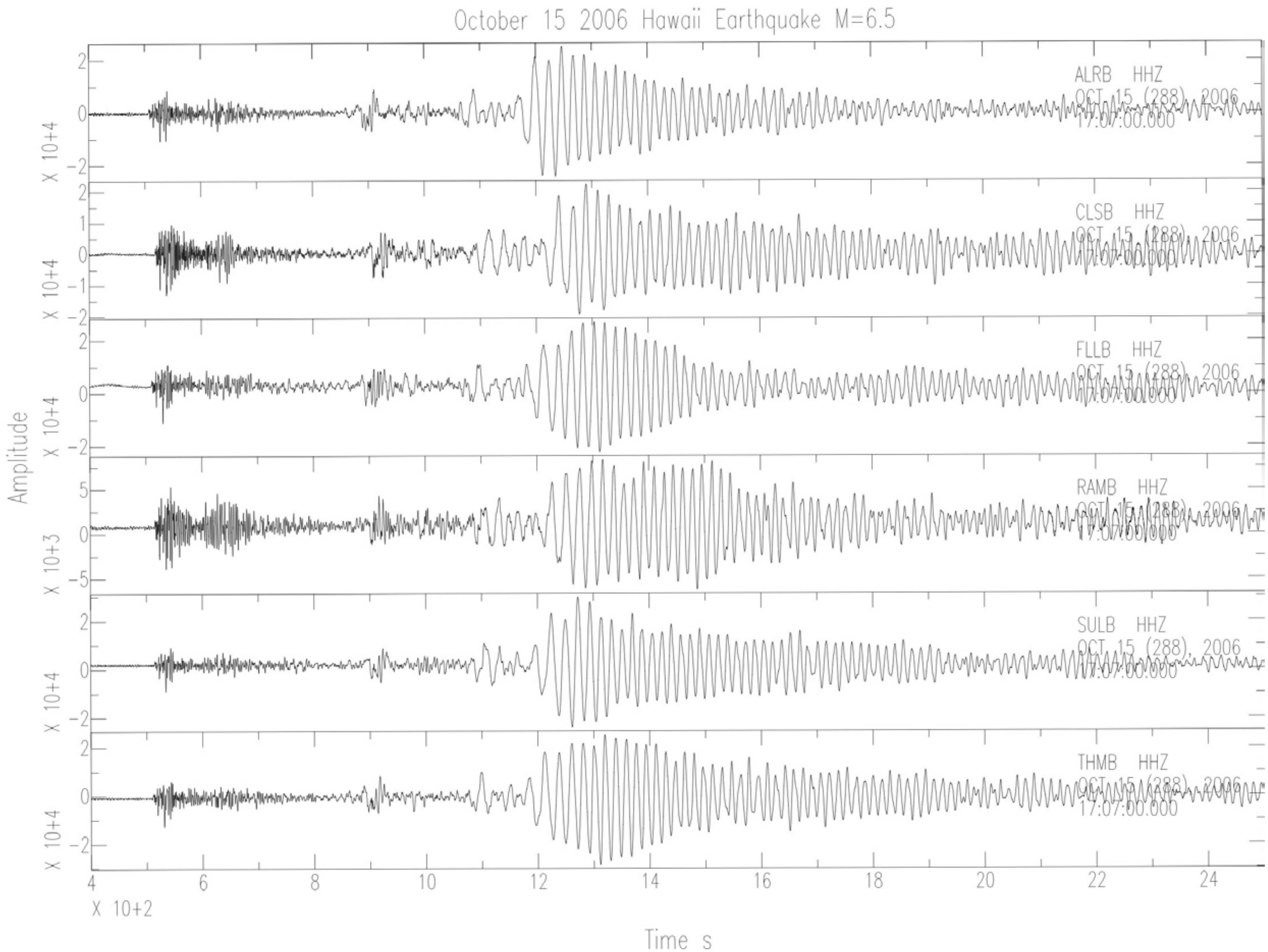

Figure 5. Sample waveforms (magnitude 6.3 earthquake near Hawaii) recorded on the Nechako seismic stations. These waves contain information on the subsurface structure of the Nechako Basin.

background noise (recorded continuously) is being used for the surface-wave tomography noise study sampling of the basin. Sample waveforms of a teleseism are provided in Figure 5.

Preliminary Results

To date, only a small number of receiver functions have been computed for stations within the Nechako Basin. These preliminary receiver functions, however, are consistent, and show arrivals indicative of sedimentary rocks in the basin and crustal thickness variations. For example, the receiver functions for the magnitude 8.1 Kuril Islands earthquake on January 13, 2007 is shown in Figure 6. The arrival at Time '0' is the direct P wave, other arrivals are locally generated P- to S-wave converted phases and free-surface multiples. The Ps-converted phase near 4 s is associated with the continental Moho (as are the multiples at 12–17 s). The earlier arrivals (i.e., the arrivals within the first 2 s) are associated with near-surface, low-velocity sedimentary rocks. As many dozens of receiver functions are processed in the near future, S-wave velocity models will be developed for each of these sites.

Future Work

Over the next six months, receiver functions will be computed for all suitable events recorded to date. These will be stacked into distance and azimuth bins and used to identify the robust phases that will be modelled for shear-wave velocity structure. Amplitudes and arrival times will be used to constrain the S-wave velocity contrast and depth of the

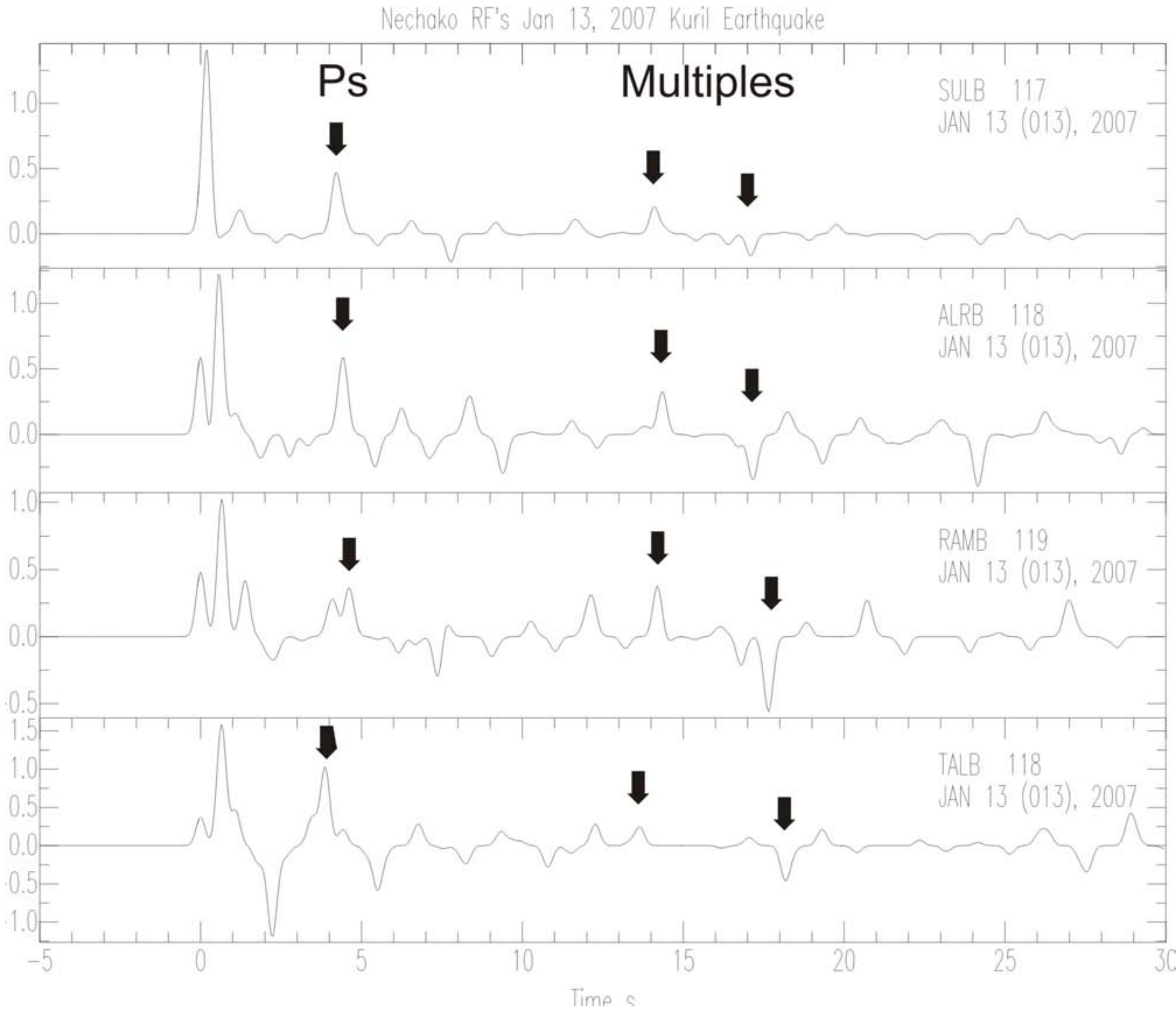

Figure 6. Sample receiver functions for select Nechako Basin stations. The arrival at Time '0' is the direct P wave. Subsequent arrivals are locally generated P- to S-wave converted phases and free-surface multiples. A small-amplitude arrival at T = 0, followed immediately by large-amplitude arrivals, is indicative of near-surface, low-velocity sedimentary rocks. The large arrivals indicated by arrows are consistent with a Ps conversion from the continental Moho (near T = 4 s) and free-surface multiples of this phase near T = 12–17 s.

boundary, and azimuth variations in the receiver functions will help constrain the geometry (dip angle and direction) of the interfaces. This research is being undertaken by a University of Victoria M.Sc. student (H. Kim). The regional surface wave tomography ambient noise study is now underway, being conducted by a University of Manitoba M.Sc. student. Initial results and interpretations, including shear-wave velocity models, will be presented in 2008.

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